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Two general classes of navigation systems are radionavigation systems which consist of transmitters and receivers and self-contained systems which depend on internally generated radio signals or other means. A review covered 13 major enroute navigation systems, 11 radionavigation and 2 self-contained, used by civilian and military travelers and by the military to improve the accuracy of weapons delivery. Findings/Conclusions: Overlapping navigation systems have proliferated because it has been costly to abandon older systems as new ones are developed. Of the 13 systems (1 was terminated after the review), only 4 and parts of a 5th may be required in the future because the military NAVSTAR satellite development has the potential for meeting the navigation needs of nearly all users. Departments and agencies plan to spend $277 million over the next 3 or 4 years for equipment or development of potentially unneeded systems. A Government-wide navigation plan is needed to reduce the proliferation and overlap of navigation systems, and a strong management focus is also needed. The Congress may have to decide whether a civil or military agency should manage the NAVSTAR navigation satellite system, recognizing that civil operation may encourage earlier civil and international use but that military operation may be needed to deny high accuracy signals to hostile forces during a war or national emergency. Recommendations: The Congress should question future requests for expenditures on navigation systems which may not be needed in later years and allow funds only when they are cost effective or on the basis of safety or combat readiness. The President should assign to a single manager the responsibility and authority to direct the prompt development and implementation of a Government-wide navigation plan along with the budgetary controls to implement those decisions. The plan should provide for its orderly and cost effective execution and be continually updated to fully recognize NAVSTAR development progress. The Secretaries of Defense and Transportation should defer unnecessary spending for unneeded

navigation systems as long as NAVASTAR remains their potential replacement. The Secretary of Transportation should become an active participant in the NAVSTAR program to ensure that civil needs are considered. (Author/HTW)

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BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Navigation Planning--Need For A New Direction

Navigation systems have proliferated, adding to Government and user costs. The Department of Defense's navigation satellite system, NAVSTAR, offers the potential to replace numerous other systems at substantial savings. But better planning and management is needed if its benefits as a national resource are to be realized.

Strong navigation management at the executive level of the President is necessary to overcome agency parochialism and to carry out a Government-wide plan.

UNITED STATES GENERAL ACCOUNTING OFFICE

LCD-77-109

MARCH 21, 1978

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-180715

To the President of the Senate and the
Speaker of the House of Representatives

This report deals with the proliferation of navigation systems and their mounting costs to the Government and users. The Department of Defense's nagivation satellite system, NAVSTAR, offers the potential to replace numerous other systems in future years. Substantial savings may be possible by deferring the spending for systems which NAVSTAR could replace. If NAVSTAR's benefits as a national resource are to be realized in a timely manner, a Government-wide navigation plan and authoritative management will be needed to overcome agency parochialism.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67). We made this review to determine if the diverse navigation needs of users could be satisfied with fewer systems and consequent cost savings to the Government and users.

We are sending copies of this report to the President of the United States; the Acting Director, Office of Management and Budget; the Acting Director, Office of Telecommunications Policy; the Secretaries of Commerce, Defense, and Transportation; and the Administrator, National Aeronautics and Space Administration.

Elmer B. Staats
Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT TO THE CONGRESS

NAVIGATION PLANNING--NEED FOR A NEW DIRECTION

D I G E S T

Navigation systems, vital to the safety of domestic and international air and sea travel, vary widely. As newer and better systems are developed, abandonments of older ones are hampered by costly changeovers. The result? A proliferation of overlapping navigation systems with significantly higher costs to the Government and users.

Of the 13 systems GAO reviewed (1 was terminated after GAO's review), only 4 and parts of a 5th system may be required in the future because the military NAVSTAR satellite development has the potential for meeting the navigation needs of nearly all users. (See pp. 20 and 21.)

Departments and agencies plan to spend $277 million over the next 3 or 4 years for equipment or development of potentially unneeded systems. This figure does not include installation or maintenance costs which could equal equipment costs. (See p. 30 .)

A Government-wide navigation plan is needed to reduce the proliferation and overlap of navigation systems. But a strong management focus is also needed to plan and direct Government-wide navigation matters. (See p. 37)

The Congress should (1) question future requests for expenditures on navigation systems which may not be needed in later years and (2) allow funds only when they can be cost/benefit justified or on the specific basis of safety or combat readiness. (See p. 41 .)

The Congress also may have to decide whether a civil or military agency should eventually manage the NAVSTAR navigation satellite system, recognizing that civil operation may encourage earlier civil and international use but that military operation may be needed to assure that the high accuracy signals used for weapons delivery would be denied to hostile forces during a war or national emergency. (See p. 41.)

GAO recommends that the President assign to a single manager, the responsibility and authority to direct the prompt development and implementation of a Government-wide navigation plan which will reduce the overlap and expenditures for unneeded systems along with the budgetary controls to implement those decisions. The plan should provide for its orderly and cost-effective execution and be continually updated to fully recognize NAVSTAR development progress. (See p. 37 .)

Until such plan is developed and agreed upon, GAO recommends that the Secretaries of Defense and Transportation defer unnecessary spending for the unneeded navigation systems as long as NAVSTAR remains their potential replacement and that the Secretary of Transportation, in concert with the Administrator of the National Aeronautics and Space Administration and the Assistant Secretary for Maritime Affairs of the Department of Commerce become an active participant in the NAVSTAR program to ensure that civil needs are considered. (See p. 37 .)

Contents

ABBREVIATIONS

CNI	communications, navigation, and identification
DME	distance measuring equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
GAO	General Accounting Office
JTIDS	Joint Tactical Information Distribution System
LF	low frequency
MF	medium frequency
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVSTAR	Navigation System using Timing and Ranging
OTP	Office of Telecommunications Policy
PLRS	Position Location Reporting System
TACAN	Tactical Air Navigation
UHF	ultra high frequency
VHF	very high frequency
VLF	very low frequency
VOR	VHF Omnidirection Range
VORTAC	VOR and TACAN

CHAPTER 1

INTRODUCTION

Navigation systems are used to determine one's position and the course and distance to a destination. They are vital to the safety of domestic and international air and sea travel and are used by the military for weapons delivery. In two earlier reports (see p. 8), we noted the proliferation of navigation systems and the mounting costs of these systems to civil users and to the Government. We made this review to determine if the diverse needs of users could be satisfied with fewer systems and if costs to the Government and to civil users could be reduced.

CLASSES OF NAVIGATION SYSTEMS

Two general classes of navigation systems are radionavigation systems, which consist of transmitters and receivers, and self-contained systems, which depend on internally generated radio signals (such as radar) or other means such as gyroscopes.

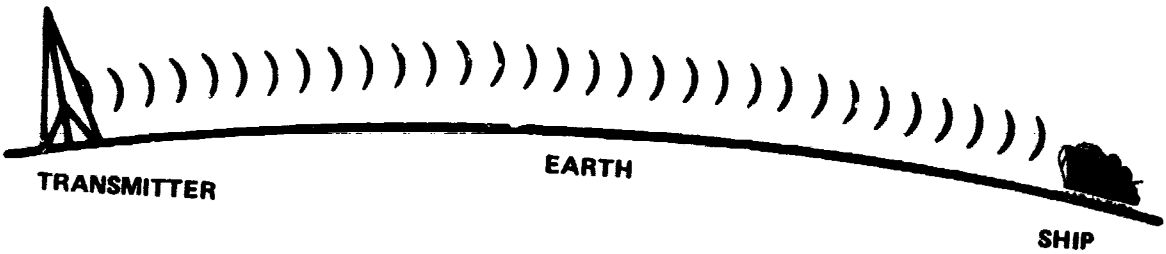
Much of this report deals with radionavigation, and the following explanation of the behavior of radio waves may assist the reader in assessing the differences among radionavigation systems and why numerous systems have come into being. The 11 radionavigation systems and the 2 self-contained navigation systems included in this review are described in appendix I.

The behavior of radio waves

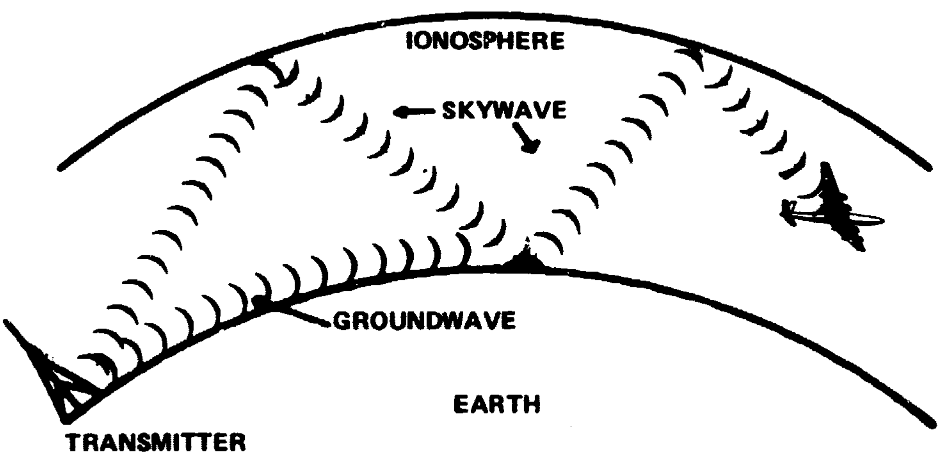
Radio waves travel at about the speed of light but propagate (or behave) in widely different ways depending upon the radio frequencies used for their transmission. These propagation characteristics strongly affect navigation coverage and accuracy.

Very low, low, and medium frequencies

For example, at the low end of the radio spectrum called the very low frequency (VLF), the low frequency (LF), and the medium frequency (MF) bands, part of the transmitter's radio energy follows the curvature of the Earth in what are known as ground waves. Although affected by atmospheric noise such as thunderstorms, ground waves can provide resonably accurate navigation. As implied from the chart, ground waves can be received at considerable distances from high power transmitters.



In addition to ground waves, radio energy transmitted in these frequency bands is reflected or bounces back from the ionosphere in what are called sky waves. See below.



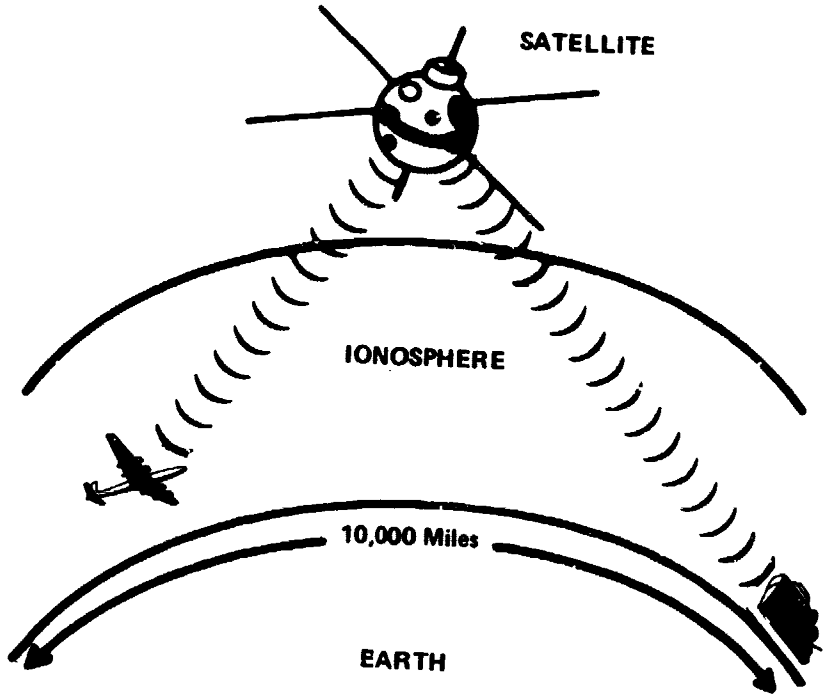
As can be seen, sky waves travel greater distances than do the ground waves, thus providing greater navigation coverage. The use of sky waves, however, results in greater navigation errors than ground waves because sky waves are also affected by daily and seasonal ionospheric variations and sudden disturbances such as those caused by sunspots. These produce changes in the distances required for the sky waves to reach the receiver and hence variations in signal arrival times.

Very high and ultra high frequencies

Radio waves transmitted in the very high frequency (VHF) or ultra high frequency (UHF) bands will not bend or appreciably follow the Earth's curvature. These radio waves tend to pass through the ionosphere rather than reflect from it. Such transmissions are called line-of-sight which means that the receiver must be nearly in "view" of the transmitter. (For example, TV reception becomes marginal or impossible at distances beyond about 50 miles or so.) Thus, navigation coverage is limited at these frequencies when ground transmitters are used. Better navigation accuracy, however, is possible at VHF or UHF than the lower frequencies because the signals are relatively unaffected by atmospheric noise and the instabilities of the ionosphere.

To summarize, sky waves provide great navigation coverage but low accuracy. Ground waves provide less coverage but better accuracy. Finally, line-of-sight signals from ground transmitters provide the least coverage but can provide the highest accuracy.

Navigation satellites, first introduced in the mid-1960s, provide users with both great navigation coverage and high accuracy. As shown below, satellites provide great coverage by reason of their altitudes. High accuracy results from the use of line-of-sight VHF or UHF radio signals.



OPERATORS OF NAVIGATION SYSTEMS

The Federal Aviation Administration (FAA), the Coast Guard, and the military services currently operate eight different radionavigation systems for aviation, maritime, and land use. At the time of our review, the military services were developing three more radionavigation systems. However, in commenting upon our earlier draft report, the Assistant Secretary of Defense advised us that one of these developments had been recently terminated. Our review of another development was concerned only with the navigation component of the system. The self-contained systems do not require Government-operated transmitting stations. The following table lists these 13 major enroute navigation systems, their operators, and corresponding page numbers in appendix I containing detailed descriptions.

Existing systems	Operators
Nondirectional beacons (p.43)	FAA, Coast Guard, military
VHF Omnidirectional Range (VOR) (p.45)	FAA, military
Tactical Air Navigation (TACAN) (p.48)	FAA, military
Loran-A (p. 49)	Coast Guard
Loran-C (p. 51)	Coast Guard
Loran-D (p. 51)	Military (Air Force)
Omega (p. 55)	Coast Guard
Transit (p.56)	Military (Navy)
Inertial (p.57)	Not applicable
Doppler radar (p. 58)	Not applicable

Planned systems	Planned operators
Differential Omega (p. 59) 1/	Military (Navy)
Position Location Reporting System (PLRS) (p.60) (navigation component)	Military (Army, Marine Corps)
Navigation System using Timing and Ranging (NAVSTAR) (p. 60)	Military

As explained below, FAA operates navigation systems for aviation use and the Coast Guard primarily for maritime use. The military services operate or plan to operate navigation systems for aviation, maritime, and land use.

Aviation use

The Federal Aviation Act of 1958 (49 U.S.C. 1301(8) and 1348(b)) authorizes FAA to operate radionavigation systems necessary to ensure the safe movement of aircraft (civil and military) throughout the airspace of the United States and its possessions. FAA operates nationwide VOR, TACAN, and nondirectional beacon systems for use by civilian and military aircraft. FAA also operates a nationwide system of ground radars and communications for air traffic control. Under international agreements, FAA is also responsible for monitoring air traffic in U.S.-assigned oceanic airspace. Since radar coverage along these oceanic routes is not possible, control is exercised by establishing minimum aircraft separation distances, alternate altitudes, and position reporting from the aircraft.

Coast Guard personnel operate two U.S. stations as part of a planned eight station Omega system providing global coverage for aviation and maritime users. Other nations will operate the other six stations.

1/Recently terminated.

The military services operate nondirectional beacons, VOR, TACAN, and Loran-D primarily for use by military aircraft. In addition, the military services are developing two more radionavigation systems, PLRS and NAVSTAR, which are to be used in part by aviation users.

The self-contained inertial and doppler radar systems also provide navigation to civilian and military aircraft.

Maritime use

The law (14 U.S.C. 81) authorizes the Coast Guard to operate radionavigation systems used by the maritime community, the military services when requested by any of them, or the aviation community when requested by FAA. The Coast Guard currently operates four different radionavigation systems. Nondirectional beacons, Loran-A, and Loran-C provide navigation for U.S. coastal areas. The Coast Guard operates two of these three systems in several overseas locations in response to U.S. military requirements. The Coast Guard also operates two transmitting stations of the planned eight station Omega radionavigation system which will provide global coverage for civilian and military maritime users.

The Maritime Administration of the Department of Commerce has no direct navigation responsibility like the Coast Guard but is concerned with navigation because of its requirement to enhance the competitiveness of U.S. merchant shipping. The Administration has been sponsoring navigation experiments using National Aeronautics and Space Administration (NASA) satellites and the Marisat communication satellites and transferred money to the military's NAVSTAR satellite development program for the development of a low-cost shipboard receiver.

The Navy operates the Transit satellite navigation system which provides global, but only periodic, positioning for military and civilian maritime users. Navy ships and submarines also use the self-contained inertial navigation system. The Navy was developing the differential Omega system to provide navigation to ships in coastal waters. In addition, the planned NAVSTAR satellite navigation system is expected to provide worldwide navigation for civilian and military maritime users.

Land use

Unlike the aviation and maritime communities, no single Government agency is responsible for satisfying the navigation needs of all prospective land users. Rather, various Government agencies are sponsoring navigation experiments, using existing systems with a variety of land vehicles, for reasons of safety, law enforcement, and similar activities. The military's planned PLRS and NAVSTAR systems are to be used by combat land forces.

USERS OF NAVIGATION SYSTEMS

Many aviation and maritime users currently carry navigation equipment. (Refer to appendixes I and II for detailed information on the use of navigation systems. Appendix I shows the total estimated population of vessels and aircraft using each navigation system. Appendix II shows the military's current and planned uses of navigation systems and current civil uses of navigation systems.)

Aviation users

Most of the estimated worldwide total of 303,000 aircraft shown in the following table use navigation systems.

	United States	Other nations	Worldwide total
Military aircraft	28,500	66,000	94,500
Commercial aircraft	2,500	8,000	10,500
General aviation aircraft	178,000	20,000	198,000
Total aircraft	209,000	94,000	303,000

Maritime users

Virtually all of the world's ocean-going ships (over 1,000 tons), most ships and larger boats operating in coastal waters (between 100 and 1,000 tons), and some fishing boats and larger pleasure boats (under 100 tons) use navigation systems included in our review. Some of the pleasure boats (under 100 tons) which operate in coastal areas use only a compass for navigation. Probably 90 percent of all ships and boats included in the following chart do not carry a compass or other navigation aid because they are used close to shore, in coastal areas, or in inland lakes and rivers.

	United States	Other nations	Worldwide total
Naval ships	800	10,900	11,700
Civilian ships and boats:			
over 1,000 tons	900	21,500	22,400
100 to 1,000 tons	3,200	35,600	38,800
under 100 tons	7,400,000	2,700,000	10,100,000
Total ships and boats	7,404,900	2,768,000	10,172,900

Land users

Although known to be still quite small, the number of land users relying on navigation systems is expected to grow in the future. Reliable population figures are not available. Various agencies, notably in the Department of Transportation, are experimenting with or show an interest in using two existing navigation systems to locate vehicles such as taxicabs, police and fire vehicles, ambulances, buses, and trucks carrying nuclear material.

OUR PREVIOUS RADIONAVIGATION STUDIES

We addressed the area of Government-sponsored radionavigation systems in two previous studies. On March 26 1974, we issued "Summary of GAO Study of Radionavigation Systems: Meeting Maritime Needs." The study was made for the Subcommittee on Coast Guard and Navigation, House of Representatives Committee on Merchant Marine and Fisheries. We evaluated the Coast Guard's plan to serve the navigation needs of the maritime community and examined problems impeding coordination of radionavigation systems, the current status of some maritime systems, and user attitudes regarding the Loran-C system. We also observed a proliferation of navigation systems resulting from the continuation of old systems, even after new systems become available, because users would have to replace their equipment and from the failure of Government planners to reconcile differences in navigation requirements for the civil and military aviation and maritime communities. We also noted that the mounting costs of these systems must be borne by the Government and by civil users.

The second report, "Information on Management and Use of the Radio Frequency Spectrum--A Little-Understood Resource," was issued to the Office of Telecommunications Policy and the Federal Communications Commission on September 13, 1974. The study described uses of the radio frequency spectrum and emphasized the need for its prudent management. We reiterated our concern over the proliferation of Government-sponsored radionavigation systems, and their mounting costs to the Government and users, and noted that radionavigation systems use large portions of the limited radio frequency spectrum. We again mentioned the hesitancy to shut down existing systems because users would have to buy new receivers.

SCOPE OF REVIEW

We examined the navigation responsibilities, navigation system capabilities, and navigation plans of several Government organizations to determine if fewer systems could satisfy user needs and if costs to both the Government and civil users could be reduced. These organizations were the

--FAA,

--Coast Guard,

--Army,

--Navy,

--Air Force, and

--Maritime Administration.

Additional information was obtained from

--the President's Office of Telecommunications Policy,

--the National Aeronautics and Space Administration,

--the Air Transport Association,

--the Aircraft Owners and Pilots Association, and

--certain contractors for some of the above Government agencies.

We reviewed major enroute navigation systems used by civilian and military travelers and by the military to improve the accuracy of weapons delivery. Our review excluded ground radars, instrument approach and landing systems, and highly specialized commercial systems (both domestic and foreign) having limited coverage and usage. We also excluded magnetic compasses and visual aids to navigation, both widely used by recreational boats and some small aircraft. Our review also excluded AM radio stations and the Navy's VLF communications stations although they are sometimes used for navigation.

CHAPTER 2

PROLIFERATION OF SYSTEMS

RESULTS IN NAVIGATION OVERLAP

The 13 navigation systems 1/, described in appendix I, provide or are expected to provide varying navigation accuracies and geographic coverages. Considerable navigation overlap exists because the navigation needs of most user communities could be satisfied, equally or better, by one or more systems other than the system primarily used.

