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DOT-TSC-RSPA-81-12-II

March 1982

Volume II (of 4)
Requirements

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16. Abstract

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

Volume II is devoted to the user requirements (civil and military) and the processes for determining them. Both general and specific requirements related to various applications and phases of navigation are discussed. Present and future anticipated needs are also addressed.

The requirements of civil and military users defined in Volume II for radionavigational services are based upon the technical and operational performance needed for military missions, transportation safety, and economic efficiency.

Volume I, Radionavigation Plans and Policy, has 80 pages; Volume III, Radionavigation System Characteristics, has 47 pages; and Volume IV, Radionavigation Research, Engineering and Development has 32 pages.

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PREFACE

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

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

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

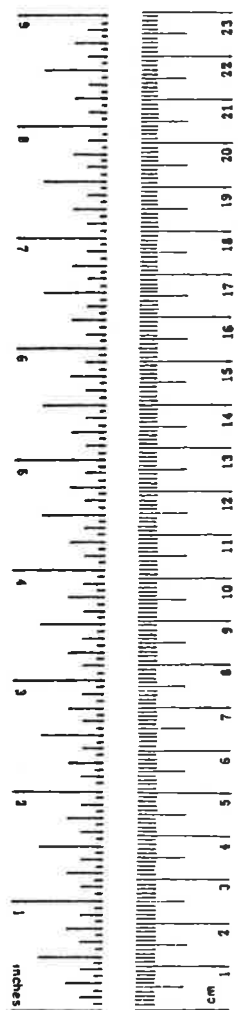
This plan will be updated annually. The established DOD/DOT interagency management approach will enable continuing control and review of U.S. radionavigation systems. For further explanation of navigational terms used in this plan consult The American Practical Navigator, Volume 2, Publication No. 9,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

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

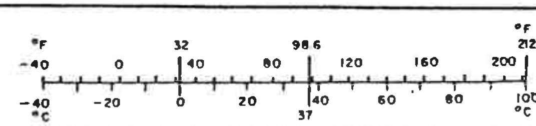
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2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

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

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



FEDERAL RADIONAVIGATION PLAN

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REQUIREMENTS

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CHAPTER I

CIVIL RADIONAVIGATION

1.0 GENERAL

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

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

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

1.1 CIVIL REQUIREMENTS

Civil users' radionavigational requirements are determined by a DOT process which begins with acknowledgment of a need for service in an area or for a class of users. This need is normally identified in public safety and cost/benefit need analysis generated internally, from other Federal agencies, the user public or as required by Congress.

Radionavigation service requirements aim to:

A. Provide a service adequate for safety

B. Enhance economic performance/benefit.

1.2 REQUIREMENTS DETERMINATION

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

1.2.1 Process

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

A. Evaluation of the acceptable level of safety risks to the government, user and general public as a function of the service provided.

B. Evaluation of the economic needs in terms of service needed to provide cost effective benefits to commerce and the public at large. This involves a detailed study of the desired service by user group measured against the benefits obtained.

C. Evaluation of the total cost impact of any government decision on radionavigation users.

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

1.2.2 User Factors

User factors requiring consideration are:

A. Vehicle size and maneuverability

B. Regulated and unregulated traffic flow

C. User skill and workload

D. Process and display requirements for navigational information

E. Environmental constraints, e.g., weather, terrain, manmade obstructions

F. Operational constraints caused by systemic technical factors

G. Economic benefits.

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

A. Activity of the vehicle or vessel. Various user groups have unique requirements that affect their ability to operate efficiently.

B. Vehicle performance variables such as fuel consumption, operating costs, and cargo value.

C. Cost/performance tradeoffs of radionavigation equipment.

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

1.3 PHASES OF NAVIGATION

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

1.3.1 Air

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

A. Approach/Landing

The approach/landing phase is that portion of flight conducted immediately prior to touchdown. It is generally conducted within 10 nm of the runway. Two sub-phases may be classified as non-precision approach and precision approach and landing.

B. En Route/Terminal

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

1. Oceanic En Route

This sub-phase covers operations over ocean areas generally characterized by low-traffic density and no independent surveillance coverage.

2. Domestic En Route

Operations in this sub-phase are typically characterized by moderate to high traffic densities. This necessitates narrower route widths than in the oceanic en route sub-phase. Independent surveillance is generally available to assist in ground monitoring of aircraft position.

3. Terminal

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

4. Remote Areas

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

5. Helicopter

Helicopter users typically have special requirements because of the geographic areas and altitudes at which they operate. Helicopter requirements are applicable in low-altitude CONUS areas (both en route and terminal) and in offshore areas. Special routes and route widths may also be applicable to helicopter operations.