We identified navigation overlap by matching the capabilities of the 13 systems to 5 civilian and military peacetime navigation needs and 6 military combat navigation needs. These navigation needs, which were based on our examination of various navigation reports and discussions with agency officials, were categorized according to the operational environment and, to a lesser extent, according to the operational characteristics of the users.

We considered each existing or planned system to be a candidate for each navigation need if the system provided or could be made to provide equal or better navigation accuracy and geographical coverage than the primary system currently being used. Some candidate systems were eliminated due to special circumstances, such as markedly higher user costs or the unsuitability for use, even though the accuracy and coverage were equal or better.

The following discussion of each civilian and military navigation need includes systems currently used and those which we believe could alternatively be used for the navigation need. Also, the summary table in appendix III shows systems which could be used for each navigation need.

1/The development of the Navy's differential Omega systems was terminated after our review was completed. We chose to retain the system in this report for comparative purposes although its exclusion would reduce navigation overlap.

OVERLAPPING SYSTEMS FOR CIVILIAN AND MILITARY PEACETIME USES

We believe considerable navigation overlap exists for the five civilian and military peacetime navigation needs. Only one system, the military's planned NAVSTAR satellite system, could be used for all five needs, but as shown in appendix III, at least three systems, although not the same ones, could be used for each of the five navigation needs.

Overland flights

FAA operates nationwide systems of VORTAC (combined VOR and TACAN) and VOR transmitters and nondirectional beacons to provide navigation for military and civilian aircraft flying over the United States. Distance measuring equipment (DME) may be used with VOR (see p. 45). The VORTAC/VOR system is the primary navigation system, and the less accurate nondirectional beacons provide navigation to aircraft not having VOR receivers or can be used as a backup navigation system to VOR.

Three other existing or planned navigation systems have the potential for replacing VOR and DME when the International Civil Aviation Organization agreement for their continued use expires on January 1, 1985. These are the Coast Guard's Loran-C system which is currently being expanded, the Navy's once planned differential Omega system if expanded, and the military's planned NAVSTAR satellite system.

All three of these systems could offer accuracies better than VOR/DME, which has a typical error of .6 mile when 10 miles for the transmitter and 4-1/2 miles when 75 miles from the transmitter. For example, Loran-C has a typical accuracy of one-quarter mile which was also expected of differential Omega. NAVSTAR could provide civil users an accuracy of 300 to 900 feet as early as late 1981 if the military reinstates its earlier plan to provide worldwide two-dimensional navigation coverage. Otherwise, NAVSTAR is scheduled to provide worldwide three-dimensional coverage in late 1984 with the high navigation accuracy of 30 feet beginning in late 1985 for military and civil users employing sophisticated receivers. Users with less expensive receivers could expect a best accuracy of 300 feet.

Loran-C, differential Omega, and NAVSTAR could provide total U.S. coverage before the international agreement on VOR and DME expires. The Coast Guard is building new Loran-C chains in the United States, and Coast Guard officials say that national coverage could be provided by the addition of four more stations. The Navy planned to have coastal coverage with differential Omega by the early 1980s. One study said that 68 differential Omega transmitters would provide national coverage. NAVSTAR could provide worldwide two-dimensional coverage in late 1981.

Transoceanic flights

Civilian and military aircraft need a worldwide navigation system for transoceanic flights. Although a higher accuracy system may be preferred, a low accuracy system is adequate because transoceanic airways are not as crowded as overland airways and because navigation errors can be corrected using more accurate systems when approaching land areas.

The self-contained inertial and doppler radar systems currently provide worldwide navigation coverage, and the Omega system will in the future when the last station is built. The military's planned NAVSTAR satellite system could provide two-dimensional worldwide coverage beginning in late 1981. Loran-A and Loran-C do not provide worldwide coverage although their sky wave signals are used in the northern latitudes for many transoceanic flights. Although providing worldwide coverage, the Transit satellite system is unsuitable because more continuous position computations are needed for fast moving aircraft.

Of the four remaining systems currently providing or scheduled to provide worldwide navigation coverage, only the military's planned NAVSTAR satellite system has a high accuracy. Inertial, doppler radar, and Omega have a low accuracy, which is adequate for transoceanic flights.

Coastal waters

Commercial ships, military ships, and some recreational vessels need a navigation system for the coastal waters. A medium accuracy system is adequate to allow the safe movement of vessels along traffic lanes from the harbor entrance to the open seas, a typical distance of about 60 miles.

The Coast Guard operates three navigation systems for use in the coastal waters. Nondirectional beacons, the oldest system, and Loran-A provide low accuracy. Loran-C, which is replacing the less accurate Loran-A, provides the needed medium accuracy. Although providing a high accuracy, we felt the Navy's Transit satellite system was inadequate for coastal waters because more continuous position computations are needed to guard against running aground.

Two planned navigation systems, the Navy's recently terminated differential Omega and the military's NAVSTAR system, could also be used for navigation in coastal waters. The accuracy of differential Omega was expected to be similar to Loran-C, while NAVSTAR's expected high accuracy is to be much better.

Thus, Loran-C, the recently terminated differential Omega, and NAVSTAR could be used in the coastal waters because they are expected to provide medium or high accuracy. However, none provides complete coastal coverage at this time. Loran-C is expected to provide complete coastal navigation beginning in mid-1978. NAVSTAR could provide worldwide two-dimensional coverage in late 1981, about the same as the 1981-1982 operational date which was planned for differential Omega.

Open seas

Civilian ships and military ships during peacetime operations need a navigation system for worldwide use on the open seas. Although a higher accuracy system may be preferred, a low accuracy navigation system is adequate because shipboard radar guards against collisions with other ships and because navigation corrections can be made using more accurate navigation systems when the ship arrives in coastal waters.

The Navy's Transit satellite system provides the needed worldwide coverage. Although not providing a continuous position for periods as long as 1-1/2 hours because a satellite may not be in view, Transit's periodic position computation is adequate for the open seas. The Omega system can also be used although not yet providing complete worldwide coverage. The military's planned NAVSTAR satellite system could provide worldwide two-dimensional coverage beginning in late 1981. Although providing worldwide coverage, shipboard inertial systems were not considered feasible for use by many commercial ships because of their high costs. Loran-A and Loran-C do not provide worldwide coverage.

Transit provides a high accuracy, and the planned NAVSTAR system is also expected to provide a high accuracy. Omega has a low accuracy which is adequate for the open seas.

Thus, Transit, Omega, and the planned NAVSTAR system could be used for navigation on the open seas.

Land movement

Civilian and peacetime military land travelers use maps, compasses, and visual aids to determine position and the route to a destination. However, there is a growing need for land vehicle navigation or, more correctly, vehicle locator systems which centrally record or display the locations of a number of vehicles. Several Federal agencies have emerging needs involving such activities as safety and efficiency of public transportation (Urban Mass Transit Authority, Federal Highway Administration, and Federal Rail Administration), police cars and emergency vehicles (Law Enforcement Assistance Administration), and the safe movement of nuclear material (Energy Research and Development Administration). These systems commonly depend upon some type of navigation equipment aboard the vehicle together with communications or data links which report its successive locations to a control center.

Two planned navigation systems, in addition to Loran-C which has been tested, have the potential for providing a land vehicle navigation system. These are the Navy's recently terminated differential Omega system and the military's NAVSTAR satellite system. Loran-C provides a typical one-quarter mile accuracy, which was also expected from differential Omega. NAVSTAR's expected accuracy is much better.

As mentioned on page 12, Loran-C and the recently terminated differential Omega could provide nationwide coverage by the addition of more transmitters. NAVSTAR could provide worldwide two-dimensional coverage beginning in late 1981.

Although Omega currently provides navigation coverage for all of the United States, its present low accuracy may not satisfy many possible applications.

OVERLAPPING SYSTEMS FOR MILITARY COMBAT USES

We believe navigation overlap also exists for some of the six military combat uses although not to the same degree as for civilian uses. The military's planned NAVSTAR satellite system could be used for all combat needs except submerged submarine operations.

Combat flight operations

Military aircraft currently use navigation systems for ...ing the delivery of weapons against their targets. When ...ose enough to the target, the aircraft uses air-to-air or air-to-ground weapons to destroy the target. When "smart weapons" are used, such as laser-guided or heat-seeking missiles, highly accurate positions, directions, and distances are not required because errors will be corrected during the weapon's flight. Also, nuclear weapons do not require as much accuracy as other weapons. When conventional weapons such as free-falling bombs and uncontrolled rockets are used, high accuracies are required because errors cannot be corrected after the weapon is released. As discussed below, some navigation systems used over land areas cannot be used over ocean areas because of limited coverages.

Operations over land areas

The existing TACAN, inertial, and doppler radar generally provide enough accuracy for flights in the combat area and the delivery of some "smart weapons." However, these systems are not accurate enough for all-weather pinpoint bombing and strafing.

Two existing systems provide better accuracies. These systems are the short range nondirectional beacons used for offset bombing and Loran-D used by the Air Force. The Army and Marine Corps' planned PLRS and the military's planned NAVSTAR satellite system are to provide even better accuracies. PLRS is scheduled to be operational in the early 1980s. NAVSTAR could provide two-dimensional coverage in late 1981 and is scheduled to provide high accuracy, three-dimensional coverage in late 1985.

Concerning the navigation coverage of the four systems, NAVSTAR is to provide worldwide coverage followed by 500 mile coverage for Loran-D. PLRS is to provide a 50 mile diameter coverage for ground units and 250 miles for aircraft. The nondirectional beacons cover 120 miles for aircraft flying at high altitudes but only 32 miles for offset bombing. Because of their limited coverages, several PLRS and beacons would be needed for large areas.

The navigation accuracies of the beacons, Loran-D, and PLRS are somewhat better than NAVSTAR's potential two-dimensional 300 foot accuracy beginning in late 1981 but not as good as NAVSTAR's expected 30 foot accuracy beginning in late 1985.

Operations over ocean areas

Shipboard TACAN transmitters, inertial, and doppler radar currently provide navigation to aircraft during combat flight operations over ocean areas. As mentioned above, none is accurate enough for all-weather pinpoint bombing and strafing. The land-based Loran-D, nondirectional beacons, and PLRS cannot provide navigation on the high seas because of their limited coverages. Only one system, the planned NAVSTAR satellite system, is expected to provide a continuous high accuracy and worldwide coverage.

Combat sea operations

Navy ships require worldwide high accuracy navigation for some but not all combat sea operations. High navigation accuracy is probably unneeded when the ships' guns are used because equipment such as optical sights and radar provide reasonably accurate direction and range to the target. When "smart weapons" such as guided and homing missiles are used, navigation errors are corrected during the weapon's flight.

Aircraft carriers need a navigation system to set starting positions in airborne inertial systems carried by carrier-based aircraft. Although desired, no high accuracy system is currently available to correct the cumulative error in the aircraft's inertial system.

A high accuracy navigation system is needed when range and direction from the ship to the target cannot be determined using optical sights or radar, but the target's position is known. If an accurate position of the ship is also known, an uncontrolled weapon, or one without a flight correction capability when close to the target, can be accurately fired at the target.

Navy ships currently use Loran-A, Omega, Transit, and inertial for navigation. Loran-A is being phased out, and Omega provides only a low accuracy. The Transit system and inertial, when used together, provide the needed high accuracy navigation. The inertial's cumulative error is periodically corrected with Transit, which cannot be used by itself because a position computation is not possible for periods up to 1-1/2 hours. NAVSTAR is expected to provide a high accuracy beginning in late 1985.

Thus, worldwide, high accuracy navigation for combat sea operations can be provided with Transit and inertial or the planned NAVSTAR system.

Combat submarine operations

The Navy has strategic and attack submarines. The strategic submarines require high accuracy navigation equipment to set an accurate starting position in the inertial guidance systems carried by their long-range ballistic missiles. The attack submarines probably do not require as much accuracy because shorter-range "smart weapons" are used to destroy ships and other submarines.

The strategic submarines use redundant inertial systems as the primary navigation system. Several high accuracy systems--Transit, Loran-C, and certain classified equipment--are used to periodically correct the cumulative errors in the inertial systems.

Most of the Navy's attack submarines use one inertial system as the primary navigation system. Transit is used to correct the error in the inertial system. Omega is used as a backup navigation system.

The military's planned NAVSTAR satellite system has the potential for use by strategic and attack submarines because of its expected high accuracy and worldwide coverage. NAVSTAR's expected accuracy of 30 feet beginning in late 1985 is better than the existing high accuracy systems. Omega provides a low accuracy compared to these systems.

Inertial, Transit, Omega, and the planned NAVSTAR provide or will provide worldwide navigation coverage. Loran-C and the classified equipment do not provide worldwide coverage.

Inertial is the primary navigation system because it shows position continuously while submerged or surfaced. Inertial's limitation is its cumulative error which requires periodic correction. When at considerable depths, which is preferred to avoid detection, a submarine cannot use Omega, Loran-C, Transit, or the planned NAVSTAR because the signals will not penetrate seawater to that depth.

Thus, high accuracy navigation for submerged strategic submarines is expected from inertial and for surfaced strategic submarines from (1) inertial and Transit, (2) inertial and Loran-C, (3) inertial and NAVSTAR, or (4) NAVSTAR by itself. When submerged and surfaced operations are combined, NAVSTAR cannot be used by itself. The operational capability of the classified equipment is not discussed in this or the preceding paragraphs.

For submerged attack submarines, high accuracy is expected from inertial for short periods of time only, but when surfaced from (1) inertial and Transit, (2) inertial and NAVSTAR, or (3) NAVSTAR by itself. When submerged and surfaced operations are combined, high accuracy is expected from inertial and Transit or inertial and NAVSTAR.

Combat land operations

Military ground forces such as artillery, tanks, trucks, and personnel rely on maps, compasses, and landmarks for navigation. Higher accuracies are desired to improve reconnaissance and weapons fire.

Two navigation systems are being developed in part to provide navigation for ground forces. These are the Army and Marine Corps' PLRS and the military's NAVSTAR satellite system. We believe the Air Force's existing Loran-D could also be used by ground forces although the Army decided not so use Loran as the primary navigation system because of the vulnerability of the transmitters.

The Air Force has two Loran-D chains, and current plans are to buy two more transportable chains. NAVSTAR could provide worldwide two-dimensional coverage beginning in late 1981. The transportable PLRS is to be received in the early 1980s.

NAVSTAR is to provide worldwide coverage. Loran-D provides coverage of less than 500 miles. PLRS is to provide the lowest navigation coverage--50 miles for ground units and 250 miles for airplanes.

The navigation accuracies of Loran-D and the planned PLRS are better than NAVSTAR's 300 foot accuracy which could be available beginning in late 1981. NAVSTAR's expected 30 foot accuracy beginning in late 1985 is better than PLRS and Loran-D.

CHAPTER 3

PHASE-OUT OF UNNEEDED SYSTEMS

WOULD REDUCE NAVIGATION OVERLAP AND

PLANNED SPENDING

The preceding chapter identified navigation overlap by showing a number of existing or planned navigation systems which could be used for many of the same navigation needs. Most of the navigation overlap has not been eliminated by the interagency navigation planning committee or by individual navigation plans of FAA, Coast Guard, and the military services.

Current navigation plans call for the continued development, modernization, or expansion of seven systems which we believe could be replaced in whole or in part by the military's NAVSTAR satellite system. The planned Government spending of $276.7 million for these potentially unneeded systems could be reduced significantly. Some Government spending will be required because the existing potentially unneeded systems may have to be operated until the mid to late 1980s.

LACK OF PROGRESS IN INTERAGENCY NAVIGATION PLANNING

In our report of March 26, 1974, we observed that the proliferation of navigation systems had two principal causes. First, as new and improved systems come along, there is a reluctance to discard older systems because of user costs to change over. Second, Government planners of navigation systems have been unable to reconcile differences in the perceived navigation requirements for civil and military aviation and maritime communities.

In the same report, we explained that the Office of Telecommunications Policy (OTP) issued Circular 12, in October 1973, which prescribed policies and procedures designed to improve coordination among Federal agencies in their planning for communication systems in mission-related areas. Transportation, including navigation, is one such area. OTP designated the Department of Transportation as lead agency of the interagency committee on navigation with the Department of Defense (DOD), Commerce, and NASA as participants. We felt that this committee seemed to be the proper forum for the reconciliation of diverse views and that it could develop a navigation plan which would eliminate or sharply reduce the number of overlapping systems.

The Department of Transportation recently advised us that a third edition of their National Plan for Navigation is in final preparation. Despite its title, however, this plan, in its most recent draft deals chiefly with civil navigation needs and resources and does not address military needs and resources in the context of a total system. We believe that a truly national navigation plan should consider the needs and resources of all Federal agencies and users, military and civil, as a total system. For example, the navigation responsibilities for civil users is generally limited to U.S.-controlled air space and territorial waters whereas military needs and resources must be considered in global terms or at least to cover areas of existing or potential U.S. military presence. There is considerable interdependence between civil and military navigation needs and resources. For example, military aircraft must ordinarily comply with civil rules and procedures. Hence, we do not believe that military and civil navigation planning should be treated in virtual isolation, which has been the case.

We believe that the proposed National Plan for Navigation does not eliminate navigation overlap, and, as discussed below, FAA, Coast Guard, and military services have not minimized their planned spending for overlapping navigation systems. Therefore, we prepared the following alternative national navigation plan containing that minimum mix of systems which we believe can satisfy the diverse needs of civil and military users and minimize unnecessary spending.

AN ALTERNATIVE NAVIGATION PLAN

Our alternative plan assigns the 13 navigation systems to 3 categories: needed systems, potentially needed systems, and unneeded systems. We considered three systems--NAVSTAR, inertial, and doppler radar--and part of another system, nondirectional beacons used by the marine community, to be needed systems. Potentially needed systems are Omega and other nondirectional beacons, those used by the aviation community. Planned spending for these needed and potentially needed systems, four complete systems and the two parts of a fifth system (nondirectional beacons), appears to be justified at this time.

We considered the remaining eight systems and still other nondirectional beacons to be unneeded because NAVSTAR has the potential for replacing them. Thus, Government spending should be minimized for the planned development, modernization, or expansion of VOR, TACAN, Loran-C, Loran-D, Transit, the navigation part of PLRS, and the military's nondirectional beacons. No spending is planned for Loran-A because of its imminent phase-out, and the Navy recently terminated its development of differential Omega.

Our alternative plan was based upon the following factors: (1) required navigation accuracy and geographical coverage, (2) system reliability and need for a backup system, (3) special military needs, (4) expected operational dates of planned systems, and (5) user equipment costs and acceptance.

Our alternative rests, basically, upon the successful development and deployment of the NAVSTAR system whose initial test phase with the satellites is not scheduled to begin until 1978. To this degree our alternative contains risk. However, there is little risk in deferring the planned spending for systems which NAVSTAR could replace because these systems are already providing navigation services to their users in their present configuration.

The alternative plan we are suggesting is but one of several possibilities. But as we pointed out on page 20 of this chapter, the interagency planning committee has not yet proposed an alternative design for navigation on a total system or national basis. Our plan is illustrative of the potential improvement by better navigation system planning.

Until a better Government-wide navigation plan is prepared, and accepted by the agencies 1/, we think this alternative can be the basis for planning and budgeting in the near term at least and should give the Congress a baseline when considering future appropriations for navigation systems.

Needed navigation systems

We believe three systems and part of a fourth will be minimally required to meet the needs of military and civil users. Planned Government spending for these systems--NAVSTAR, inertial, doppler radar, and marine nondirectional beacons--should be allowed to continue. Our reasons are given below for each system.

NAVSTAR

Coverage and accuracy--The NAVSTAR system could be made to provide global, two-dimensional coverage by 1981. Initial accuracies (which depend in part upon satellite population) will be on the order of 300 feet. When the full population of 24 satellites becomes operative by late 1985, military users and others employing receivers using all of the satellite's signals can expect accuracies on the order of 30 feet. Civil and military users employing the lower cost receivers, which use only the nondeniable signal component, can expect accuracies beginning at about 900 feet and improving to 300 feet by late 1985. To

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1/In late September 1977, while we were awaiting agency comments on our draft report, the Office of Management and Budget sent a proposed Government-wide radionavigation plan to the Secretaries of Defense, Commerce, and Transportation, and to the Administrator of the National Aeronautics and Space Administration for their comments. This proposed plan, which was prepared by OTP, covered enroute radionavigation systems, terminal approach and landing systems, and air traffic control systems. The proposed plan resembles our alternative in placing primary reliance upon NAVSTAR and the phase-out of numerous systems which NAVSTAR can replace. The OTP plan and our alternative are in considerable agreement with the exceptions noted later in this report on p. 39 . The OTP plan also predicted large cost savings by phasing out numerous systems in the 1985-1995 time frame. The transmittal letter also said that the President had been briefed on the plan and upon receipt of all comments and its finalization, the plan would be sent to the President for approval and implementation.

summarize, NAVSTAR's coverage is worldwide, and its expected 30 foot accuracy exceeds that of any other navigation system we considered.

Reliability--NAVSTAR's reliability depends on the reliability of the satellites, the receivers, and the ground stations controlling the satellites. With a full 24 satellite population, the failure of one or two satellites will not significantly affect accuracy or coverage for an extended period of time. Hence the system can be said to degrade gracefully rather than abruptly. In order to enhance reliability, it is, of course, possible to place one or more spare satellites in orbit, turning them on only when needed. The satellites are to have features protecting them from the effects of radiation. Military receivers are to contain anti-jam features although civil receivers probably will not because of the additional cost. The satellite control and monitor stations will be located in the United States and its possessions, and if thought necessary, backup stations could be built. Finally, user equipment reliability can be enhanced through redundancy as is commonly done by aircraft carrying dual VOR receivers. We believe, therefore, that NAVSTAR's reliability should be adequate, although not as reliable as the self-contained systems.

Special military needs--The primary military use of NAVSTAR is to enhance weapons delivery by providing more accurate navigation and weapons guidance. NAVSTAR is expected to provide highly accurate navigation for land, sea, and air launch platforms so that weapons can be accurately fired at targets. Also, NAVSTAR receivers may be put into missiles to provide midcourse corrections.

Expected operational date--As noted above, the military could provide global, two-dimensional coverage in late 1981 and expects to have high accuracy, three-dimensional coverage in late 1985.

User equipment costs and acceptance--Costs for the different classes of military receivers are estimated to be in the range from $15,000 to $30,000 depending upon their accuracy, ruggedness, and anti-jam features. Two studies were done for the Air Force concerning low cost civil NAVSTAR receivers. Both studies identified cost advantages for receivers if different signal waveform could be added to the satellite at a lower frequency. However, one contractor concluded that receivers in large volume production, using the NAVSTAR signals, could be sold for $2,500. The other contractor, based upon adding the new signals, concluded that less accurate receivers could be sold for about $1,650. In either case, these prices are comparable to the lowest prices for civil Omega and VOR/DME receivers but are higher than the lowest price (about $1,000) for Loran-C and VOR receivers.

We believe that wide civil acceptance of NAVSTAR (including international use) and the phaseout of other systems will depend upon the extent to which NAVSTAR will ultimately satisfy civil needs. Since relatively little effort has gone into the application of NAVSTAR for civil use, we believe that it is becoming increasingly urgent for the Government 1/ to

--determine navigation accuracy requirements, desired receiver operating characteristics, and acceptable receiver prices for civil aviation and maritime users,

--determine if these civil needs would be satisfied by the present NAVSTAR configuration (if not, determine the preferred signal waveform and frequency),

--evaluate the merits of providing two-dimensional NAVSTAR coverage for civil use beginning as early as late 1981 but before the scheduled initial availability in late 1984, and

--determine if Government participation in development of a low-cost civil receiver is required, rather than development solely by private manufacturers without Federal financial or technical support, to assure that low-cost receivers are available at the time or shortly after the satellite system becomes operational.

The Government may have to take action to assure availability of a low-cost receiver for civil airborne and shipboard use if its development by private contractors is considered too slow. In either case, the development

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1/As will be seen later (see p. 37) we recommend that the President designate a single authoritative manager for navigation matters empowered to coordinate and direct, as necessary, the navigation affairs of the Departments of Defense, Transportation, and Commerce and the National Aeronautics and Space Agency. This manager should direct the efforts noted in this paragraph.

is urgent because (1) the feasibility of declaring NAVSTAR as the primary navigation system for U.S. use depends heavily upon the demonstrated capability to produce receivers at costs to civil users comparable to those of equipments they are using, such as Loran-C and VOR/DME, and (2) the early availability of low-cost NAVSTAR receivers will allow the curtailment of planned spending for unneeded systems and their phase-out several years sooner than if the development were simply left to market demand.

During our review several officials raised questions concerning both civil and international acceptance of NAVSTAR if it were to remain under U.S. military control. Fears were expressed that the military might deny its use in war or other emergency. We agree that such fears could inhibit user acceptance, particularly foreign use. Although we think it would be unwise to change NAVSTAR's management during its development (to NASA, for instance), it may be that its eventual operation by civil agency would allay these fears. We also believe, however, that the military should retain the capability to deny possible enemy use of the very high accuracy components of the NAVSTAR signals in war or national emergency. We were told that this denial would still allow the 300 foot accuracies. As evidenced below, the military operation of navigation systems does not appear to have entirely constained their use by civil and international interests. Though not widely used because of their costs, we were told that Transit receivers have been sold to civil users at home and abroad and that TACAN is being used by some domestic civil aircraft. In any event, NAVSTAR will be a national asset, and the Congress may wish to consider this question of military versus civil control at the time NAVSTAR is due for operational employment.

Inertial

Coverage and accuracy--The self-contained inertial system provides worldwide navigation coverage. The navigation error for airborne systems is typically 1 mile for each hour of flight time. More accurate systems are being developed. Submarines, which depend upon inertial systems for sustained navigation at depths, carry very expensive systems whose error is far less than those carried by aircraft.

Reliability--Inertial systems are immune from jamming and do not depend on transmitters subject to sabotage or hostile actions. Inertial's error is sometimes corrected by the use of self-contained doppler radar or an external signal such as Loran, Transit, or for the future, by NAVSTAR.

Inertial equipment is complex, thus being subject to failure. Accordingly, airplanes flying oceanic routes commonly carry a second or even a third inertial for backup in event of failure. The Navy and Air Force plan to use inertial systems in combination with NAVSTAR in most combat aircraft because of inertial's immunity to jamming and NAVSTAR's high accuracy. Each would back up the other.

Special military needs--The military services require inertial for special military needs. As previously mentioned, submerged submarines use inertial because signals from radionavigation systems cannot reach normal operating depths. Inertial guidance systems are used in missiles for midcourse corrections. In addition, inertial systems are required to stabilize weapons platforms.

User equipment cost and acceptance--Airborne inertial systems are typically used by U.S. military cargo, bomber, and fighter aircraft. About 70 percent of U.S. commercial aircraft flying transoceanic routes carry dual inertial systems. The airborne systems currently cost $100,000, but the Navy and Air Force are developing systems expected to cost $40,000 to $50,000. Even the lower cost will be too high for use by most general aviation aircraft.

Most Navy submarines and many ships carry shipboard inertial systems. These systems cost from $135,000 to over $1 million, which would probably preclude their use by commercial ships.

Doppler radar

Coverage and accuracy--As with inertial systems, the self-contained doppler radar can be used by aircraft for worldwide navigation. Doppler radar is also used to correct speed errors in inertial systems. When used with a compass to provide direction, doppler radar's position error is 1 to 2 percent of the distance flown. Like the more accurate inertial, the cumulative position error can be corrected with a radionavigation system.

Reliability--Like inertial systems, doppler radar does not use signals from external transmitters which are subject to sabotage or hostile actions. Its internally-generated signal is relatively immune to jamming. Doppler radar is less prone to failure than inertial which is more complex and delicate.

User equipment cost and acceptance--Doppler radar is used by military airplanes and helicopters and by commercial airplanes flying transoceanic routes. Although costing less than inertial, the $30,000 to $60,000 cost is too high for most general aviation aircraft.

In summary, doppler radar is an alternative to inertial for a self-contained airborne navigation system.

Marine nondirectional beacons

Coverage and accuracy--The Coast Guard's marine beacons provide navigation to vessels on the Great Lakes and in coastal waters. Coverage is limited to about 200 miles, and accuracies depend upon distances from the beacons. Direction errors are typically plus or minus 5 degrees. However, these accuracies seem to be adequate for the large number of recreational vessels and smaller commercial craft which use the beacons. They do not provide the accuracy which fishermen need to return to their nets or that which the Coast Guard believes is needed by larger vessels to stay within 1 mile fairways or to prevent groundings in congested waters.

Reliability--The beacons are probably sufficiently reliable for small marine craft use. Users of direction finding receivers can also tune in on local AM broadcast stations for bearings so they are not entirely without coverage in case of beacon failure.

User equipment cost and acceptance--We also felt that the marine beacons should be retained because the beacons and the direction finding receivers are inexpensive and they are already widely used. It does not appear likely that any of the other navigation systems can approach the low cost of direction finding receivers. The better manual units sell in the $250 to $350 price range. Hand-held, portable units can be bought for around $100.

Potentially needed navigation systems

We place Omega and FAA's aviation nondirectional beacons in this category primarily because one or both would be required if a backup system is needed and until volume production and competition reduce the costs of NAVSTAR receivers. Thus, planned Government spending should be allowed at this time.

Omega

Omega will provide worldwide navigation coverage when the last of the eight transmitters is working. Omega's low accuracy is suitable for ships and aircraft operating in oceanic areas and as a worldwide backup system to NAVSTAR. Omega is a recognized international system with six transmitters to be operated by other nations.

We selected Omega, rather than Loran-C, as the interim backup system to the planned NAVSTAR satellite system primarily because the Omega system already provides navigation to most of the world. We felt that more money should not be spent for a backup system which may not be required if the NAVSTAR system proves to be highly reliable. If Loran-C were selected, several Loran-C chains would have to be built in the Southern Hemisphere to provide worldwide navigation.

The United States currently funds the operation and maintenance of five transmitters at an annual cost of $1.5 million, which is inexpensive compared to other systems. Shipboard receivers cost $2,000 to $8,000 while airborne receivers cost $10,000 to $60,000. The more expensive military receivers provide better accuracies and are easier to operate. Receiver costs should come down with growing usage.

Aviation nondirectional beacons

FAA's nondirectional beacons currently provide low-cost, low-accuracy navigation to aircraft during overland flights. Airborne direction finding receivers currently cost as low as $1,000, which is likely to remain lower than the cost of NAVSTAR and Omega receivers. The beacons are also inexpensive. FAA plans to replace existing beacons with new ones costing $1 million.

Unneeded navigation systems

We believe eight systems and part of one more, the military nondirectional beacons, will not be needed if NAVSTAR can be made the primary navigation system for aviation and marine use. As shown below, spending is planned for six systems and part of a seventh--the military nondirectional beacons. No spending is planned for Loran-A because of its scheduled phase-out and for differential Omega because of the recent termination of its development. Costs include planned spending for new equipment and the development of one system from fiscal year 1978 through the early 1980s.

Existing systems	FAA	Coast Guard	Military	Total
	(millions)			
Military nondirectional beacons			$ 8.8	$ 8.8
VOR	$31.5		9.9	41.4
TACAN	73.5		69.0	142.5
Loran-A				
Loran-C		$24.0		24.0
Loran-D			15.3	15.3
Transit			5.5	5.5
Systems being developed				
Differential Omega (recently terminated)				
PLRS			39.2	39.2
Total	$105.0	$24.0	$147.7	$276.7

We believe that much of the above planned spending for the development, expansion, or modernization of these systems should be deferred as long as NAVSTAR remains their potential replacement. However, VOR, TACAN, Loran-C, Loran-D, Transit, and the military's nondirectional beacons will probably be needed by current users until NAVSTAR becomes operational in the early or mid-1980s and for several more years to allow users to replace their navigation receivers with NAVSTAR receivers. Thus, some new equipment will have to be bought and deteriorating equipment replaced even though these expenditures would overlap with the development of NAVSTAR. Some spending may be justified:

--When safety of travel or combat readiness may be imperiled.

--For new vehicles entering service prior to the availability of NAVSTAR receivers.

--For equipment whose age or condition make their maintenance and operating costs prior to phase-out greater than their cost to replace.

--Where even limited duration use of a system will provide clear cost benefits.

As shown above, the FAA, Coast Guard, and military services plan to spend $276.7 million for equipment and the development of the potentially unneeded systems. Most of this spending is planned over the next 3 or 4 years because plans beyond the early 1980s were incomplete or not disclosed to us. The dollar amounts excluded installation, operation, and maintenance costs which could equal equipment costs. The extent that this planned spending can ultimately be deferred is unknown, but substantial amounts are possible.

The phaseout of the unneeded systems would also eliminate their operating and maintenance costs. A study made for the military estimated that the Government spends $55.5 million annually to operate and maintain the VOR, VORTAC, TACAN, and Loran transmitters. Of course these costs would be appreciably reduced if the older equipments were replaced with modern gear.

The point to be made, however, Is that the sooner NAVSTAR can be used to replace the unneeded systems the greater are the opportunities for avoiding the spending for modernizing equipments which NAVSTAR can replace. Earlier NAVSTAR use would also save the annual operating and maintenance costs for the systems which could be phased out.

At the time we were conducting our fieldwork the military had planned to deploy 11 satellites in mid-1981 which would have provided worldwide two-dimensional coverage with accuracies on the order of 300 feet. Since that time (for reasons which have no bearing on our report) the military no longer plans to deploy two-dimensional coverage in 1981 but intends to have worldwide three-dimensional coverage beginning in late 1984 with accuracies on the order of 30 feet by late 1985.

Cognizant military officials have told us that if civil needs for NAVSTAR could be justified beginning in the late-1981 and 1982 time frame, the annual costs for providing such two-dimensional coverage would be on the order of $18 million ($6 million to operate the satellite control system and $12 million annual amortization of the $60 million cost of the 5 additional satellites needed).

It is our view that such earlier NAVSTAR coverage, in the 1981-82 period, may be justified if it could, in fact, advance the transition to NAVSTAR by 3 years. The cost of providing it would appear to be more than offset from savings in operating and maintenance costs for systems which could be phased out 3 years sooner. Further offsets might be possible by avoiding the modernization or expansion of the unneeded systems. Finally, there may be cost savings to users, such as in avionics wherein NAVSTAR receivers may either provide improved capabilities or equal capabilities at lower costs. These savings could benefit both civil and Government users.

We believe the public announcement of NAVSTAR as the potential primary navigation system should be made at the time the decision is made to deploy NAVSTAR either as a two-dimensional system for civil use beginning in late 1981 (an early 1979 decision) or as a three-dimensional system for civil and military users beginning in late 1984 (a mid-1982 decision). Thus, the civil users would be alerted to the planned availability of NAVSTAR in the 2-1/2 years or so needed to buy and deploy the satellites. If another 6 years or so were allowed to effect the changeover to NAVSTAR, civil users would have 8 to 9 years use of their VOR 1/, Loran, and other receivers before they would have to be replaced.

The following discussions of each of the potentially unneeded systems, including our specific recommendations concerning planned spending, are based on the possible earlier availability of a two-dimensional NAVSTAR system for civil use and the scheduled late 1985 availability of a high accuracy system for civil and military use. Major deviations from these dates or the nonavailability of a low-cost NAVSTAR receiver for civil use may affect our recommendations.

Nondirectional beacons

Although we have said that marine beacons will be needed and that aviation beacons are potentially needed, we believe that continued military use of navigation beacons is questionable since NAVSTAR will provide far better accuracy and coverage beginning in the middle 1980s. Thus, the Army's planned buy of 425 additional portable beacons,

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1/The Coast Guard, for example, estimates a 7 year useful life for marine Loran-C.

costing $3.6 million, should be deferred because their scheduled deliveries in 1980 and 1981 will be only a few years before military NAVSTAR receivers are scheduled to be available.

The Navy, Air Force, and Marine Corps' planned buy of portable offset bombing beacons, costing $5.2 million, should be reduced because existing beacons could be used and because NAVSTAR is scheduled to provide better accuracy beginning in 1985. The Air Force considers the new beacons to be an interim system which will be replaced by NAVSTAR. Some of the beacons, which are scheduled for delivery in 1979 and 1980, may be justified in case NAVSTAR's development is delayed.

VOR

The NAVSTAR system has the potential for replacing VOR and DME as the primary navigation system for aviation worldwide. NAVSTAR is expected to provide superior accuracies and coverage for all aircraft and will allow aircraft to fly the shortest paths to their destinations with resultant time and fuel savings. If used in combination with a communications satellite, data links and displays, NAVSTAR could provide an aircraft surveillance system over ocean areas comparable to that provided by ground radars over land areas.

If a 1979 decision is made to deploy two-dimensional NAVSTAR in late 1981 for civil use, we think that ground VOR/DME equipments could be phased out beginning in the late 1987 time frame. If NAVSTAR coverage does not become available until the scheduled 1984-85 period, the VOR/DME equipments would have to be operated until about 1990-91 to allow users to transition to NAVSTAR. It would also be highly desirable to promote wide international acceptance of NAVSTAR. In this regard, we think other countries would find it in their economic interests to use NAVSTAR provided they had assurance of its availability. In present circumstances, at least, the United States will pay for the space segment of NAVSTAR. Use of NAVSTAR would thus relieve other countries from having to install, operate, maintain, and flight check or calibrate ground based transmitters, including VOR/DME.

In view of the potential for closing down the VOR/DME system in the late 1980s, we believe that FAA should defer its plan to replace all VOR transmitters with new ones costing $31.5 million. Exceptions should be made where the age or condition of equipment make it more costly to maintain than to replace.

The Army plans to buy VOR transmitters costing $1.5 million and combination VOR and instrument landing receivers costing $6.25 million. The Navy plans to buy VOR receivers costing $693,000, and the Air Force plans to buy combination VOR and instrument landing receivers costing $1.5 million.

We think the Army should defer its planned buy of VOR transmitters and many, if not all, receivers because NAVSTAR could be used for navigation. Some receivers included in the Navy and Air Force's planned buys may be needed for new aircraft prior to the availability of NAVSTAR receivers.

TACAN

FAA plans to spend $73.5 million to replace the TACAN portion of its VORTAC system. We believe FAA should defer its plan to replace all TACAN transmitters because virtually all military use is currently planned to be phased out in the 1980s and the remainder is likely to be phased out. As with VOR, some deteriorating TACAN equipment may have to be replaced.

The Navy plans to buy TACAN transmitters, costing $28.5 million, during fiscal years 1978 through 1981 and receivers, costing $26.7 million, during fiscal years 1978 through 1980. The Air Force plans to buy more new receivers, costing $13.8 million, in 1978. These planned buys are questionable because the military services plan to replace TACAN in the 1980s with NAVSTAR or the planned Joint Tactical Information Distribution System (JTIDS). The receipt of the NAVSTAR receivers for combat aricraft is scheduled to begin in 1984. JTIDS receivers having a TACAN component, which eliminates the need for a separate TACAN receiver, are scheduled for receipt beginning in 1983.

Loran-A

In 1974, the Coast Guard announced the intended phase-out of Loran-A in 1979 and 1980. This gave Loran-A users 5 or 6 years to switch over to the more accurate Loran-C system or another system.

Loran-C

We believe the planned NAVSTAR system could replace the navigation function of Loran-C during the late 1980s if two-dimensional NAVSTAR coverage is provided in late 1981 and around 1990 if NAVSTAR coverage is not provided until the scheduled 1984 and 1985 period. We realize that implementation of our recommendation to phase out Loran-C may create special problems for the Coast Guard and Loran users. However, 7-1/2 years use of the Loran-C equipment resulting from a mid-1982 announcement to deploy NAVSTAR for use beginning in late 1984 and a Loran-C phase-out by 1990 would equal or exceed the 7-year life for marine Loran-C estimated by the Coast Guard. Although a few Loran-C stations are also used for military communications, other means are currently available and improved means are being developed.

The Coast Guard is building Loran-C stations to provide navigation to maritime users in the coastal waters and the Great Lakes. These stations are to become operational in 1977 and 1978. The Coast Guard plans to build four more stations at an estimated cost of $24 million. We believe the four station expansion should be deferred because the earliest planned operational date is 1980, which is 1 year before NAVSTAR could provide two-dimensional navigation.

Loran-D

The Air Force believes its Loran-D will satisfy a need for a transportable navigation system which can be moved and set up in 3 days. Loran-D is to be an interim system until NAVSTAR becomes operational. A second chain was received in late 1976, and two more chains may be bought for delivery in late 1979.

We believe, however, that the planned buy of more Loran-D transmitters, costing $15.3 million, may be questionable because (1) the Army, Navy, and North Atlantic Treaty Organization (NATO) countries do not plan to use Loran-D, (2) the existing Loran-D equipment and offset bombing beacons can be used for bombing, (3) the planned NAVSTAR system could provide better accuracy and coverage beginning in late 1985, and (4) most Air Force aircraft currently equipped or scheduled to receive the Loran bombing equipment are scheduled for phase-out.

Transit

The Transit satellite system is currently used to provide periodic but highly accurate navigation for Navy ships and submarines and for U.S. and foreign merchant ships. It is also used for geophysical exploration because of its high accuracy when used from fixed platforms. NAVSTAR is scheduled to provide continuous coverage and higher accuracies by late 1985. Depending upon the time needed to retrofit Navy ships and submarines with NAVSTAR receivers, we believe the Navy can phase out Transit during the late 1980s.

The Navy spent almost $15 million during fiscal year 1977 for three improved Transit satellites to be received in fiscal years 1979 and 1980. Officials told us that more may be bought later. We believe future procurements should be deferred because (1) the scheduled receipt of the improved satellites is just a few years before NAVSTAR could be used, (2) the Navy already has 14 spare satellites, although not the improved type, which should keep the system operable at least until 1990, and (3) the existing satellites provide the same accuracy as expected from the improved satellites.

The Navy also plans to buy more Transit receivers costing $5.5 million. The planned buy for some of these receivers should be deferred except those needed prior to NAVSTAR's scheduled operation to correct cumulative errors in inertial systems.

Differential Omega

The Navy was developing differential Omega at a cost of $2.7 million for use in U.S. coastal waters beginning in the 1981-82 time frame. We had felt this development should be deferred or canceled because NAVSTAR receivers were scheduled to become available soon after and because the Coast Guard is expanding Loran-C coverage in U.S. coastal waters.

PLRS

We believe this Army and Marine Corps' development, costing $39.2 million, should be redirected so as to include the derivation of the vehicle position from the NAVSTAR signals. PLRS is expected to become operational in the early 1980s. Two-dimensional NAVSTAR coverage could be provided in late 1981, and the more accurate three-dimensional coverage is scheduled in late 1985.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Navigation systems vary widely with respect to geographical coverage, accuracy, suitability for use, and user costs for equipment. As newer and better systems are developed, the abandonment of older systems has been largely frustrated by user investments and costs to changeover. As a result navigation systems have proliferated with resultant higher costs to the Government and users. Moreover, we found substantial overlap among the 13 navigation systems included in our review. By this we mean that the navigation requirement for a particular community of users could be satisfied, equally well or better, by one or more systems other than that primarily used.

We believe future civil and military requirements can be met with the

--military's planned NAVSTAR satellite system as the primary navigation system for most land, sea, and air users;

--self-contained inertial and doppler radar systems for jam-proof and sabotage-free military operations, and as a backup system for some civil aviation; and

--Coast Guard's marine nondirectional beacons as a low-cost, low-accuracy system for small watercraft.

However, two events are key to this proposal. First, it depends upon the successful development and deployment of NAVSTAR. Second, much depends upon the timely development of a civil NAVSTAR receiver which, in quantity production, can be priced in the range of existing equipments, such as VOR/DME.

Since a backup system may be needed for NAVSTAR and since low-cost receivers will depend upon volume production and competition, we believe that Omega and the civil aviation nondirectional beacons should be retained at least for the next several years.