1.3.2 Marine

Marine navigation in the United States consists of five distinct phases identified as Ocean, Coastal, Harbor Approach, Harbor, and Inland Waterway navigation. Standards or requirements for safety of navigation and reasonable economic efficiency can be developed around these five phases. Specialized requirements, which may be generated by the specific activity of a ship, must be addressed separately.

A. Ocean Navigation

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

B. Coastal Navigation

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

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

1. 50 miles from land, or

2. The outer limit of offshore, offshore shoals, other hazards on the Continental Shelf or

3. Other waters where traffic separation schemes have been established, and where requirements for the accuracy of navigation are thereby made more rigid than the safety requirements for ocean navigation.

C. Harbor Approach, Harbor

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

From the viewpoint of establishing standards or requirements for safety of navigation and promotion of economic efficiency, there is some generic commonality between the Harbor Approach and Harbor phases. In each case, the nature of the waterway, the physical characteristics of the vessel, the need for frequent maneuvering of the vessel to avoid collision, and the closer proximity to grounding danger impose more stringent requirements for accuracy and for real-time guidance information than for the Coastal phase. For analytical purposes, the phases of Harbor Approach and Harbor navigation are built around the problems of precise navigation of large seagoing and Great Lakes ships in narrow channels between the transition zone and the dock.

D. Inland Waterways

Inland Waterway navigation is conducted in restricted areas similar to those for harbors or harbor approaches. However, in the inland waterway case, the focus is on non-seagoing ships and their requirements on long voyages in restricted waterways, typified by tows and barges in the U.S. Western Rivers system and the U.S. Intracoastal Waterway.

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

1.3.3 Land

The two basic phases of land location systems are:

A. Site Registration: recording the location of a place or event for record purposes or to return to it at a later time

B. Automatic Vehicle Monitoring (AVM): the tracking of land vehicles by measuring radionavigation or location signals in the vehicle and transmitting the results of that measurement to a central tracking facility for display.

1.3.4 Space

For earth orbiting space activities the mission phases can be generally categorized as launch phase, in-flight/in-orbit phase, and reentry and landing phase.

A. Launch Phase

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

B. In-Flight/In-Orbit Phase

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

C. Reentry and Landing Phase

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

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CHAPTER 2

CIVIL AIR RADIONAVIGATION

2.0 CIVIL AIR RADIONAVIGATION REQUIREMENTS

2.1 GENERAL CONSIDERATIONS

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

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

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

2.1.1 Aviation Requirements

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

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

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

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

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

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

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

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

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

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

I. The navigation system signal source element must provide immediate and positive indication of malfunction.

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

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

L. The navigation systems must be capable, in conjunction with other flight instruments, of providing to the pilot and aircraft system in a convenient, natural, and rapidly assimilable form in all circumstances, and the appropriate phases of flight, information directly applicable to the handling of the aircraft, for the purposes of:

1. Continuous track guidance
2. Continuous determination of distance along track
3. Continuous determination of position of aircraft
4. Position reporting
5. Manual or automatic flight

The navigation system shall also provide for input and utilization of the above in conveniently operable form; and must permit design of indicators and controls which can be directly interpreted or operated by the pilot at his normal station aboard the aircraft.

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

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

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

P. The navigation system must permit the establishment and the servicing of any practical, defined, system of routes for the appropriate phases of flight as required.

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

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

S. The navigation system must be cost-effective to both government and users.

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

U. The navigation system must be free from signal fades or other propagation anomalies below which the systems cannot operate in the operating area.

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

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

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

2.1.2 Navigation Signal Error Characteristics

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

Slowly varying errors such as the seasonal and diurnal variations can also be compensated for by implementing correction algorithms in aircraft equipment logic.

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

Errors varying at a very high frequency can be readily integrated or filtered out in the aircraft equipment. Errors occurring at a slower rate can, however, be troublesome and result in disconcerting indications to the pilot. An example of one of these would be an apparently moving runway as the aircraft equipment responds to the slowly varying error and the pilot follows the Course Deviation Indicator (CDI) needle to maintain what is believed to be the proper non-precision approach course. This indication can be further aggravated if navigation systems exhibit different error characteristics during different phases of flight or when the aircraft is maneuvering. The method of determining the total system error is affected by the navigation signal error characteristics. In most current systems the error components are ground system errors, airborne receiver errors, and flight technical errors. These errors are combined using the Root-Sum-Square (RSS) method. In analyzing new systems, it may be necessary to utilize alternative methods of combining errors, but each element must be properly considered.