The planned development, modernization, or expansion of VOR, TACAN, Loran-C, Loran-D, Transit, the navigation portion of PLRS, and the military's nondirectional beacons are questionable because these systems could be replaced by the above-named systems. Loran-A is already scheduled for phase-out, and the Navy recently terminated its differential Omega development.

Although potentially unneeded in the future, VOR, TACAN, Loran-C, Loran-D, Transit, and the military's nondirectional beacons may continue to be required for navigation until they can be replaced by NAVSTAR in the late 1980s and perhaps into the 1990s. Thus, some new equipment will have to be bought and deteriorating equipment replaced even though these expenditures would overlap with the deployment of NAVSTAR.

The departments and agencies plan to spend $276.7 million for equipment or development of these potentially unneeded systems. Most of this spending is over the next 3 or 4 years and does not include installation or maintenance costs. Lacking details on the condition of equipment, we cannot assert how much of this planned spending can ultimately be deferred. However, we believe that substantial savings are possible.

Although it has been in existence since 1973, the interagency navigation planning committee has been unsuccessful in reconciling the parochial views and interests of the various departments and thereby eliminating navigation overlap because it lacked the needed authority and budgeting controls. In our view such planning efforts will likely succeed only if they are directed by an office or individual empowered to mandate a specific selection of navigation systems for retention and elimination and the necessary budgetary controls to implement those decisions.

RECOMMENDATIONS

We recommend that the President establish a single manager for navigation matters, within one of his Executive Offices, and give the manager the responsibility and authority (including budgetary controls) to direct the prompt development and implementation of a Government-wide navigation plan. The plan should eliminate or sharply reduce navigation overlap and contain the milestones and strategies for its orderly and cost-effective implementation. It should also be kept updated to reflect NAVSTAR development progress.

We also recommend, pending full implementation of the above Government-wide navigation plan, that the

--Secretaries of Defense and Transportation defer unneeded spending for VOR, TACAN, Loran-C, Loran-D, Transit, the navigational function of PLRS, and the military's nondirectional beacons as long as NAVSTAR remains their potential replacement and

--Secretary of Transportation, the Administrator of the National Aeronautics and Space Administration, and the Assistant Secretary for Maritime Affairs of the Department of Commerce become active participants in the NAVSTAR program to ensure that civil needs are considered including the possible earlier availability of a two-dimensional system and the timely availability of low-cost civil receivers.

AGENCY COMMENTS TO OUR DRAFT REPORT

Most Government departments and offices agreed that a Government-wide navigation plan is needed to reduce the proliferation and overlap of navigation systems. The Department of Transportation did not agree that civil navigation systems have proliferated, and the Department felt its pending National Plan for Navigation completely addresses the needs of the civil community.

OTP, the Maritime Administration of the Department of Commerce, and NASA agreed that a single high-level management focus is needed to assume Government-wide responsibility for navigation. The Director of the Office of Management and Budget advised us that the need for such an office was being considered. The Department of Transportation disagreed that a single office is needed, saying that navigation management should remain with the agencies responsible. DOD did not comment on this matter.

FAA, Coast Guard, and the military services (to some extent) felt that most of their plans to modernize, expand, or develop the systems we considered to be potentially unneeded should continue because the system could not be replaced by NAVSTAR, would continue to be needed as a backup, or would be required for several years after NAVSTAR became operational.

The lone exception is the Navy's termination of the differential Omega development. The Office of Management and Budget, OTP, the Assistant Secretary of Defense, and NASA agreed that NAVSTAR could replace most of the systems which we said may not be needed. The Maritime Administration disagreed somewhat with our selection of potentially unneeded systems, pointing out that navigators have traditionally relied upon considerable redundancy of systems for their tasks.

The Office of Management and Budget, the Assistant Secretary of Defense, the Department of Transportation, and the Maritime Administration felt that the transition to NAVSTAR could not occur as early as we proposed; OTP and NASA did not comment on the transition timing.

Although not commenting on our recommendation that the civil agencies become active participants in the NAVSTAR program, the Maritime Administration has already funded the modification of a military NAVSTAR receiver for civil maritime test and evaluation. NASA said it would like to develop low-cost NAVSTAR receivers for civil (land, sea and air) use. The Department of Transportation said that it is working closely with DOD on the possible civil use of NAVSTAR but doubts that NAVSTAR can replace the existing systems until the uncertainties (discussed in this report) have been resolved. DOD said it would cooperate with the civil agencies concerning the possible civil use of NAVSTAR and, in fact, had invited both the Department of Transportation and NASA to participate in the program as early as 1973.

OTHER CONSIDERATIONS

The Office of Management and Budget letter of September 26, 1977, (see footnote 1 on p. 22) raises matters which are relevant to our review. The radionavigation plan which accompanied the Office of Management and Budget's letter was prepared by OTP. The latter office had kept us informed of the plan during its preparation although we did not fully evaluate it. In particular, we did not evaluate the dollar savings which it postulated. However, the OTP plan is similar to our proposed alternative in that it, too, places primary reliance upon NAVSTAR and proposes the phase-out of numerous other systems. The OTP plan and our alternative differ in other respects. First, the OTP plan suggests that NAVSTAR can replace a number of systems, such as landing systems, ground radars, etc., which we did not consider. However, we agree that NAVSTAR may eventually replace such systems. On the other hand, the OTP plan suggested keeping Loran-C as a backup while we suggested its phase-out. Finally, the OTP plan showed a phase-out of unneeded systems essentially beginning in 1985 and completing in 1995 or later whereas we suggested a phase-out beginning somewhat sooner and ending by 1990. A final matter, as yet unresolved, concerns agency comments and reactions to the OTP plan and what actions the Office of Management and Budget (or the President) may take with respect thereto.

There are other matters which our draft report did not discuss but which have, or may have, a bearing on the possible transition to NAVSTAR. FAA believes that the international aviation agreement on the use of VOR/DME will have to be extended beyond its January 1985 expiration date.

The Coast Guard has proposed a regulation which would require that larger vessels entering U.S. waters carry Loran-C, or equipment providing comparable accuracy, to guard against groundings and oil spills.

EVALUATION OF AGENCY COMMENTS AND OTHER CONSIDERATIONS

We believe that a single management focus for navigation matters will be needed to oversee the preparation and execution of a truly Government-wide navigation plan, such as our alternative or the OTP plan. This is particularly so with the recent abolishment of OTP. We believe that the Department of Transportation's National Plan for Navigation is too limited in its scope because it does not fully consider military navigation needs and resources and ways in which the overlap between civil and military systems could be reduced by an orderly phase-out of redundant systems.

We do not agree that the spending for the unneeded systems should continue unabated. Although we said that some spending will be needed to replace equipment whose age or deterioration make it uneconomical to maintain or for new vehicles which must have equipment prior to the availability of NAVSTAR receivers, we believe that significant savings can be realized by deferring spending on the unneeded systems as long as NAVSTAR continues to offer the potential to replace them within the time frames now postulated. We also believe that FAA should not recommend the extension of the VOR/DME international agreement until the NAVSTAR system has been fully evaluated. We do not question the proposed Coast Guard regulations requiring Loran-C or comparable equipment because under our proposed alternative, users would still have 10 or more years in which to amortize their equipment investment.

We continue to believe that a single manager for navigation matters is required to ensure a coordinated and economical approach to the identification of the civil NAVSTAR receiver to be tested and evaluated for shipboard use in late 1978. In late 1977 NASA solicited industry proposals for the design of a NAVSTAR receiver for civil aviation use. Also, in late 1977, FAA had initiated a study of a civil aviation NAVSTAR receiver, and the Department of Transportation itself has recently begun studies of civil NAVSTAR applications. We believe these efforts could benefit materially if they were coordinated under a single manager. To our knowledge, the Coast Guard has not pursued any civil applications of NAVSTAR. Civil NAVSTAR receiver developments are important, and need early and authoritative management attention, including possible changes to the NAVSTAR signal waveform amd frequency which could afford significant benefits to civil users. (See p. 24.) In addition, the cost benefits of two-dimensional civil NAVSTAR coverage by 1982 need to be evaluated as a matter of urgency because a decision in this matter would be needed as early as 1979.

Several agencies commented that our proposed timing for the transition to NAVSTAR was too optimistic. As noted earlier, there has been little or no consensus on navigation systems usage or the selection of systems for retention or phaseout. Also, the prevailing navigation management arrangements within DOD and the Department of Transportation have not, in our view, been fully effective in resolving the parochialism within the services and agencies. In these circumstances we would have to agree that our timing is optimistic. However, we think that it may be possible to achieve the transition within the time periods we have suggested as long as NAVSTAR stays on schedule and if firm management focus is applied at the appropriate high levels we have recommended. The matter of timing, however, in no way ameliorates the need for closer management of navigation resources.

MATTERS FOR CONSIDERATION BY THE CONGRESS

The Congress should question future requests for expenditures on navigation systems which may not be needed in later years, allowing funds only when they can be cost/benefit justified or on the specific basis of safety or combat readiness.

The Congress also may have to decide whether a civil or military agency should eventually manage NAVSTAR, recognizing that civil operation may encourage earlier civil and international use but that military operation may be needed to assure that the high accuracy signals used for weapons delivery would be denied to hostile forces during a war or national emergency.

DESCRIPTION AND USES OF

NAVIGATION SYSTEMS

Our review covered 13 different navigation systems. The FAA, Coast Guard, and the military services operate eight different major enroute radionavigation systems. The other two existing systems are self-contained systems not depending on external radio signals. The military services are developing two new radionavigation systems having improved navigation capabilities. One of these planned systems will also be used for communications and identification, but our review dealt only with the navigation function. The military development of a third new system was recently terminated.

These 13 systems will be described in this appendix including their methods of operation, typical accuracies and geographical coverages, current and planned users, equipment costs, and agency plans. Summaries of current and planned users for various categories of ships and aircraft are shown in appendix II (see pp.66 and 67). As shown in the following table, the FAA, Coast Guard, and the military services plan to spend $3.8 billion for new navigation equipment (including the geographic extension or modernization of all but one of the existing radionavigation systems) and the continued development of the two new systems.

Navigation System	FAA	Coast Guard	Military	Total
	(millions)			
Nondirectional beacons and receivers	$ 1.0	$ 3.4	$ 13.4	$ 17.8
VOR	31.5		9.9	41.4
TACAN	73.5		69.0	142.5
Loran-A				
Loran-C		24.0		24.0
Loran-D			15.3	15.3
Omega			21.4	21.4
Transit			5.5	5.5
Inertial			438.2	438.2
Doppler radar			123.8	123.8
Differential Omega				
PLRS			39.2	39.2
NAVSTAR			2,895.0	2,895.0
Total	$106.0	$27.4	$3,630.7	$3,764.1

These dollar amounts, which include most estimated costs for fiscal years 1978 through the mid-1980s, reflect the estimates of cognizant agency officials at the time of our review. We cannot attest to the accuracy of these estimates because, in part, planned future spending is subject to change and several constraints, such as congressional appropriation. A more detailed breakdown of planned spending is included below for each system.

Nondirectional beacons

A nondirectional beacon transmits its radio signals in all directions. A direction finding receiver rotates its antenna to obtain the direction or heading in degrees to the beacon. Signals from two or more beacons can be used to determine position, the position being a point on a map where the direction lines cross.

FAA operates almost 290 enroute beacons throughout the United States and possessions to provide navigation for overland flights. The beacons, which were first used in the 1930s, cannot be used for navigation on transoceanic flights because their radio signals have ranges of 25 to 500 miles. The typical 5-degree direction error results in an error of 6-1/2 miles when 75 miles from the beacon but 0.9 mile when 10 miles from the beacon. Hence, the navigation error increases as the distance from the transmitter increases.

The Coast Guard operates over 200 marine beacons to provide navigation for commercial and recreational vessels in coastal and inland waterways. These beacons have ranges of 10 to 200 miles. The navigation error is also typically 5 degrees. The location of these beacons as well as some AM broadcast stations, which may also be used, are depicted on nautical charts commonly used by boat operators.

The Army, Navy, and Air Force have navigation beacons at their airfields and portable beacons for navigation in combat areas. In addition, the Navy, Air Force, and Marine Corps use another type of portable beacon, transmitting line-of-sight signals, for radar offset bombing. When queried by the airplane's radar, the beacon emits a signal which is received by the airplane's weapons delivery system. The ground observer, who has the portable beacon, radios to the pilot the direction and distance of the target from the beacon. This data is input to the airplane's avionics system which guides the airplane to the target area and automatically releases the bombs. These beacons have a navigation range of 60 miles but only a maximum range of 16 miles for offset bombing. The classified bombing accuracy obtained from the beacons is superior to all other existing navigation systems but not as accurate as the military's planned NAVSTAR satellite system (see p. 61).

Users

Nondirectional beacons and direction finding receivers are used worldwide because of their simplicity, reliability, and low cost. Aviation and maritime users carry direction finding receivers as a backup to more accurate navigation systems or as a low cost primary navigation system when greater accuracy is not needed. Receivers are used by an estimated 153,000 aircraft worldwide, including some 21,000 U.S. military aircraft and 78,000 civilian aircraft, and 300,000 U.S. ships and boats. International maritime regulations require that vessels grossing 1,600 tons or more carry a direction finding receiver.

U.S. naval ships and submarines do not carry direction finding receivers for navigation, but some ships carry receivers for showing the direction of signals from emergency transmitters used by aircraft in distress.

Equipment costs

Nondirectional beacons typically cost from $6,000 to $35,000 with the lower amounts for military portable beacons used for offset bombing and the higher costs for military beacons used for navigation. Direction finding receivers for military and civilian aircraft cost from $1,000 to $5,000. Shipboard receivers typically cost in the range of $200 for a manually operated unit used on recreational boats to $5,000 for a more accurate receiver used by large ships.

Agency plans

The FAA, Coast Guard, and the military services plan to spend $17.8 million for nondirectional beacons and direction finding receivers.

The FAA plans to operate its beacons indefinitely because of their reliability and low cost. The FAA plans to replace existing beacons during 1978 and 1979 with new beacons costing $1 million.

The Coast Guard plans to operate its beacons indefinitely and to replace the 15- to 20-year old beacons during fiscal years 1978 through 1980 with new beacons costing $2.5 million. In addition, the Coast Guard plans to pay $880,000 during 1978 for 176 shipboard direction finding receivers to show the direction of distress signals and for navigation.

The Army recently selected nondirectional beacons and direction finding receivers as the primary combat navigation system for helicopters. The earlier plan to use Loran-C and the Air Force's Loran-D was changed because of the vulnerability of the transmitters. The Army recently bought 270 new portable beacons and plans to buy 425 more during fiscal years 1979 and 1980, at a cost of $3.6 million, for delivery in 1980 and 1981. The longer range version, up to 115 miles, is to replace existing beacons at Army airfields and to replace existing beacons used to locate landing zones in battlefield areas. The shorter range version, 30 miles, is to be issued to regular and reserve Army units for setting up a grid in the battlefield area to establish airways for the helicopters. Most beacons are going to Army units currently without beacons.

The Navy intends to continue using nondirectional beacons and direction finding receivers for aircraft navigation. Some beacons at airfields were recently replaced, and the remainder may be replaced at a later time. The Navy plans to buy about 500 airborne receivers, costing $1.2 million, during fiscal years 1978 through 1980. The Navy also plans to pay $3.4 million over fiscal years 1980 through 1982 for new shipboard receivers to replace less accurate receivers showing the direction to rescue downed pilots.

The Air Force is phasing out its use of navigation beacons and direction finding receivers.

The Navy, Air Force, and Marine Corps plan to buy 850 new portable beacons for offset bombing. This new beacon will replace two existing beacons. The three services plan to spend $5.2 million for the beacons, with planned deliveries in 1979 and 1980.

VHF Omnidirectional Range (VOR)

The VOR transmitter sends out a radio signal which in effect shows 360 directions at one degree intervals. The VOR receivers pick up the part of the signal which corresponds to the direction to the transmitter. Like nondirectional beacons, signals from two VOR transmitters can be used to determine position on a map. An aircraft having a VOR receiver and distance measuring equipment (DME) can determine the direction and the distance of a single VOR, thereby enabling the user to position himself on a map when within range of only one transmitter.

VOR has a typical range of 200 miles, but its effective range is less for low-flying aircraft because the system uses line-of-sight radio signals. Aircraft at 26,000 feet or higher can receive VOR signals up to about 200 miles. On the other hand, an aircraft at 800 feet altitude can receive the signal only when within 35 miles of the VOR.

VOR has a typical navigation error of about 3-1/2 degrees in direction, which translates to 0.6 miles at 10 miles from the transmitter. At 75 miles from the transmitter the error could be as much as 4-1/2 miles. The distance measurement of DME is accurate to 1/2 mile.

Many VOR transmitters are combined with the military TACAN system (described on p. 48) in what are called VORTAC transmitters. These provide both direction and distance to civil or military aircraft equipped with VOR and DME receivers or those equipped with TACAN receivers.

FAA operates a nationwide system of 704 VORTAC transmitters, 203 VOR transmitters, and 17 VOR/DME transmitters as the primary radionavigation system used by civil and military aircraft for overland flights. These transmitters are located between airfields for enroute navigation. In fact, they form the electronic airways which lace our country. Additionally, they are located at airfields to aid aircraft in approach and landings. FAA is required by international agreement to operate VOR and DME until January 1, 1985.

The military services operate VOR transmitters at many of their airfields for the same reasons that FAA provides them at civil airports. The Army has 17 VOR transmitters at airfields and plans to put in 15 more at other airfields. The Navy has six VOR transmitters. The Air Force has VOR transmitters at 36 airfields and VORTAC transmitters at 14.

Users

VOR is used by an estimated 280,000 civilian aircraft and 13,000 military aircraft worldwide. Estimated U.S. users include 8,000 military aircraft, 2,500 commercial airliners, and 136,000 private aircraft ranging from company-owned jets to single-engined, propeller-driven airplanes.

The Army currently has VOR receivers on 3,500 helicopters (40 percent of all helicopters) and many of its 800 fixed wing aircraft. The Army uses VOR because VOR equipment costs less than TACAN and because Army helicopters can follow established airways in the United States and Europe. Current plans are to have VOR in 6,000 helicopters (70 percent of all helicopters) by the late 1980s.

The Navy has VOR receivers on most cargo, patrol, and training aircraft. Some helicopters and other aircraft also have VOR.

The Air Force has VOR receivers in most bombers, cargo, and training aircraft and in some other aircraft.

Current Navy and Air Force plans call for the phase-out of VOR by 1990.

Equipment costs

A VOR transmitter typically costs about $45,000. The airborne VOR receiver costs from $1,000 for the lowest priced civilian receiver to $15,000 or more for a military receiver. Airborne DME costs from $2,000 for the lowest priced civilian equipment to $10,000 for equipment used by commercial airliners.

Agency plans

FAA and the military services plan to spend $41.4 million for VOR transmitters (includes $11.5 million for FAA's remote monitoring equipment) and receivers.

FAA may buy new VOR and TACAN transmitting equipment to reduce its operating and maintenance costs since much of its equipment is aging. For example, 35 percent of the VOR equipment was installed during 1943-1946, 27 percent during 1951-1956, and 38 percent during 1957-1962. The TACAN transmitters were installed from 1957 to 1960.

The new equipment costs are estimated at $105 million consisting of $20 million for VOR equipment, $62 million for TACAN equipment, and $23 million for remote monitoring equipment. Total estimated costs would be an estimated $36 million higher if all dual VOR and TACAN transmitters were obtained to decrease down-time. FAA plans to obtain the new equipment over a 5-year period beginning in 1978.

APPENDIX I

The Army expects to buy 32 VOR transmitters during fiscal years 1977 and 1978. Seventeen are to replace existing transmitters, and 15 are to go to airfields currently without VOR transmitters. The 12 transmitters to be bought in fiscal year 1978 are expected to cost $1.5 million.

The Army also plans to buy over 4,000 combination VOR receivers. An aircraft can use the VOR portion of the combination receiver to reach the airfield and the instrument landing portion to land at the airfield. Over 1,500 receivers are to be bought in fiscal years 1977 and 1978 for helicopters generally without VOR receivers, and 2,500 receivers, costing $6.25 million, may be bought in 1979 and 1980 for planned new aircraft.

The Navy plans to buy 40 VOR receivers costing $693,000 during fiscal years 1978 through 1980.

The Air Force recently bought some combination VOR receivers and may buy almost 700 more, costing $1.5 million, if a contract option expiring in late 1977 is exercised. Like the Army's receivers, these receivers can also be used for instrument landing.

Tactical Air Navigation (TACAN)

The military's TACAN system operates in a manner similar to FAA's VOR and DME. The distance measuring portion of TACAN is identical to FAA's DME, but the direction portions cannot be interchanged because different frequencies are used. TACAN's accuracy and operational range are the same as VOR and DME. TACAN was first used in the mid-1950s.

The FAA, Navy, and Air Force have TACAN transmitters. As discussed in the above VOR section, FAA's TACAN transmitters are combined with VOR to become VORTAC which provides navigation during overland flights to civilian and military aircraft. The Navy and Air Force have TACAN transmitters at their airfields, and the Air Force and Marine Corps have portable TACAN transmitters to locate combat area landing fields and for navigation during combat flight operations. Some of the Navy's ships have TACAN transmitters so aircraft can determine the direction and distance to the ship.

Users

An estimated 14,000 U.S. military aircraft carry TACAN receivers for navigation during overland flights and combat area flights. Except for Army helicopters, most military aircraft currently carry TACAN receivers. Current military plans call for the phase-out of TACAN by the late 1980s.

Equipment costs

TACAN transmitters cost from $200,000 for a ground version to almost $500,000 for a shipboard version. Portable transmitters cost over $60,000 each. TACAN receivers cost from $10,000 to $30,000.

Agency plans

FAA, Navy, and Air Force plan to spend $142.5 million for TACAN transmitters and receivers.

As discussed in the above VOR section, FAA may spend $73.5 million to replace its TACAN transmitters (includes $11.5 million for remote monitoring equipment).

The Navy plans to buy 174 TACAN transmitters to replace all shore-based transmitters, to replace some shipboard transmitters, and to put shipboard transmitters on new ships. Most transmitters are to be bought during fiscal years 1978 through 1981 at an estimated cost of $28.5 million. The Air Force has been buying new parts for its TACAN ground transmitters.

The Marine Corps plans to buy new components during fiscal years 1977 and 1978 for 24 portable TACAN transmitters. The Air Force planned to buy 30 portable TACAN transmitters during fiscal year 1977.

The Navy plans to spend $26.7 million during fiscal years 1978 through 1980 for over 700 airborne receivers. The Air Force is buying TACAN receivers under a contract, having options, to buy as many as 8,300 receivers. Under the last option, which expires in September 1978, 1,600 receivers could be bought for $13.8 million.

Loran-A

The Coast Guard's Loran-A, first used during World War II, is set up in chains of at least two pairs of transmitting stations. The stations are a few hundred miles apart. The two transmitters of the first pair send out matching radio signals to be picked up by the Loran-A receiver. A line of position is determined from the difference in time it takes for the signals from each transmitter in the pair to reach the receiver. Signals from a second pair of stations are used to compute a second line of position. One's location on a chart or map is where the two lines of position cross.

The ground wave geographical coverage from 2 pairs of stations is typically 750 miles with a positioning error of 1 to 2 miles. The sky waves from stations operated by the Coast Guard and other nations provide navigation coverage for most of the Northern Hemisphere but with a higher positioning error of 6 to 7 miles.

The Coast Guard operates stations along the East Coast, Gulf of Mexico, Caribbean, West Coast, Gulf of Alaska, Aleutian Islands, and the Hawaiian Islands primarily for civilian use. The Coast Guard announced in 1974 that these stations were to be turned off in 1979 and 1980. The Coast Guard also operates other stations outside of the United States primarily for use by the military. These stations are to be turned off at the end of 1977.

Users

Loran-A is used by commercial airlines on oceanic flights, by civilian ships and boats on the high seas and in coastal waters, and by some military sea and air users. Loran-A has been used by an estimated 11,500 civilian and 7,500 military users, but these numbers will be decreasing because of the Coast Guard's announced plan to shut down its stations.

Many Navy ships and submarines currently carry Loran-A receivers, but these are being phased out. Some Navy patrol and cargo aircraft and Air Force cargo aircraft currently have Loran-A receivers, some of which have been modified so Loran-C signals could also be received. There is no military requirement for Loran-A after 1977.

Equipment costs

Because of its imminent phase-out, it is unlikely that users will buy any more Loran-A receivers. If bought, receivers would probably cost about the same as low-cost Loran-C receivers.

Agency plans

There are no spending plans for new Loran-A equipment because of the planned phase-out.

Loran-C and Loran-D

The Coast Guard's Loran-C, first used in 1958, is set up in chains of three or more transmitting stations. Like Loran-A, the Loran-C receiver computes lines of position based on time-of-arrival differences between signals from selected combinations of two transmitters of the same chain. One's position is where these lines of position cross. Although similar in operation, Loran-A equipment cannot be interchanged with Loran-C and Loran-D equipment, because they use different frequency bands. The Air Force's Loran-D system is a transportable version of Loran-C, and the receiving equipment is interchangeable.

The Loran-C ground wave signals provide a position error of three-tenths of a mile to as low as a few hundred feet. Loran-D is more accurate primarily because of proximity of receivers to the transmitters. Existing Loran-C chains provide geographical coverage of 900 miles to 2,400 miles from the ground wave signals, but Loran-D covers less than 500 miles. Loran-C sky waves, which provide a position error of 2 miles, cover most of the Northern Hemisphere. See the next page for Loran-C coverage chart.

APPENDIX I

SOURCE: COAST GUARD

NOTE: THE DARK SHADED AREAS RECEIVE GROUNDWAVE SIGNALS GIVING A NAVIGATION ACCURACY OF THREE–TENTHS OF A MILE TO AS LOW AS A FEW HUNDRED FEET.
THE LIGHT SHADED AREAS RECEIVE SKYWAVE SIGNALS GIVING A TYPICAL ACCURACY OF 2 MILES.

The Coast Guard operates seven Loran-C chains, the East Coast chain and six chains outside of the United States, primarily to provide navigation for submarine operations. As discussed below, the Coast Guard is building other stations along U.S. coastal areas for civilian use.

The Air Force operates two Loran-D chains in Germany to provide all-weather navigation during combat flight operations. The second chain was received in late 1976, and more chains are planned.

Users

Loran-C is currently used by an estimated 3,400 civilian maritime users, some U.S. military aircraft, and some Navy submarines. Military aircraft carrying Loran-C receivers include some Air Force and Navy cargo aircraft, some Air Force fighters, and some Navy patrol airplanes.

Except for the strategic submarines, the military will be phasing out their use of Loran-C in the 1980s. However, the number of civilian users is expected to grow as Loran-A receivers are replaced with Loran-C receivers.

Equipment costs

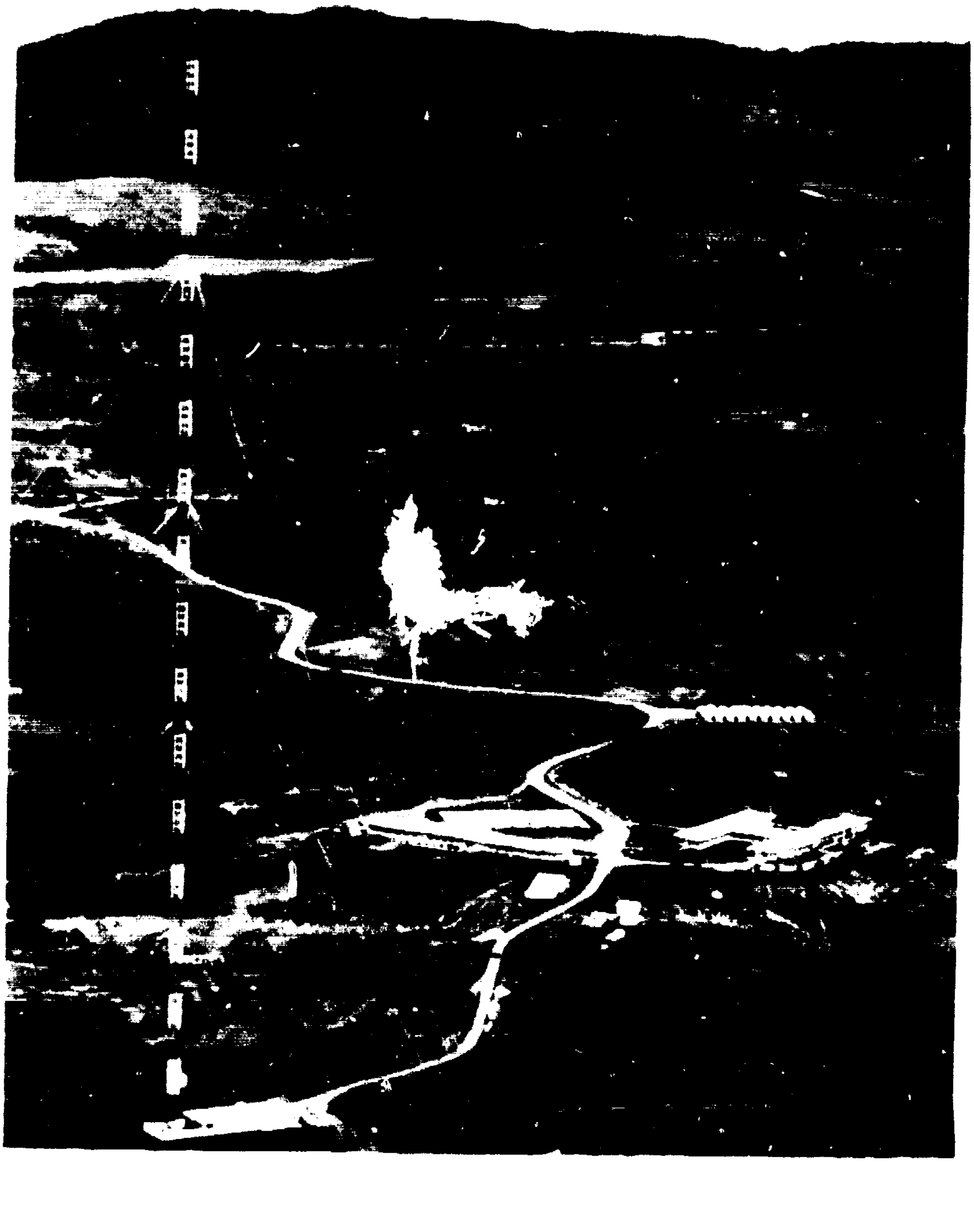
A Loran-C transmitting station currently costs $4 million. See the next page for an aerial view of a typical station. Loran-C and Loran-D receivers cost from $1,100 to $5,000 for civilian maritime receivers to as much as $20,000 for a military airborne receiver.

Agency plans

The Coast Guard and the Air Force plan to spend $39.3 million for Loran-C and Loran-D transmitters and receivers.

The Coast Guard is building several Loran-C stations to provide navigation coverage in the U.S. coastal waters and the Great Lakes. The eight stations being built along the West Coast from Alaska to California are scheduled to start working in early 1977. The three stations being built for the Gulf of Mexico have a scheduled operational date of July 1978. One station being built to expand the present East Coast chain is to become operational in July 1978. The Coast Guard plans to build one station, scheduled to become operational in early 1980, to complete coverage on the Great Lakes. The Coast Guard is also considering building three more stations in the western United States to provide total

APPENDIX I



SOURCE: COAST GUARD

U.S. coverage. Total cost of the stations being built is $51.2 million. The three proposed western stations are estimated to cost $18 million, and the one Great Lakes station will cost $6 million, based on the estimated costs of western stations.

The Air Force plans to spend $15.3 million in early 1978 for two more Loran-D chains to be received in late 1979. The Air Force recently bought 240 airborne Loran receivers for installation from late 1978 through late 1980.

Omega

The Navy-developed Omega system will eventually consist of eight ground-based transmitters with each transmitter having a range of about 5,000 miles. Seven stations are at least partially working, and the last permanent station will be built in the near future, thus providing worldwide coverage.

The Omega transmitters send out coded and precisely timed signals to the Omega receiver which computes a line of position based on the time required for signals from two transmitters to reach the receiver. The receiver computes at least two lines of position to determine location, which is the point where the lines of position cross. The system currently provides an accuracy of 1 to 5 miles over most of the Earth's surface and is expected to provide worldwide coverage with 1 to 2 miles accuracy.

Coast Guard personnel operate the two U.S. stations, and other nations operate the other five. The Navy expects to continue paying the operating cost of the U.S. stations until the Coast Guard assumes full responsibility in 1980.

Users

Omega provides navigation to airplanes on transoceanic flights and ships operating on the high seas. Although probably no more than 10,000 users now have Omega receivers, the number is expected to grow. The Navy is putting Omega receivers on surface ships and attack submarines and on some helicopters, patrol aircraft, and cargo aircraft. The Air Force is putting Omega on some cargo aircraft. The commercial airlines are experimenting with Omega for use on transoceanic flights, and commercial cargo and some fishing vessels already use Omega.

As a matter of interest, anyone living in the Washington, D.C., area can obtain an Omega system status report by dialing 245-0298.

Equipment costs

Shipboard Omega receivers cost from $2,000 to $8,000. The Navy, however, recently paid $65,000 for receivers used on submarines. Airborne receivers cost from $10,000 to over $60,000. Each transmitting station costs $5.5 million to $8 million for installation and equipment.

Agency plans

The Navy and Air Force plan to spend $21.4 million for airborne Omega receivers.

The Navy plans to buy 160 airborne receivers, costing $10.9 million, in fiscal years 1978 through 1980, for use in helicopters, patrol airplanes, and cargo airplanes.

The Air Force recently contracted to buy almost 700 airborne receivers to put on cargo airplanes flying trans-oceanic routes. Total cost is $14.2 million, including $10.5 million for unexercised options.

Transit

The Navy's Transit satellite system uses 4 to 6 satellites in 600 mile altitude orbits. The system, which became operational in 1964, provides worldwide two-dimensional navigation to slow-moving or stationary platforms. Accuracies vary from three-tenths of a mile from one satellite pass using a low cost receiver to tens of feet from many satellite passes over a stationary platform. A typical Navy receiver provides an accuracy of one-tenth of a mile from one satellite pass. The low altitude of the orbiting satellites restricts the user community to slow-moving platforms because a satellite may not be in view for long periods thus preventing position computations for up to 1-1/2 hours.

Users

Transit is currently used by an estimated several hundred commercial ships worldwide, virtually all Navy submarines and many Navy ships. Current Navy plans are to phase out most usage of Transit by the late 1980s. The strategic submarine personnel, who also operate Transit, plan to continue using the system until a proven system provides similar or better capability.

Equipment costs

Transit receivers cost from $6,000 to as much as $100,000 for some military models.

Agency plans

The Navy plans to spend $5.5 million during fiscal years 1978 through 1980 for 225 more shipboard Transit receivers. The Navy wants to put Transit receivers on three-fourths of its ships. The Navy spent almost $15 million in late 1977 for 3 improved Transit satellites, to be delivered in fiscal years 1979 and 1980, and more may be bought in fiscal year 1979. The improved satellites are to be less susceptible to radiation than the existing satellites.

Inertial

Inertial navigation systems depend upon gyroscopic principles for their operation. They are self-contained; that is, they do not depend upon external radio aids. They calculate position by measuring acceleration or deceleration in relation to time and direction. Although they can be accurately set at the point of departure, inertial systems have drift errors over time. For example, systems commonly used by transoceanic aircraft drift about 1 mile for each hour of flight time. Hence, the errors are cumulative. Aircraft can correct for such drift either by self-contained doppler radar or by using one of the radionavigation systems (Loran or Omega) described earlier. Being self-contained, inertial systems can be used worldwide including areas not having radionavigation coverage.

Users

An estimated 4,000 military aircraft, some Navy ships, and virtually all Navy submarines carry inertial because unlike radionavigation systems, inertial is not subject to signal jamming or sabotage of the transmitters. Submarines also depend heavily upon inertial systems for navigation when submerged because signals from radionavigation systems cannot penetrate seawater to any appreciable depth. The commercial airlines are experimenting with a hybrid Omega/inertial system using one $100,000 inertial and one $20,000 Omega receiver rather than three $100,000 inertials. This hybrid system should give a maximum positioning error of 2 miles, the Omega system error, as long as the Omega system is operating. If the inertial stopped operating, the Omega system would provide navigation. If the Omega receiver stopped operating, the inertial system would become the navigation system starting with the Omega error of up to 2 miles.

Equipment costs

Airborne inertial systems used by commercial airlines and the military services currently cost about $100,000 each and have a typical error of 1 mile per flight hour. As discussed below, the Air Force is developing two new inertial systems.

Inertial systems used in aircraft carriers and submarines may cost over $1 million each but provide far better accuracies. The Navy plans to pay about $135,000 each for a new inertial system going on cruisers and perhaps some destroyers.

Agency plans

The Navy and Air Force plan to spend $438.2 million for inertial systems.

The Navy plans to buy 371 airborne units costing $62.8 million during fiscal years 1978 through 1980 and 40 shipboard units costing $5.4 million during fiscal years 1977 through 1983.

The Air Force plans two large buys which will extend into the early 1980s. These are for 1,000 high accuracy units costing an estimated $120 million and up to 5,000 low-cost units costing $250 million. The high accuracy system, which is hoped to provide an error of one-tenth of a mile per flight hour, is to be used in the existing B-52 bomber and the new B-1 bomber for setting an accurate starting position in missile inertial guidance systems. The low-cost system is to have the standard 1 mile per flight hour accuracy but is to cost only $50,000 each.

Doppler radar

This self-contained airborne system, which can be used worldwide, measures speed by bouncing signals off the Earth's surface. When used with a compass, which provides direction, navigation estimates can be obtained at accuracies of 1 to 2 percent of the distance travelled. Like an inertial system, doppler radar's cumulative navigation error can be corrected with a radionavigation system. Doppler can also be used to correct speed errors in inertial navigation systems.

Users

Doppler radar is currently used by almost 6,000 U.S. military aircraft. Navy aircraft typically carrying doppler include helicopters, and patrol, cargo, and attack airplanes. Air Force bombers, cargo, and attack airplanes have doppler.

Typical planned usage of doppler in 1990 consist of Navy attack airplanes, Air Force bombers and cargo airplanes, and Army and Navy helicopters.

Some commercial airlines currently use doppler during transoceanic flights but plan to phase them out.

Equipment costs

Military and civilian doppler radar systems cost from $30,000 to $60,000.

Agency plans

The Army, Navy, and Air Force plan to spend $123.8 million for doppler radar systems.

The Army plans to buy almost 2,000 navigation units during fiscal year 1979 through the early 1980s at a cost of $60 million. Most of these dopplers are to go into new helicopters.

The Navy plans to buy 213 dopplers for $13.8 million during fiscal years 1978 through 1980. These dopplers are to be used by helicopters and patrol airplanes for navigation.

The Air Force plans to put 1,000 dopplers, costing $50 million over several years, in bombers for navigation and to correct speed errors in inertial systems.

Differential Omega

The navigation errors of Omega are attributable to daily ionospheric variations and sudden ionospheric disturbances caused by sunspots. These errors can be continuously measured by receivers at fixed locations such as at nondirectional beacon transmitters. The latter can then broadcast local corrections (called differential Omega) to Omega users within range of the beacon. The Navy had planned one-fourth mile accuracies up to 300 miles from its differential beacons (a system like this is being tested in France) but recently discontinued its development plans.

Planned users

The Navy wanted differential Omega for ship navigation in U.S. coastal waters. The system was to become operational beginning in late 1981 or 1982.

Planned spending

The Navy planned to spend $2.7 million in fiscal years 1980 through 1983 for 29 transmitters to be placed along the East Coast, West Coast, Gulf of Mexico, and southern Alaskan coast and for the modification of 450 Omega receivers so the differential signal can also be received.

PLRS

The Army and Marine Corps' planned PLRS will consist of a ground-based master control unit and over 300 user units. PLRS is to be a communications, navigation, and identification (CNI) system with navigation being one of its functions. Using line-of-sight signals received from the user units, the master control unit computes distance and direction of the user units, sends the position back to the user units for navigation purposes, and locates all user units on a large plot board so the commander will know where his units are. The maximum diameter coverage of the system is 50 miles for ground units and 250 miles for airplanes. Test results show about 150 foot accuracies for stationary ground units but poorer accuracies for fast-moving user units at longer distances. PLRS is scheduled for receipt in the early 1980s.

Planned users

User units are to be carried by individuals and vehicles for navigation during combat area land movements and by aircraft for navigation during combat area flights.

Planned spending

The Army and Marine Corps plan to spend $39.2 million during fiscal years 1978 through 1982 for the development of PLRS. Equipment procurement plans and dollar amounts had not been made at the time of our review.

NAVSTAR

The Army, Navy, and Air Force's planned NAVSTAR satellite radionavigation system will eventually consist of a space segment of 24 satellites in 3 orbits each containing 8 satellites, a ground control segment in the United States, and about 25,000 receivers of various models and complexities. The military services believe NAVSTAR will improve navigation and weapons delivery and will slow the proliferation of other military navigation systems. (See next page for an artist's conception of the NAVSTAR system.)

The satellites will transmit two accurately timed UHF signals, with each signal containing a precise and one, a coarse component. The military plans to have the capability to deny the precise components to other than authorized users in time of war. Should denial occur, users relying on the precise signal components would suffer reduced accuracy.

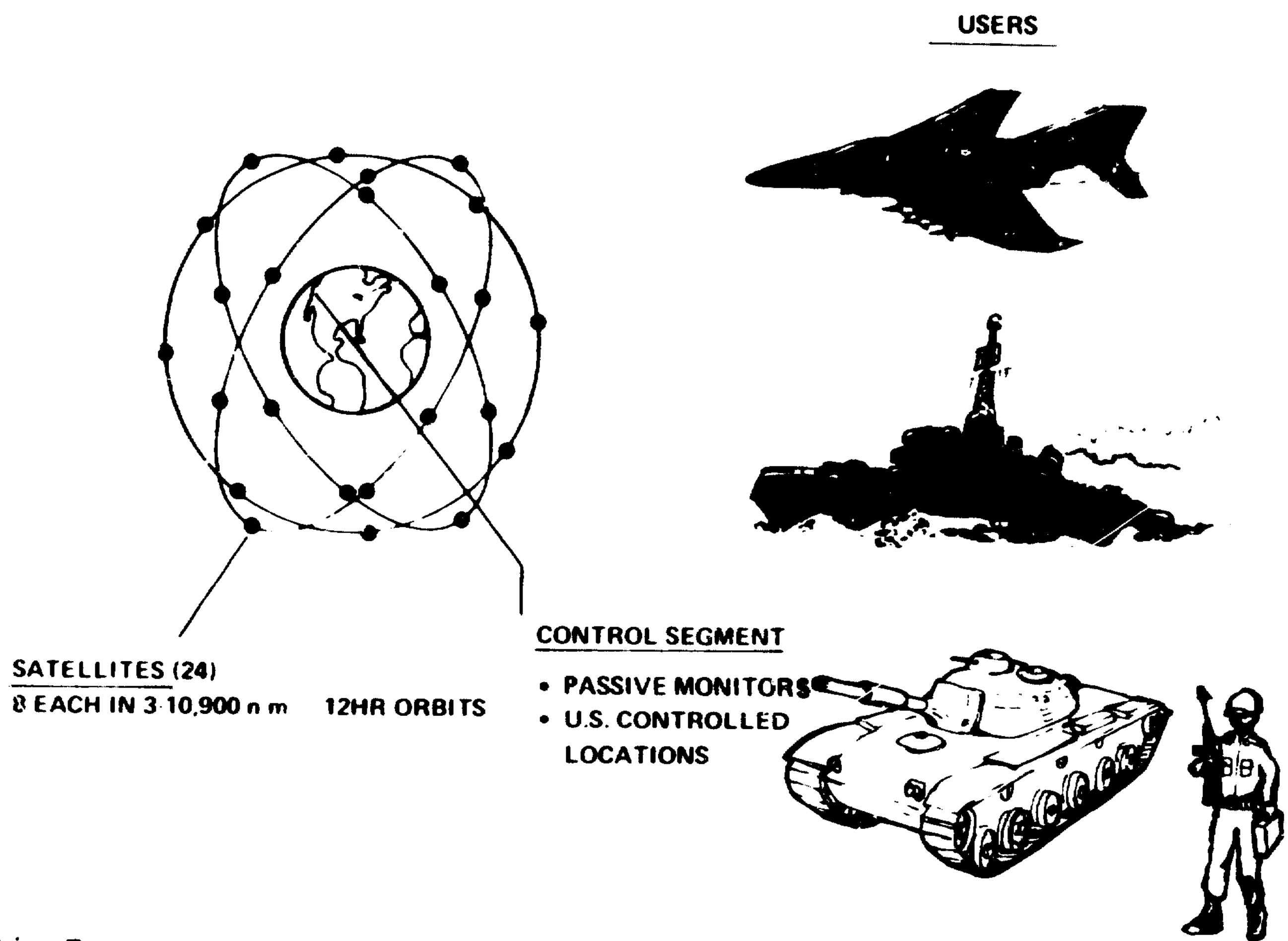
Worldwide two-dimensional coverage using 9 to 11 satellites was planned to begin in 1981 with an expected accuracy of 300 feet for receivers using both signal components and between 300 and 900 feet for receivers using only the nondeniable coarse component. Worldwide three-dimensional coverage was planned in 1984 with the full complement of 24 satellites. Receivers using both components could then obtain an accuracy of 30 feet while those designed only for the nondeniable component should obtain 300 foot accuracies.

The NAVSTAR development plan was recently revised because of technical problems (reportedly claimed to be solved), cost growth and the decision to defer the planned installation of NAVSTAR receivers in 1,000 military cargo airplanes during 1980 through 1982. The revision eliminated the scheduled worldwide two-dimensional navigation coverage beginning in 1981 and changed the scheduled worldwide, three-dimensional, high accuracy coverage from 1984 to 1985. The military felt that worldwide two-dimensional coverage could still be provided in late 1981 or early 1982 for civil use although the military does not plan to install NAVSTAR receivers until 1984. A military official said the two-dimensional coverage could be obtained by adding five more satellites to the six already scheduled for testing. He said the five additional satellites would cost $12 million each and the earlier operation of the ground control stations would cost $5 million to $6 million annually.

The present NAVSTAR development plan consists of three phases. Phase I, the concept validation phase, consists of testing receivers with ground-based transmitters (late 1976 and 1977) and with up to 6 satellites providing navigation coverage for 4 hours daily over the test areas (mid-1978).

APPENDIX I

DEPARTMENT OF DEFENSE
NAVSTAR GLOBAL POSITIONING SYSTEM (GPS)
SYSTEM CONCEPT



Source: Air Force

If the early 1979 program evaluation results in NAVSTAR's continuation, Phase II, the full scale development and system test phase, will continue using the six satellites for testing prototype receivers and for other testing.

If the mid-1982 program evaluation results in NAVSTAR's continuation, more satellites will be added during Phase III, the full operational capability phase, to provide worldwide three-dimensional navigation coverage in late 1984 with 18 satellites and to reach the full complement of 24 satellites by late 1985. The full complement is expected to provide worldwide three-dimensional coverage with an accuracy of 30 feet to receivers using both signal components and 300 foot accuracies to receivers using only the nondeniable course signal component. The 25,000 NAVSTAR receivers are to be installed from 1984 through 1987. The NAVSTAR implementation schedule is shown on the next page.

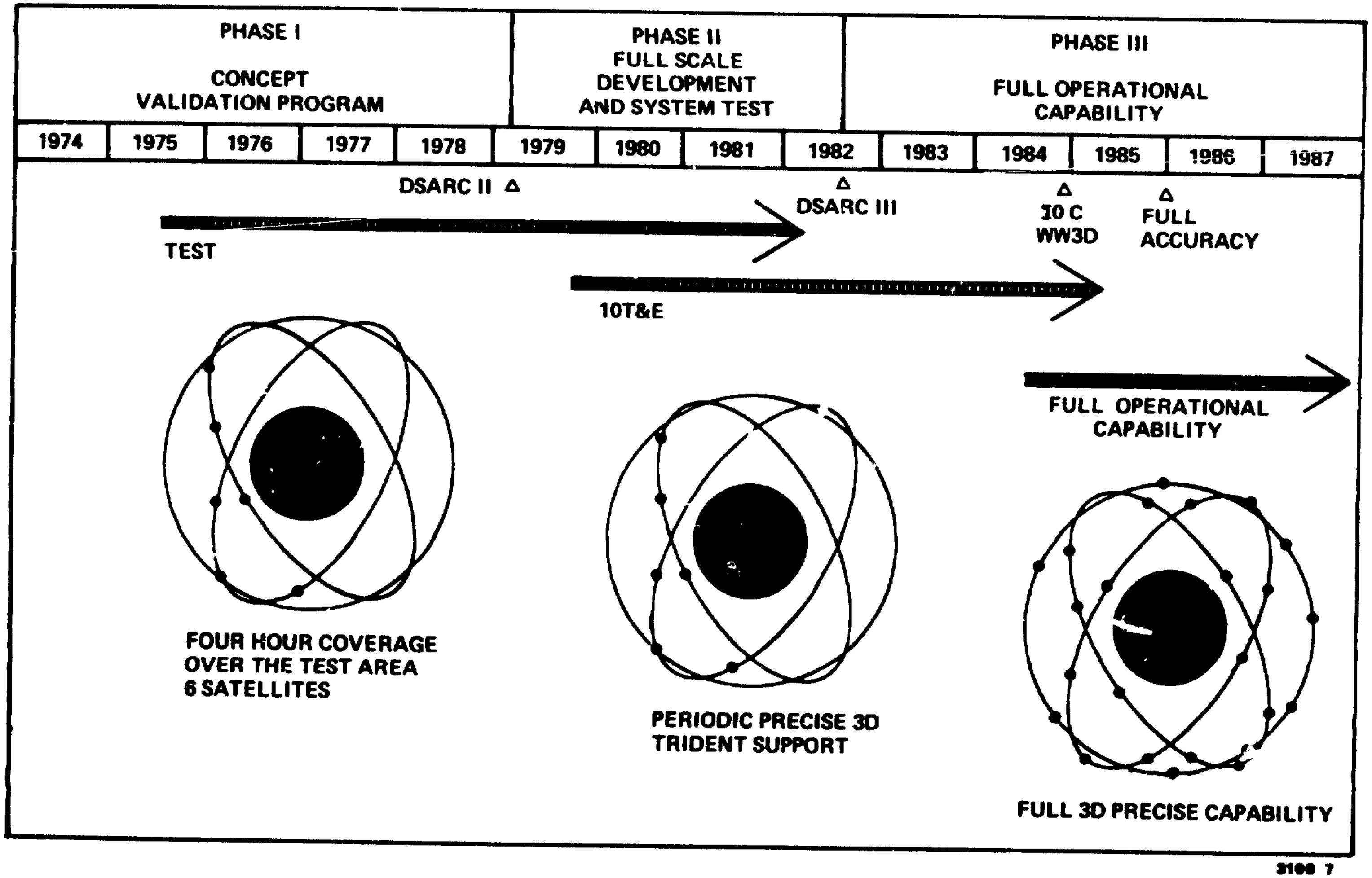
Planned users

Military receivers are to be carried by 25,000 individuals, vehicles, ships, submarines, and aircraft. Most military receivers will use both signal components. Military receivers are expected to cost between $15,000 and $30,000 depending on accuracy, signal anti-jam resistance, mobility, and ruggedness.

The military has not spent its own money for the development of a low cost NAVSTAR receiver for civilian use. The Air Force, however, sponsored two studies to estimate the cost of simpler, less accurate civilian receivers if they were built. Both studies were based upon using integrated circuit (chip) technology similar to that used in hand calculators. In contemplation of a market of 100,000 receivers, one study said that receivers providing 300-foot accuracies (using the nondeniable portion of the signal) could be produced to retail at about $2,500. The other study said that if a different signal at a lower frequency could be added to the satellites, receivers providing accuracies of 2,800 feet could be made to sell for $1,655. This estimate was based on a much lower production quantity of 15,000 receivers.

In fiscal year 1976, the Maritime Administration of the Department of Commerce transferred $310,000 to the NAVSTAR program office to modify a military receiver for civil maritime use.

NAVSTAR GLOBAL POSITIONING SYSTEM SCHEDULE



Source: Air Force

Planned spending

The NAVSTAR system is expected to cost $3.13 1/ billion including $750 million for development and $2,380 million for the installed equipment ($1,150 million for the satellite segment, $130 million for the ground control segment, and $1,100 million for the installed receivers). Of the total amount, $235 million has already been spent, and the remaining $2,895 million is to be spent from fiscal years 1978 through 1987.

1/See our report entitled, "Status of the NAVSTAR Global Positioning System" (PSAD-77-23) dated March 2, 1977, which deals more fully with NAVSTAR's testing and total estimated cost of $3.4 billion. The $3.13 billion excludes certain operation and maintenance costs.

APPENDIX II

TABLE 1

TYPICAL CURRENT AND PLANNED USES OF NAVIGATION SYSTEMS BY THE MILITARY SERVICES

	Direction finders	VOR	TACAN	Loran-A	Loran-C/D	Omega	Transit	Inertial	Doppler radar	PLRS	NAVSTAR
Land											
Vehicles										*	*
Personnel										*	*
Ships											
Aircraft carriers				C		C F	C	C F			F
Cruisers				C		C F	(C)	F			F
Destroyers and frigates				C		C F	(C)	F			F
Strategic submarines					C F		C F	C F			
Attack submarines				C		C F	C	C F			F
Aircraft											
AF fighters	C		C		(C)			C F	(C)		F
Navy fighters	C F		C					(C)	(C)		
AF attack	C		C					C (F)	C		F
Navy attack	C F		C					(C) F	C F		F
AF bombers	C	C	C					C F	C (F)		F
AF cargo	C	C	C	C	(C)			(C) F	C (F)		F
Navy cargo	C F	C	C	(C)	(C)	(C) F		(C)	(C)		F
Army helicopters	C F	(C) F							(F)	*	*
Navy helicopters	C F	(C)	C			(F)			C F	*	*

Notes: C=currently used by more than 50 percent.
(C)=currently used by some (less than 50 percent).
F=1990 planned use by more than 50 percent.
(F)=1990 planned use by some (less than 50 percent).
*=1990 likely use but plans are incomplete.

APPENDIX II

TABLE 2

CURRENT USE OF NAVIGATION SYSTEMS BY CIVIL USERS

	Direction finders	VOR	Loran-A	Loran-C	Omega	Transit	Inertial	Doppler radar
Civil ships and boats:								
Ocean-going	C		(C)	(C)	(C)	(C)		
Coastal waters	(C)		(C)	(C)				
Pleasure craft	(C)		(C)	(C)				
Civil aircraft:								
Commercial	C	C	(C)				(C)	(C)
General aviation	(C)	C						

Notes: C=currently used by more than 50 percent.
(C)=currently used by some (less than 50 percent).

APPENDIX III

NAVIGATION SYSTEMS WHICH COULD BE USED FOR EACH NAVIGATION NEED

	Existing systems									Proposed systems			
	Nondirectional beacons	VOR	TACAN	Loran-A	Loran C/D	Omega	Transit	Inertial	Doppler radar	Differential (note a)	Omega	PLRS	NAVSTAR
Civilian and military peacetime needs													
Overland flights		X	X		X					X			X
Transoceanic flights						X		X	X				X
Coastal waters					X					X			X
Open seas						X	X						X
Land movement					X					X			X
Military combat needs													
Combat flight operations over													
1. Land areas	X				X							X	X
2. Sea areas													X
Combat ship operations							b/X	b/X					X
Combat submarine operations (note c)													
1. Strategic submarines					b/X		b/X	b/X					b/X
2. Attack submarines							b/X	b/X					b/X
Combat land operations					X							X	X

Notes: a/Development was recently terminated.

b/Two systems, inertial and a radionavigation system, are required for navigation.

c/The operational capability of the classified equipment is excluded.

APPENDIX IV

EXECUTIVE OFFICE OF THE PRESIDENT

OFFICE OF MANAGEMENT AND BUDGET

WASHINGTON, D.C. 20503

AUG 24 1977

Mr. Victor L. Lowe
Director, General Government Division
General Accounting Office
Washington, D.C. 20548

Dear Mr. Lowe:

This is in response to your letter of June 15, 1977, which transmitted the draft GAO report "Navigation Planning - A New Direction is Needed" (GAO Code 941100).

While we agree with the spirit and intent of the draft report we believe that it has oversimplified the complex issues involved in the procurement and management of government-owned and operated navigation systems. In particular, the introduction of a major redirection in Government navigation systems is significantly more difficult than indicated by this report. Past history has shown that technical and economic factors - especially where the civil users are concerned - have combined to make transitions difficult and time-consuming. We cite the LORAN-A phase-out as a prime example of the difficulties faced in this area.

We do agree that improvements which are in the best interests of the Federal Government should be initiated, without regard to the difficulties their implementation entails. Such improvements, however, should be based on and consistent with a fully integrated, comprehensive national plan for Government navigation systems. The "Radio Navigation Systems Economic and Planning Analysis" prepared by the Office of Telecommunications Policy in July 1977, is a step in this direction. The President's recent reorganization proposal for the Executive Office of the President assigns to the Office of Management and Budget the responsibility for establishing policy relative to the procurement and management of Government telecommunications. After congressional action on this proposal OMB will work to assure that a comprehensive national plan for navigation systems is created.

2

GAO note: Part of this paragraph has been deleted because matters discussed in our draft report were omitted in this final report.

more, we believe the authority to select navigation systems for retention or phase-out should and does properly reside in the President and that the budgetary controls to implement such decisions currently exist. To delegate this authority to someone else would, in our opinion, be inappropriate. However, we will recommend that the President's Reorganization Project consider the need for a single agency or office to assume responsibility for Government navigation systems.

Your interest in this area is appreciated.

Sincerely,

Bert Lance
Director

OFFICE OF TELECOMMUNICATIONS POLICY
EXECUTIVE OFFICE OF THE PRESIDENT
WASHINGTON, D.C. 20504

August 29, 1977

ASSISTANT DIRECTOR

Mr. Fred J. Shafer
Director
Logistics and Communications
Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Shafer:

Dr. Thaler has asked me to reply to your letter of June 15, 1977, requesting comments on the draft report entitled, "Navigation Planning--A New Direction is Needed," GAO Assignment Code 911400. We have reviewed this report with interest as it closely parallels OTP's ongoing radio navigation efforts.

We are in agreement with your conclusion that the prompt development and implementation of a government-wide navigation plan can and will reduce unneeded overlap of navigation systems and reduce government expenditures. We also concur that it will take a strong, non-agency aligned, focal point such as you recommend for OMB and/or OTP to effect the implementation of such a plan.

However, we feel that the scope of the GAO study was somewhat restrictive in that it did not fully address the capabilities that will be available from a navigation satellite. Since a satellite not only offers the long range coverage obtained from lower frequency ground based systems but also the high accuracy obtained from higher frequency systems, the traditional approach of comparing or evaluating radio navigation systems no longer applies. Therefore, the recently completed OTP study which included a broader base of systems revealed even a greater degree of unneeded duplication.

Earlier this year OTP and OMB made a recommendation to the President that a concerted, government-wide effort be initiated to consolidate Federal navigation programs. This recommendation, which includes many of the GAO recommendations, has been approved by the President and procedures to implement such a program are now being formulated.

Sincerely,

Don Jansky

Donald M. Jansky

APPENDIX VI

UNITED STATES DEPARTMENT OF COMMERCE
The Assistant Secretary for Maritime Affairs
Washington, D.C. 20230

AUG 24 1977

Mr. Fred J. Shafer
Director, Logistics and
Communications Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Shafer:

The Secretary of Commerce has asked me to comment on your draft report "Navigation Planning -- A New Direction is Needed" (GAO Code 941100).

This report has been carefully reviewed by our staff. The report appears to contain a reasonable synopsis of radio navigation systems and documents their proliferation. The need for a single Governmental Executive focus for Radio Navigation Affairs is defined and the Maritime Administration strongly supports this concept. This group should have the authority to coordinate user requirements, develop implementation and operational plans, and obtain funding by appropriation from the Congress.

Another factor to be emphasized in this regard is coordination of conversion costs for governmental user transition from one system to its successor. For aircraft, particularly, these costs can far surpass system equipment costs as well as costs for continuation of duplicative services for many years. Unduly rapid schedules for transition from one system to another can also place a severe and perhaps unacceptable economic burden on civil users of individual systems.

Although the draft report does not consider the potential for a commercial satellite radio determination system, studies conducted by the Maritime Administration indicate that such services could be privately provided with a profit to suppliers and reasonable costs to users. Accordingly, this concept or a concept for recovery of investment and operating costs for the NAVSTAR system is commended to you for consideration.

Review of the report does not reveal specific information known to be classified. The Maritime Administration believes, however, that unlimited distribution of the report either as classified or unclassified material could be deleterious to the national interests.

APPENDIX VI

2

Radio navigation planning with its intricate national and international interaction networks is an extremely challenging task.

Thank you for the opportunity to review and comment on this interesting report.

Sincerely,

for Howard F. Casey

ROBERT J. BLACKWELL
Assistant Secretary
for Maritime Affairs

Attachment

GENERAL COMMENTS ON GAO REPORT (CODE 941100)
"NAVIGATION PLANNING - A NEW DIRECTION IS NEEDED"

1. Adoption of NAVSTAR GPS as the National Civil and Military Standard

A system cannot be adopted as a national standard until it has demonstrated proven performance. In the case of radio navigation systems, the military have historically developed and used such systems long before their adoption by the civil community. A more reasonable goal would be to press for adoption of the GPS as the standard military system in the 1990 time frame. This in itself would reduce the overall expenditures to a small fraction of the figure given on page 37 and includes the elimination of FAA funding for TACAN which is done under agreement with DOD. Furthermore, the initial military standardization would be entirely internal to the U.S. Government and would not be influenced by international considerations or the political pressures of civil users. Subsequent to military standardization, efforts could be made to obtain full national and international acceptance.

2. Elimination of "Unnecessary Systems"

LORAN-C

The LORAN-C coastal chains are considered as vital navigation aids for waterborne commerce and ocean resource development. This is particularly true on the Pacific Coast where LORAN-C is to serve as the primary navigation aid for the marine segment of the Trans-Alaskan Pipeline system as well as for commercial fishing in the Pacific Northwest and Alaska. The importance of LORAN-C is well recognized in the National Navigation Plan as well as within the Congress itself where the use of LORAN-C as a navigation aid and as the basis for vessel surveillance has been proposed in two recent bills before the Congress. The critical, immediate need for proven, reliable, affordable navigation within U.S. territorial waters mandates the retention of LORAN-C for the next several decades and the extension of this system to provide full coverage for the U.S. coastal confluence. The LORAN-C stations being built for this purpose are highly automated, reliable aids to navigation which have low operating and maintenance costs.

3. NAVSTAR Backup Systems

a. OMEGA and NDB's

The report suggests that Omega and civil aviation nondirectional beacons (NDB's) should be retained for the next several years and concludes that the Coast Guard's marine NDB's will be a surviving system. For the merchant maritime community, the Navy Navigation Satellite System provides global coverage and accuracy which approaches that of NAVSTAR

GPS. Although service is not continously available, the Navigation Satellite System is significantly preferable over Omega as a backup system for NAVSTAR.

b. LORAN-C

As discussed in a prior paragraph, LORAN-C appears to be a mandatory backup for NAVSTAR in the U.S. coastal confluence.

4. Redundance Requirements for Safe Maritime Navigation

A navigator is rarely content to rely on a single source of position and bearing measurement when more than one is available. Typically, he will combine optical, electronic, and inertial measurements together, using his experience and judgment to obtain the best estimate of ship position, course and speed. The use of several navaids rather than a single instrument permits partial compensation of errors and guards against catastrophic failure in a particular sensor. Redundant information provides the navigator with an ongoing check on his results that enables him to navigate with confidence.

The development of a National Navigation Service which is wholly dependent on the operation of a single system would be very unwise. Service must be "fail-safe" in the event of the loss or temporary outage of the primary system. The retention of the VOR and LORAN-C systems together with the GPS could provide this desirable capability at a minor additional cost to the government. The overall degree of redundancy for navigation must be based on the effect of foreseeable failures on segments of the GPS together with a determination of the permissable degradation in navigation during such an event. Some service duplication with different navigation systems is desirable. Redundancy is in fact necessary in a well thought out system.

GAO note: Page references in this appendix may not correspond to pages of the final report.

ASSISTANT SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

13 October 1977

COMMUNICATIONS, COMMAND,
CONTROL, AND INTELLIGENCE

Mr. Fred J. Shafer
Director, Logistics and
Communications Division
General Accounting Office
Washington, D.C. 20548

Dear Mr. Shafer:

This is in reply to your letter to the Secretary of Defense regarding your report dated June 15, 1977 on "Navigation Planning--A New Direction is Needed," OSD Case #4644, GAO Code 941100.

The Department of Defense agrees with the recommendations to reduce the number of radionavigation systems and make NAVSTAR GPS the primary radionavigation system. As we gain confidence in this system, we will make firm commitments to phase out and decrease dependence on others and discontinue the development and deployment of still others.

We have been participating with the Department of Transportation on their development of a national plan for civil systems. Also, we are currently reviewing the "for comment" draft Federal Radio Navigation System Plan recently sent to us by the Office of Management and Budget (OMB).

It appears that the thrust of your report and OMB's plan are congruent and consistent with DoD's plans. There are some phaseouts and dates which must be tempered with the needs to have overlapping capabilities as we transition to an adequately operational NAVSTAR GPS system. Therefore, the schedule in the report is optimistic.

We are not normally concerned with the needs of the civil sector; however, we are aware of the value of military systems for such use. We would therefore be pleased to participate in the development and implementation of a national program.

We expect to complete our validation of the NAVSTAR GPS concept and decide on its operational deployment in February 1979. Our current thinking is that we will make navigation information of 100-200 meters available for civil use under all conditions. We expect to maintain control of the system so that we can deny the precision information to unauthorized users under certain conditions.

In addition to the above general comments, we have included an enclosure with more specific comments. It addresses explicit points in the report and provides comments by the Military Departments on various aspects.

We appreciate your efforts with regard to this complex matter. We will be pleased to work with you toward completing a final report and determining better ways of addressing navigation system needs.

Sincerely,

Robert J. Hermann
Principal Deputy

Enclosure

GAO DRAFT REPORT: "NAVIGATION PLANNING A NEW DIRECTION IS NEEDED" (U)

1. (C) General Comments: (U)

a. (U) The Department concurs in the reduction of navigation systems. However, a plan to accomplish this must be tempered by the practical considerations of equipment transition problems and by military operational or safety requirements. The following comments apply:

(1) (U) Experience shows that transition periods, when large numbers of equipment are involved, require several years to accomplish. This is dictated by funding limitations, production schedules, platform availability dates, old platform phaseout dates, installation priorities and general logistical and operational considerations.

(2) (U) It is believed that more recognition should be given to the need for backup systems for safety or combat effectiveness reasons. Also, it should be recognized that the phaseout of certain current navigation systems are subject to other criteria, such as availability of Integrated Communications Navigation and Identification (ICNI) systems which are not within the scope of the draft report. In addition, more consideration should be given to requirements for tactical land combat environments or the need to maintain interoperability between U.S. and NATO forces and to recognize existing standardization agreements, treaties or other international agreements.

[See GAO note 1, p. 85.]

c. (U) The report addresses enroute aviation and maritime navigation primarily and does not adequately consider enroute/terminal and navigation/approach systems. DoD must continue to fund terminal approach systems to comply with civil aviation requirements and to interface with the national and international airways.

d. (C) The following subsections address the specific equipments which are recommended for deferral: (U)

[See GAO note 2, p. 85.]

(a) (U) VOR receivers are needed in Army aircraft to facilitate instrument flight training and to enable use of U.S. and other country VOR facilities for enroute navigation and instrument approaches in peacetime and during hostilities since:

1. (U) A significant phaseout of VOR facilities in the U.S. and elsewhere in the early 1980's is not anticipated; also during NAVSTAR phasein, many aircraft will probably need both a VOR and NAVSTAR capability.

2. (U) Civil government agencies have not yet expressed support for a 'low cost" civil receive.

(b) (U) TACAN receivers are used in special mission (surveillance and electronic warfare) aircraft to update the self-contained (inertial) navigational system and cannot be dispensed with.

[See GAO note 2, p. 85.]

(d) (C) The following addresses Navy plans to procure additional TACAN and beacons: (U)

1. (U) Ground TACAN transmitters are 15-25 years old, of obsolete design, unreliable and, because of component non-availability, difficult and expensive to support. They cannot be expected to provide safe and reliable navigation until all aircraft are carrying NAVSTAR GPS. Replacement of these systems as currently funded over the period FY 77 through FY 81 will permit an average of 11 to 16 years useful life prior to the 1991-1996 predicted shutdown, thus justifying the expenditure on economic recovery grounds, as well as on safety, reliability and maintainability. Shipboard beacons are similarly needed to replace existing obsolete beacons.

[See GAO note 1, p. 85.]

3. (U) It should be noted that NAVSTAR will work with a data link or transponder of some sort to provide relative

navigation at sea. The most logical candidate for such a data link would be the JTIDS in which case a relative navigation capability is already inherent. Nevertheless, NAVSTAR will be needed for precise geographic positioning and, in fact, can be used to advantage with JTIDS to lock the JTIDS relative grid to geographic coordinates. Integration of these two complementary systems will continue to be addressed.

[See GAO note 1, p. 85.]

(2) (U) LORAN-D. The planned airborne equipment procurement is for a digital avionics update (ARN-101) of 180 F-4E's and 60 RF-4C's. The ARN-101, which includes a LORAN sensor, will provide the aircraft with a night all-weather bombing system in selected geographical areas in the near-term before NAVSTAR precision accuracy is available. Air Force aircraft equipped or scheduled to receive LORAN-D will be in the inventory through the late 1980's and in some cases into the 1990's. In these aircraft, the LORAN-D sensor can be replaced with a NAVSTAR GPS receiver.

[See GAO note 2, p. 85.]

(4) (U) TRANSIT. The DoD policy on TRANSIT is that it will be phased out contingent upon the operational deployment of NAVSTAR. However, there is military necessity for improved TRANSIT satellites which cannot and should not be deferred. The Navy has many spare older satellites, but unfortunately these cannot serve the purpose of the improved versions.

(5) (U) PLRS. The navigation function of the PLRS should not be deferred until the feasibility of deriving vehicle positions from the NAVSTAR GPS signals and cost implications are determined. Some NAVSTAR/PLRS technical considerations which need study and resolution include:

(a) (U) There is a question of NAVSTAR GPS signal adequacy for Manpack set operations. Initial study indicates that if GPS is to be considered as a field navigational aid for ground-based troops, the satellite's ERP may have to be increased.

(b) (U) PLRS has been designed to be the primary position location reporting element for the Marine Tactical Command and Control System (MTACCS), providing the ground combat commander with near-real time command and control data. The inherent PLRS navigation capability is integral to the position/location functions and cannot be separated. It generates automatic transmission of positioning information to a master unit which is collocated at a higher headquarters command post. NAVSTAR position information would be available for use with PLRS but would need separate communication networks.

2. (C) Specific Comments: (U) [See GAO note 3, p. 85.]

a. (U) Par i, Par 1, Line 4. Replace words "weapons delivery" with "command and control and weapons delivery". In this regard, systems are used by the military for more than weapons delivery.

b. (U) Page 2, "CLASSES OF NAVIGATION SYSTEMS." There are other classes of navigation systems, such as celestial, visual or aural aids to piloting, etc., which are not included in the classes addressed in the report. The interrelationship of the radionavigation systems discussed in the GAO draft report with these other systems should be considered in making decisions with regard to any future required mix of systems.

c. (U) Page 5-6. LORAN-D is a tactical system for use in the objective areas. Therefore, it should be identified as such rather than as a major enroute navigation system. The Army/Marine Corps Position Location Reporting System (PLRS) falls in the same category.

d. (U) Pages 6, 20, 37, 45 and 74. Recommend general deletion of references to PLRS as a navigation system. Instead, there should be a short statement that PLRS is basically a CNI system with a relative navigation capability. Any program decisions regarding PLRS will be made on other than its secondary capability of navigation.

[See GAO note 2, p. 85.]

g. (U) Page 14, Lines 19-21. While the present ICAO VOR/DME agreement expires in 1985, present international investment in that system as well as the slip in NAVSTAR's Initial Operational Capability to 1984, only one year prior, indicates that the agreement likely will be extended for some period. The mid-1990's appears to be the earliest that VOR/DME protection will be withdrawn. The avionics transition period for civil as well as military aircraft can be expected to consume a decade.

[See GAO note 2, p. 85.]

i. (U) Pages 14-18 and 32. The report states that the NAVSTAR system should be used by civil air, land and seaborne users on a national and international basis; however, this may be premature since a decision has not been reached as to what signals NAVSTAR will provide to civil receivers. DoD has not been actively considering the potential civil use of NAVSTAR. However, DoD has concluded that the coarse/acquisition signal of NAVSTAR could be made available for civil use, but since the precision (30-foot) signal could provide adversaries with a capability detrimental to national security, it has been recommended that DoD control the capability to restrict this signal. DoD believes civil government agencies should investigate options that would allow the system to accommodate civil uses. Questions such as accuracy needed, method of incorporation, weight and cost tradeoffs on the spacecraft and foreign military utility require answers before decisions on civil use and phaseout of existing systems can be made.

[See GAO note 2, p. 85.]

l. (U) Page 20, par 1. It should be noted that TACAN coverage generally would not be available in the combat area.

m. (U) Page 20 (and throughout the plan). Delete all references to radar bombing beacons, since these are not navigation systems as inferred by the report; rather when combined with the aircraft radar, they are a part of a bombing system.

[See GAO note 2, p. 85.]

o. (U) Pages 20 and 21, "Operations over ocean areas." During open ocean operations, targets are fixed by sensors relative to the sensor platform and transferred to a weapons system (not necessarily on the sensing platform) in relative coordinates. There is a need for high relative accuracy vice geographical navigation information in many tactical situations. Also, P-3C and AWACS aircraft use OMEGA (integrated with inertial systems) over land and ocean areas.

[See GAO note 2, p. 85.]

s. (U) Page 24, first paragraph. High accuracy, long term (approaching mission times) Electrostatically Supported Gyro (ESG) Inertial navigators are under development.

[See GAO note 2, p. 85.]

u. (U) Page 26, lines 12-14. Concur except that the systems will have to be operated into the 1990's.

v. (U) Page 30, "Expected operational date." With an Initial Operational Capability in 1984, full changeover to NAVSTAR could probably not be expected to occur prior to 1990 even if announcement is made in 1981 that NAVSTAR will be the primary navigational system for the U.S.

[See GAO note 2, p. 85.]

z. (U) Page 34, "Doppler radar." Recommend this section be expanded in scope to include correlation velocity sensors and Doppler Sonars presently under development.

aa. (U) Pages 41 and 42, "TACAN." Some military (Navy) requirement for enroute TACAN navigation capability will exist into the 1990's, and FAA facilities must be capable of meeting that need reliably. Present Navy TACAN transmitters are not capable of providing reliable service into the 1990's which is the most probable phaseout date for TACAN.

[See GAO note 2, p. 85.]

kk. (U) Page 83. This table needs to be reworked extensively to correct omissions and misleading information. For example, the proposed systems mix does not meet Navy relative navigation requirements at sea, although the inference of the table is that military combat needs over sea areas would be satisfied by the systems indicated.

GAO notes: 1. Classified portions of this letter have been deleted.

2. Portions of this enclosure have been deleted because they are no longer relevant to the matters discussed in this report or because revisions have been made.

3. Page references in this appendix may not correspond to pages of the final report.

National Aeronautics and
Space Administration

Washington, D C
20546

NOV 30 1977

W

Mr. R. W. Gutmann
Director
Procurement and Systems
Acquisition Division
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Gutmann:

Thank you for the opportunity to comment on GAO's draft report entitled "Navigation Planning--A New Direction Is Needed", Code 941100, which was prepared by the Logistics and Communications Division. It was forwarded to NASA for comments with your letter, dated October 13, 1977, at the suggestion of the Subcommittee on Transportation, Aviation, and Weather, House Committee on Science and Technology.

General comments

We agree that the management of Federal radio navigation systems offers opportunities for improvement through greater economies and efficiencies. In this connection, NASA recently reviewed for the Office of Management and Budget (OMB) a Federal Radio Navigation System Plan, which was prepared by the Office of Telecommunications Policy (OTP). In general the OTP plan and GAO's proposed report are congruent.

[See GAO note, p. 88.]

We have a variety of interests in navigation systems and currently are pursuing several technology efforts with other agencies, in addition to participating on the Navigation working group of the DOT-chaired Transportation Telecommunications Steering Group. Two DOT/FAA radio navigation aid programs (Microwave Landing System and Omega) are being supported by NASA. Instrument approach and landing systems were excluded from GAO's proposed report, yet these facilities are used for terminal area navigation and approaches as well as the VOR, TACAN, and non-directional radio beacons which were cited.

Also, sponsoring development of civil airborne avionic equipment technology is characteristically a role which NASA has fulfilled for the federal government. For example, NASA has completed a preliminary study of NAVSTAR/GPS applications for general aviation and is pursuing several technology efforts which would be directly applicable to low-cost airborne receivers for NAVSTAR/GPS. In addition, NASA undertook the role of developing civilian applications for the Navy's Transit navigation satellite system. And, several military models of receivers are currently under development for the Air Force.

Technology from these programs should be helpful in reducing risk for industry development of a low-cost civil NAVSTAR/GPS receiver. Examples of NASA development interest in civil NAVSTAR receiver technology are:

(a) NAVSTAR receivers for satellite navigation and position location applications.

(b) Low-cost NAVSTAR receiver/transmitters capable of transponding the GPS signals received at a user vehicle to a geostationary satellite for relay to a ground computing station. This receiver/transmitter has application to aeronautical and marine traffic control needs.

It may be noted that one of the main NASA concerns with future navigation systems is the Space Shuttle. The primary navigation system for the Shuttle is an inertial system augmented by TACAN in the near-term Orbital Flight Test (OFT) time period with the GPS being introduced during the operational period. The proposed GAO report appropriately indicates these systems should continue to be supported.

<u>Comments on GAO recommendations</u>

[See GAO note, p. 88.]

2. We further recommend that an early decision be made concerning the management responsibility (civil vs. military) for the civil use of NAVSTAR.

[See GAO note, p. 88.]

APPENDIX VIII

3

If we can be of further assistance to you, please let me know.

Sincerely,

Kenneth R. Chapman
Acting Associate Administrator
for External Affairs

GAO note: Portions of this appendix have been deleted because they relate to matters discussed in the draft report but omitted or revised in this final report.

OFFICE OF THE SECRETARY OF TRANSPORTATION
WASHINGTON, D.C. 20590

ASSISTANT SECRETARY

January 6, 1978

Mr. Henry Eschwege
Director
Community and Economic Development Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Eschwege:

I am enclosing two copies of our response to the GAO Draft Report, "Navigation Planning -- A New Direction Is Needed." I regret the delay in our response.

As you know, since the draft report was received several Congressional Committees have indicated strong interest in several of the issues that the report raises. Departmental witnesses testified on the subject in October before the Subcommittee on Transportation, Aviation and Weather, and addressed the present status of civil navigation planning in the Department.

More recently, the Office of Management and Budget and the Office of Telecommunications Policy communicated with the Department on a range of issues relating to navigation planning and the future potential role of the NAVSTAR GPS which is currently under development in the Department of Defense. While the Department believes it is premature to reach decisions now on the role which NAVSTAR GPS might play in meeting civil aviation navigation requirements, we are fully aware of its potential capabilities. Both the U.S. Coast Guard and the Federal Aviation Administration have programs underway in coordination with DOD to identify and explore possibilities for civil use of the planned Defense navigation satellite system.

Please let us know if we can provide additional information or further clarify our position on civil navigation matters.

Sincerely,

Edward W. Scott, Jr.
Assistant Secretary for Administration

Enclosure: 2 copies

DEPARTMENT OF TRANSPORTATION REPLY

TO

GAO DRAFT REPORT TO THE CONGRESS

ON

NAVIGATION PLANNING - A NEW DIRECTION NEEDED

SUMMARY OF GAO FINDINGS AND RECOMMENDATIONS

There are a large number of navigation systems operated by the Federal Government to meet the needs of diverse users. These needs may be satisfied by a lesser number of systems. While the report does acknowledge that navigation systems vary widely with respect to geographic coverage, suitability for use, and user costs for equipment, it claims there is substantial overlap among the 13 existing and planned systems.

The military NAVSTAR satellite development has the potential for meeting the needs of nearly all users. This should be the primary system with some essential back-up. Only 4 or 5 systems out of the 13 could suffice for the navigation needs of all users. However, this program depends on the successful test validation of NAVSTAR by mid-1978 and the timely development of a civil receiver in the price range of existing equipments. Also some consideration might be given to civil vs. military control of NAVSTAR.

In the meantime all unneeded spending should be deferred on existing systems. It is expected that they can be replaced by NAVSTAR by the mid or late 1980's. If spending can be deferred, GAO believes substantial savings can be achieved.

SUMMARY OF DEPARTMENT OF TRANSPORTATION POSITION

The Departmental comments which follow have treated only the civil navigation systems, or the civil uses of military sponsored systems. Their use for weapons delivery and other military missions is the province of the Department of Defense (DOD).

The Department of Transportation (DOT) agrees that NAVSTAR GPS has the potential for widespread civil use and may replace some other systems in the future. To this end we are working closely with DOD as well as condidering NAVSTAR GPS an important possible future system in the National Plan for Navigation. However, it must be emphasized that NAVSTAR GPS is only a developmental system and it will be several years before a decision is made whether or not to go operational. This leads to the points wherein DOT strongly disagrees with the conclusions and recommendations of the GAO Report.

The first is in the matter of timing. As yet there has been no decision on operational development of NAVSTAR GPS. The earliest date for making that decision is now February 1979. If everything goes according to schedule and if the system meets expectations, the earliest time for full operation is 1985. After a suitable test period, then and only then can it be determined which civil navigation systems can be replaced. Since suitable notice must be given before systems can be phased out it is patently obvious it will be the early or mid-1990's before NAVSTAR GPS can play a significant role in civil navigation. To stop all expenditure on other systems until then is to invite disaster. DOT cannot afford the luxury of theorizing about some future system. The Department is responsible for the safe operation of marine and air transportation today and tomorrow and until some new system has proven itself as a future replacement. Until they can be phased out, the Department must be permitted to make cost beneficial improvements and expansions to the proven systems which are currently in use.

The second point of disagreement is in the proposed mix of systems. Several items could be cited here, but only one is considered, Omega continued mainly as the back-up for NAVSTAR GPS. DOT agrees on the need for redundancy in case of the non-availability of one system. However, the only advantage of Omega as a back-up for NAVSTAR GPS is that it is worldwide. On the other hand, it is the least accurate of the major systems, and in the case of non-availability of NAVSTAR GPS, it is much more important to have the necessary accuracy for marine coastal and confluence navigation and air overland enroute operations than to provide for on and over the high seas.

The third point concerns the title of your draft report. The Department believes it is contentious and not consistent with fact. The 3rd Edition of the National Plan for Navigation is now in final preparation. It has been concurred in by DOD, Commerce, and NASA, and will be issued shortly. It provides a detailed and realistic plan for civil navigation which takes into account current systems and their possible reduction as well as replacement by future systems.

In preparation of this reply, the Coast Guard and FAA were asked to comment on the GAO report. It is felt that you should have the benefit of their complete comments. They have therefore been included as Attachments A and B.

POSITION STATEMENT

Page i* - States there is a proliferation of navigation systems. This is not true of civil systems. As yet it has not been shown that any existing system can effectively do the job of any other existing system with the exception of Loran-A. The latter has been scheduled for phase-out.

Page i - Do not concur on giving authority for decisions on navigation systems to OTP or OMB. The authority must rest with the organization that has the responsibilty for safe navigation. Also, the conclusion on the "ultimate" system is based on the not yet proven capability of NAVSTAR GPS. The progress of this system is being monitored.

Page ii - Implies that any spending on existing navigation systems is unnecessary and that in the past unneeded expenditures have been made. This is not true. Any proposed expenditure must be justified on a cost benefit basis. Firm planning for continued safe, effective, and economical navigation cannot be predicated on an as yet unproven system.

Page ii - The discussion of the eight listed systems implies that they are all capable of providing the same service. This is not true. Modernization of any components of the systems that has to be done must be justified on cost benefits based on the planned "end of Life" of the system.

Page iii - We do not concur in the statement on abandonment of existing systems. Investment in existing equipment is only one factor that must be taken into account. For example, the total investment in VOR-DME is of the order of $2 billion. This cannot be scrapped overnight. As yet it has not been shown that any major civil used system currently scheduled for continuation is duplicated by another system. The so-called overlap is based on superficial analysis and does not take all the navigation system requirements into account. Thus, the so-called proliferation of civil navigation systems is non-existent.

Page iii - The conclusion that all the present navigation systems can be replaced by the 4 (or 5) listed systems is based upon some questionable and as yet unproven assumptions. It does not take all system requirements into account. While it may be true at some time in the future; to base current planning on such conditions would be to invite disaster.

Page iv - We do not concur in delaying any improvements in existing civil navigation systems because of possible replacement by NAVSTAR GPS. The timing of replacement as postulated by GAO is off by at least 5-7 years. Delays would only increase costs of needed improvements, lead to greater future operating costs, and not provide the required navigation aids in many areas leading to possible disasters. These existing systems will be required until the mid-1990's or later.

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*Page numbers refer to those of the GAO Draft Report

Page iv - The spending figures are incorrect in that they do not take into account savings by replacement with equipment having a lower operating cost. We agree that substantial savings could be achieved. The ultimate would be to reduce expenditures to zero, but the attendant probability of disaster would rise to 100%. The program proposed by the NPN makes a judicious balance between expenditure and risk. The expenditures are needed for continued safe and efficient navigation.

[See GAO note 1, p. 104.]

Page 6 - Lists differential Omega as a separate system. We consider it an extension of the basic Omega system.

Page 7 - Seven of the planned eight permanent Omega stations are actually operating. An agreement has just been signed for construction in Australia of the eighth station.

Page 7 - There is an implication of dual (overlapping) operation of nondirectional beacons, VOR, and TACAN by both the FAA and the military. This is not the case. In the U.S. these are all part of a single, unified system.

Page 8 - Omega and Loran-C are listed only for maritime use. There is also aeronautical use of these systems.

Page 10 - The report speaks of 90% of the listed boats not even carrying a compass. It should be noted that practically all of these are boats less than 20 feet long and operating only on inland or other protected waters.

[See GAO note 1, p. 104.]

Also, this report mentions the hesitancy to shut down systems because users would have to buy new receivers. When any system is considered for phase-out amortization of existing investment, sufficient notice of shut-down, and the economics of operating the existing system for its remaining life must be balanced against each other.

Page 12 - The Scope of the Draft Report mentions the Coast Guard and FAA but fails to include the Office of the Secretary of Transportation which is responsible for the coordination of the components as well as issuing the National Plan for Navigation.

Page 13 - States that only geographic coverage and accuracy were considered in assessing the interchangeability of radionavigation systems. This is a highly simplistic approach to an extremely complicated subject, and cannot be acceptable in the real world. Some of the other factors that must be considered for a realistic approach are system availability, system reliability, failure mode, method of usage in the traffic control systems, current investment by both system provider and users, and cost of user equipment.

Page 14 - Implies that Loran-C, differential Omega, and NAVSTAR GPS will be available to replace VOR-DME on January 1, 1985. As of now this is only true of Loran-C in the coast and confluence region of the contiguous 48 states. Mid-continent coverage for Loran-C has not been authorized and there are no firm operational plans for the other two systems.

Page 15 - While four stations may provide minimal mid-continent Loran-C coverage, it is highly doubtful if this is sufficient for aeronautical use. Neither NAVSTAR GPS nor differential Omega have been approved for operational use.

Page 15 - States that Doppler radar is a worldwide system. This is not altogether true. While the system is self-contained, aircraft using Doppler for flights of over 1000 miles are required to have some externally referenced radio aid to bound errors.

[See GAO note 1, p. 104.]

Page 16 - States that differential Omega or NAVSTAR GPS could provide for maritime service in the coastal and confluence zone. The former system was considered in the study chosing a system for this area and was rejected in favor of Loran-C because of the latter's greater accuracy and better cost effectiveness. NAVSTAR GPS will not be available for many years while the required accurate system is needed now.

Page 17 - Equates the three systems as if they were all proven equally effective. Only Loran-C is an operating and proven system. The other two are only concepts.

[See GAO note 1, p. 104.]

Page 18 -

DOT as the agency responsible for safe navigation cannot make firm plans on unsupported assumptions and then be faced with failing systems if the assumptions do not come true. Lives and property depend on a safe and efficient operating system, not assumptions.

Page 26 - DOT does not concur. These systems are needed now and will have to operate well beyond the 1980's. The significant reduction in the GAO expenditure figure could come about by system modernization and attendant savings in operating costs based on a realistic "end of life" period.

[See GAO note 1, p. 104.]

Page 27 - Implies that the various Federal agencies concerned with navigation are going their separate ways. This is not true. DOD, DOT, Commerce, and NASA have cooperated in preparing the National Plan for Navigation which is to be issued shortly.

Page 28 - The entire proposed GAO program depends on the success and timeliness of NAVSTAR GPS. Further it fails to take into account realistic costs of user equipment, present system investment, and system availability. For the agency responsible for safe navigation to forego necessary and cost beneficial improvements to currently proven and needed systems based on the above premises would come very close to dereliction of duty.

Page 29 - Speaks as if NAVSTAR GPS would be fully operational and tested in 1984. This is only the presently scheduled initial deployment date, if there is an affirmative decision on an operational system. An acceptable system, if any, for civil use is several years further down the line. The low cost receiver being mentioned by DOD is of the order of $10,000, while commercial low cost Loran-C marine receivers are now available for about $2,000.

[See GAO note 2, p. 104.]

Page 31 - The figures given for low cost receivers are highly misleading.

[See GAO note 1, p. 104.]

There are a number of manufacturers and the market is highly competitive. Also, Loran-C is not something theoretical, it has been in operation for many years. Texas Instruments which has just entered the marine market has announced a receiver to sell for about $2095. Commercial prices are therefore realistic. The NAVSTAR GPS receiver is considerably more complicated than Loran-C and is only in the development stage; therefore, to postulate a lower cost for it is highly questionable. It should also be noted that receivers for aircraft use are more complicated and therefore more costly.

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Page 33 - Implies no interest in radio aids by the users of Inertial Navigation Systems. This is not the case. Commercial airlines have expressed great interest in radio aids because of the high initial and operating cost of INS.

Page 34 - Implies that the Doppler Navigator is a self-sufficient system. It fails to mention the ICAO (and FAA) requirement for an external radio aid for update when Doppler is used for over ocean flight. Commercial airlines are currently using Loran-A for this purpose, and are planning to use Omega when Loran-A is phased out at the end of this calendar year.

Page 37 - The premise of unsubtantiated spending is false. Any proposed expenditures are based on cost-benefits and realistic (not indefinite) dates when existing systems may be replaced by NAVSTAR GPS or other improved systems. This is in agreement with the statement made on Page 38 of the GAO report, but does not agree with its time phasing.

Page 38 - The statement that substantial savings are possible is unsubstantiated. Its correctness, if any, is based on false premises.

Page 39 - As yet there is no proof that there are any unused civil systems. DOT currently has a joint Coast Guard-FAA program to study the possibility of replacing VOR-DME with Loran-C.

Page 40 - Based on all currently available data VOR-DME will have to be maintained at its present capability until 1995, not the late 1980's.

Page 42 - Based on all current plans there is no possible way that NAVSTAR GPS could be available for civil use by 1982. If the system is approved for operation the earliest date for civil use would be the late 1980's. Loran-C, the only proven system, will therefore have to be continued. This would bring the end of useful life of the current system to 2000.

[See GAO note 1, p. 104.]

Page 43 - A satisfactory radionavigation system for the Great Lakes is required now. Deferral of Loran-C for a possible future NAVSTAR GPS in the late 1980's is not acceptable.

Page 46 - As yet there is no proven overlap of civil navigation systems. (See comment regarding Page 39.)

Page 47 - Both the interagency group and DOT (see comment regarding Page 27) have been working together to eliminate any possible duplication of civil systems. Loran-A has been scheduled for phase out and elimination of other possible duplication is under study. (See comment regarding Page 39.)

Page 48 - The NPN does consider the possible use of NAVSTAR GPS. However, it makes a realistic assessment of its progress, implementation, and application.

Attachments:
(A) Comments of U.S. Coast Guard
(B) Comments of Federal Aviation Administration

Attachment A

U.S. Coast Guard Comment on GAO Report

We agree that NAVSTAR-GPS has the potential for wide use by the civil sector, and that it mav replace some other systems in the future. We agree also that the Department of Transportation should become an active participant in the NAVSTAR program. We believe that DOT, as a first step, should make a thorough evaluation of the potential usefulness and cost of NAVSTAR service to civil users, and then support such additional or supplementary development as may be justified by the results of that evaluation.

We do not agree that either the technical or economic aspects of NAVSTAR's future usefulness to civil navigation can be predicted accurately enough at present to decide which specific systems might be phased out, or when. We disagree most emphatically with the conclusion that the development and improvement of other systems can be brought virtually to a standstill pending a decision on NAVSTAR-GPS. Such action would be detremental to navigation in general. It would have a particularly adverse effect upon the civil maritime community, which would have to suspend an ongoing conversion to a new navigation system, and operate for years with an inefficient and expensive mix of systems.

The GAO's expectations for the successful completion and development of NAVSTAR are overly optimistic. The DSARC decision which GAO admits is a key event in its proposed course of action has slipped already from the date given in the draft report.

Even if NAVSTAR were implemented on the schedule stated, and performed completely in accordance with expectations, it could not necessarily replace all the systems identified by GAO. It is not yet clear just how much of NAVSTAR's capability will be available to the civil community, nationally and internationally. The GAO report implies that the coarse acquisition signal of NAVSTAR is sufficient to serve the civil needs which would be satisfied by those systems identified for replacement. This is not entirely correct. Loran-C, for example, will provide position-fixing service, at a needed accuracy well beyond that expected from the coarse signal of NAVSTAR, to a broad spectrum of users whose requirements have been overlooked entirely in the GAO report. These users include marine navigators in restricted waters, some fishermen, and land users whose number may exceed the combined total of all others who might be satisfied by the coarse signal of NAVSTAR. Clearly, the full capability of NAVSTAR must be available to the civil community if that system is to replace all those identified by GAO.

Even if its expected full capability is available to civil users at the predicted time, the general adoption of NAVSTAR within the time frame specified by GAO would have an intolerable economic impact on the civil community. GAO's expectations concerning the availability of low-cost NAVSTAR receivers are unrealistic. The predicted availability of a $2500 receiver is based upon an incredibly large production lot. The predicted $1650 receiver is based upon a significant degradation in capability; it would not, for example, be suitable for marine navigation in the CCZ. Even if these low-cost receivers did materialize as predicted, they would not serve the needs of those who require the high-level accuracy of GPS. Many civil users thus would need much more expensive receivers than the "low-cost" NAVSTAR receiver, whatever the cost of the latter might be.

Even if all the GAO's expectations about the availability and performance of NAVSTAR, and the availability and cost of receivers were realized, the GAO study has not addressed navigational requirements in nearly enough detail to determine the specific mix of systems that will be needed in the future. As indicated earlier, they have not addressed the needs of all users. Neither have they provided any credible basis for their selection of backup systems for GPS. They admit, for example, that navigation on and over the ocean need not be very accurate, as long as accurate navigation is available near the coast. Yet, they propose, as backups to NAVSTAR, only the least accurate of current navigation systems, OMEGA and radiobeacons.

Attachment B

Federal Aviation Administration Comments on GAO Report

The GAO report states that there is substantial overlapping in the 13 existing and planned navigation systems included in their review. GAO believes that the abandonment of older systems has been largely frustrated by user investments and costs to changeover. As a result, navigation systems have proliferated with resultant higher costs to Government and users.

The report also states that future civil/military requirements can be met with (1) the military's planned NAVSTAR system for most land, sea and air users, (2) the inertial and doppler systems for military operations and as a civil aviation backup system and (3) the marine nondirectional beacons for small watercraft. This would be dependent upon the successful test validation of NAVSTAR and upon the timely development of a reasonably priced civil NAVSTAR receiver. The GAO further states that the planned development, modernization or expansion of VOR, TACAN, Loran-C, Loran-D, Transit, differential Omega, the navigation portion of Position Location Reporting System, and the military's nondirectional beacons are questionable because these systems could be replaced by the above three systems. Departments and agencies plan to spend $360 million over the next four or five years for equipment/development of these potentially unneeded systems and GAO believes that substantial savings are possible.

In addition, the report states that the interagency navigation planning committee, which has existed since 1973, has made no apparent progress in eliminating navigation overlap. The GAO recommends implementation of a Government-wide navigation plan to reduce overlap and costs. They also recommend, pending full implementation of a plan, that DOT and DOD defer unnecessary spending on potentially unneeded systems and that DOT move promptly to become an active participant in the NAVSTAR program to ensure that civil needs are considered. The report further states that Congress may wish to question future requests for expenditures on navigation systems that may not be needed in the future and to consider the matter of eventual military versus civil management of NAVSTAR.

2

We do not concur with the report conclusions and recommendations.

The new National Plan for Navigation (NPN), prepared by an interagency navigation working group, is near completion and will be published in the autumn of this year. This new version of the National Plan addresses the navigation situation in the U. S. in a much more realistic fashion than the GAO report. Specifically, in the matter of Very High Frequency Omnidirectional Range/Distance Measuring Equipment (VOR/DME), it is explained in the NPN that the VOR/DME system is the basis of the airways structure and thus affects most air traffic control operation. No system has been identified by the Federal Aviation Administration (FAA) as a replacement for VOR/DME since no other system has been adequately proven to be able to safely meet domestic air navigation requirements.

The fundamental weakness of the report lies in the presumed implementation schedule of the NAVSTAR Global Positioning System (GPS) and in the assumption that a low-cost user system for NAVSTAR can be developed in a short time. A further failing is in the omission of data on the expected reduction in operating and maintenance costs that will be realized when VOR and DME equipment are upgraded to a more modern form. Also, the hope that NAVSTAR will be internationally acceptable as a VOR/DME replacement is very questionable.

NAVSTAR is just aproaching its first series of problems and delays. The probability of the system becoming operational in the 1981-1984 time period is very remote. Variations in system configuration are possible. There have been recent discussions concerning the addition of three geostationary satellites to the system to overcome interference difficulties in some areas. Also, elimination of the satellite configuration that would have permitted a two-dimensional position fix is planned. With this change in schedule, there will be no operational system until at least 1985, and most probably later than 1985. A recent report (March 1977) by the Comptroller General of the United States entitled "Status of the Schedule NAVSTAR Global Positioning System" indicated that schedule slippage might occur in beginning Phase II of the GPS program.

It is unlikely that the formidable technical problems facing development of a low-cost NAVSTAR airborne unit can be overcome by 1981, as suggested in the report, if they can be overcome at all. The most difficult problem probably lies in the performance of an aircraft antenna that would be used in a low-cost installation. The high-cost military aircraft antennas can be directional and have a high gain; but the low-cost antenna must be essentially omnidirectional and thus have a low gain. Use of the new microprocessor technology to reduce avionics costs will be of only academic interest if adequate signals cannot be received from the satellites. Anticipated problems with cockpit workload, time-to-first-fix, and information update rate may also be significant in the use of NAVSTAR as a low-cost navigation aid.

3

The report suggests the use of Omega as a backup system for NAVSTAR. This might be a valid position except for a large portion of the 48 contiguous states. With low-cost receivers, there are not adequate Omega signals in the central U. S. to support navigation. This situation is the result of signals from Norway being blocked by the Greenland ice cap, by the great distance to four of the Omega stations, and by the uncertainty of utility of the North Dakota signal in the area of the station (i.e., within 400-to-600 miles). In the GAC plan, then, there would be no backup in the event of NAVSTAR failure over much of the U. S. Use of nondirectional beacons as a backup for Instrument Flight Rules (IFR) navigation is not acceptable.

It is recommended in the report that funds not be expended to replace obsolete components of the VOR/DME system. Only VOR and TACAN are currently operating systems in the National Airspace System. Additionally, there are no plans for further development of these systems or for their expansion. There is, however, a plan for modernization in the Second Generation VORTAC Program. This is a 4-year program starting in FY-78 totalling approximately $105 million. The present outlook is that Congress will approve the initial portion of the program in the amount of $15 million. This program has been justified as cost beneficial on the basis of reduced annual operating costs in that it is calculated to provide a 13-percent return of investment for a system life until year 1995. This is the earliest date by which the system could be shut down based on the various reasons discussed in the NPN. The GAO report alludes to a requirement for VOR/DME "until the late 1980's" (page 40) or until 1990 (page 30). Even with these unlikely estimates for system life, the investment would still be justified in light of the expected recovery of investment by 1987.

In regard to the apportionment of the $105 million between VOR and TACAN, the GAO Report (page 37) cites $31.5 million for VOR and $73.5 million for TACAN. These figures are in error, presumably arising from the GAO's lack of understanding of the differences between VOR, DME, TACAN, and VORTAC. Of the $105 million, actually only about $39 million is attributable to TACAN. FAA TACANs also provide the DME portion of the VOR/DME system which is the International Civil Aviation Organization standard for short-range air navigation. The portion of the program attributable to the military's continuing need for TACAN is, therefore, only the azimuth (bearing) generating portion of TACAN which cost we estimate at $7 million out of the $105 million total. This fact would be significant in the event that the military need for TACAN were to disappear before the civil requirement for VOR/DME. We have no reason to believe that this will be the case; however, DOD will have to comment on this portion of the report.

4

It has been suggested that NAVSTAR derived aircraft positions, transmitted via a communication satellite to a control center, could provide oceanic surveillances. This could be done, but it would be dependent surveillance; that is, using the same position for surveillance as the aircraft system is using for navigation. An error in the navigation system would cause an error in surveillance. This concept may or may not be acceptable for future oceanic control. Also, a cost/benefit study of the use of communication satellites to perform the surveillance function versus use of relayed NAVSTAR positions should be conducted before this subject is further pursued.

The manner in which civil aviation nondirectional beacons are referred to in the report is not appropriate. Collectively they do not comprise a complete coverage system in the same sense as Omega or Loran-C. They are used individually, primarily as positive fix "locators" which are part of Instrument Landing Systems, and as supplementary en route navigation aids where VOR/DME has not been implemented.

The reference to Doppler as a worldwide system may also be inappropriate. It should not, for example, be used on long overwater or remote area flights as the sole means of navigation since Doppler requires periodic updating using other navigational means.

Although national coverage may be attained by installing four additional Loran-C stations, it could require as many as 13 new stations to attain the coverage with adequate redundancy to meet FAA regulatory requirements.

We agree with the GAO report in the general view that navigation may ultimately transition to a satellite-based system and that civil community participation in the NAVSTAR program should increase. That viewpoint must, however, recognize the magnitude of the institutional problems that must be resolved before civil participation can be realized. An example of the types of problems to be addressed includes the civil, domestic, and international use of NAVSTAR which is a tactical military system with attendant security requirements.

Our major disagreement is with the time frame suggested for transition to a satellite system. It is realistic, in our view, to continue operation of the VOR/DME system at least through 1995. Past efforts with other systems have shown that development of a prototype low-cost NAVSTAR unit will require five to seven years. It might well be accomplished by 1985 if given adequate priority and funding. If modified to reflect a 1985 selection of NAVSTAR as a primary system with a 10-year transition from VOR/DME, then the GAO position would be little different in that respect than present planning within the FAA.

5

We do not think it advantageous to the FAA (and perhaps not prudent) to accept the designation of a single office in Office of Telecommunications Policy (OTP) or OMB to be the national level decision authority concerning navigation systems. We support the present arrangement with DOT as the focal point for developing plans and policies. OTP and OMB should remain in a review capacity.

GAO notes: 1. Portions of this appendix have been deleted because they relate to matters discussed in in the draft report but omitted or revised in this final report.

2. The presently scheduled operational dates are discussed on page 61, and receiver costs on page 63 .

PRINCIPAL OFFICIALS RESPONSIBLE FOR ACTIVITIES DISCUSSED IN THIS REPORT

	Tenure of office	
	From	To
OFFICE OF MANAGEMENT AND BUDGET		
DIRECTOR:		
James T. McIntyre, Jr. (acting)	Sept. 1977	Present
Bert Lance	Jan. 1977	Sept. 1977
James T. Lynn	Feb. 1975	Jan. 1977
Roy L. Ash	Feb. 1973	Feb. 1975
OFFICE OF TELECOMMUNICATIONS POLICY		
DIRECTOR:		
Dr. W. V. Thaler (acting)	Feb. 1977	Present
Thomas J. Houser (acting)	Sept. 1976	Jan. 1977
John M. Eger (acting)	Sept. 1974	July 1976
Clay Whitehead	Sept. 1970	Sept. 1974
DEPARTMENT OF COMMERCE		
SECRETARY OF COMMERCE:		
Juanita M. Kreps	Jan. 1977	Present
Elliott L. Richardson	Feb. 1976	Jan. 1977
Rogers C. B. Morton	May 1975	Feb. 1976
John F. Tabor (acting)	Mar. 1975	Apr. 1975
Frederick B. Dent	Feb. 1973	Feb. 1975
ASSISTANT SECRETARY FOR MARITIME AFFAIRS:		
Robert J. Blackwell	July 1972	Present
DEPARTMENT OF DEFENSE		
SECRETARY OF DEFENSE:		
Dr. Harold Brown	Jan. 1977	Present
Donald H. Rumsfeld	Nov. 1975	Jan. 1977
James R. Schlesinger	June 1973	Nov. 1975
SECRETARY OF THE AIR FORCE:		
John C. Stetson	Apr. 1977	Present
Thomas C. Reed	Jan. 1976	Apr. 1977
James W. Plummer (acting)	Nov. 1975	Jan. 1976
Dr. John L. McLucas	June 1973	Nov. 1975

	Tenure of office From	To
ASSISTANT SECRETARY OF DEFENSE (COMMUNICATIONS, COMMAND, CONTROL AND INTELLIGENCE):		
Dr. Gerald P. Dineen	Feb. 1977	Present
Richard Schriver	Jan. 1976	Feb. 1977
Thomas C. Reed	Feb. 1974	Jan. 1976
SECRETARY OF THE ARMY:		
Clifford L. Alexander, Jr.	Feb. 1977	Present
Martin R. Hoffmann	Aug. 1975	Jan. 1977
Howard H. Callaway	July 1973	Aug. 1975
SECRETARY OF THE NAVY:		
W. Graham Claytor, Jr.	Feb. 1977	Present
Gary D. Penisten (acting)	Feb. 1977	Feb. 1977
Joseph T. McCullum	Feb. 1977	Feb. 1977
David R. MacDonald	Jan. 1977	Feb. 1977
J. William Middendorf II	Apr. 1974	Jan. 1977
John W. Warner	May 1972	Apr. 1974
COMMANDANT OF THE MARINE CORPS:		
General Louis H. Wilson	July 1975	Present
General Robert E. Cushman, Jr.	Jan. 1972	June 1975

DEPARTMENT OF TRANSPORTATION

	From	To
SECRETARY OF TRANSPORTATION:		
Brock Adams	Jan. 1977	Present
William T. Coleman, Jr.	Mar. 1975	Jan. 1977
John W. Barnum (acting)	Feb. 1975	Mar. 1975
Claude S. Brinegar	Feb. 1973	Feb. 1975
ADMINISTRATOR, FEDERAL AVIATION ADMINISTRATION:		
Langhorne M. Bond	May 1977	Present
Quentin S. Taylor (acting)	Mar. 1977	May 1977
John L. McLucas	Nov. 1975	Mar. 1977
James E. Dow (acting)	Apr. 1975	Nov. 1975
Alexander P. Butterfield	Mar. 1973	Apr. 1975
COMMANDANT, U.S. COAST GUARD:		
Adm. Owen W. Siler	May 1974	Present
Adm. Chester R. Bender	June 1970	May 1974

APPENDIX X

	Tenure of office From	To
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION		
ADMINISTRATOR:		
Robert A. Frosch	June 1977	Present
Alan M. Lovelace (acting)	May 1977	June 1977
James C. Fletcher	Apr. 1971	May 1977
George M. Low (acting)	Sept. 1970	Apr. 1971
DEPUTY ADMINISTRATOR:		
Alan M. Lovelace	June 1976	Present
George M. Low	Dec. 1969	June 1976

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