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

2.2 CURRENT AVIATION NAVIGATION REQUIREMENTS

2.2.1 En Route/Terminal Phase

The en route/terminal phase of air navigation (as defined in Section 1.3) includes the following subphases:

1. Oceanic En Route
2. Domestic En Route
3. Terminal
4. Remote Area
5. Helicopter.

The general requirements in Section 2.1 are applicable to the en route/terminal phase of navigation. In addition, to facilitate aircraft operations in this phase, the system must be capable of being operationally integrated with the system used for approach and landing. The system used for domestic en route and terminal navigation must be suitable for non-precision approaches.

Federal Aviation Regulations (FAR) paragraphs 91.109 and 91.121 specify the vertical separation required below and above flight level 290 (29,000 feet). The current separation requirement is 1,000 feet below Flight Level 290, and 2,000 feet at and above Flight Level 290. In order to justify the 1,000 foot vertical separation below Flight Level 290, the RSS altitude keeping requirement is ±350 feet (3 sigma). This error is comprised of ±250 feet (3 sigma) aircraft altimetry system error, of which the altimeter error is limited to ±125 feet by TSO C-10B below Flight Level 290.

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

A. <u>Oceanic En Route</u>

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

A 60 nm lateral separation standard has gone into effect on the North Atlantic fixed route system. The following system performance is required to achieve this separation:

(1) The standard deviation of the lateral track errors shall be less than 6.3 nm, 1 sigma (12.6 nm, 2 sigma).

(2) The proportion of the total flight time spent by aircraft 30 nm or more off track shall be less than 5.3×10^{-4}, i.e., less than 1 hour in about 2,000 flight hours.

(3) The proportion of the total flight time spent by aircraft between 50 nm and 70 nm off track shall be less than 1.3×10^{-4}, i.e., less than 1 hour in about 8,000 flight hours.

B. Domestic En Route

Domestic air routes are designed to provide as nearly direct airways as practical between city pairs that have significant air traffic. For altitudes below Flight Level (FL) 180 (18,000 feet), the airways are defined as 8 nm in width out to 51 nm from the VOR facility. Beyond 51 nm the airway increases uniformly in width on either side of the centerline ± 4.5 degrees, with the apex of the angle at the VOR facility.

For altitudes above FL 180 (18,000 feet and above), the airways consist of jet routes which have the same protected airspace as the low-altitude structure except the VOR stations may be spaced farther apart and the route width may be as large as 20 nm.

Area Navigation (RNAV) routes have the same protected airspace as regular airways.

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

1. Azimuth Accuracy in Degrees

ERROR COMPONENT	2 SIGMA DEVIATION VALUES	SOURCE
VOR Ground	$\pm 1.4^{o}$	Semi-Automatic Flight Inspection (SAFI) System
VOR Air	$\pm 3.0^{o}$	Equipment Manufacturer
Course Selection (CSE)	$\pm 2.0^{o}$	FAA Tests
Flight Technical (FTE)	$\pm 2.3^{o}$	FAA Tests
Total System Error (95% Confidence)	$\pm 4.5^{o}$	(RSS derived)

2. Range Accuracy

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

3. Area Navigation (RNAV)

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

ERROR COMPONENT	2 SIGMA DEVIATION VALUES	SOURCE
VOR Ground	$\pm 1.4^{\circ}$	SAFI
VOR Air	$\pm 3.0^{\circ}$	Equipment Manufacturer and FAA Tests
DME Ground	±0.1 nm	SAFI

ERROR COMPONENT	2 SIGMA DEVIATION VALUES	SOURCE
DME Air	±0.2 nm + 1% of Range	Equipment Manufacturer*
FTE	±1.0 nm	FAA Tests**
CSE	$\pm 2.0^{\circ}$	FAA Tests
RNAV System	±0.5 nm	Equipment Manufacturer and FAA Tests

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

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

C. Terminal

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

D. Remote Areas

Remote areas are defined as regions which either do not meet the requirements for installation of VOR/DME service or where it is impractical to install this system. These include offshore areas, mountainous areas and a large portion of the State of Alaska. Thus the minimum route width varies and can be greater than ±10 nm. The minimum requirements are shown in Table II-2.1.

E. Helicopter Operations

Helicopter operations occur in offshore areas and on low-altitude domestic routes. For operations from U. S. coastline to offshore points, the following requirements must be met:

(1) Range from shore to 300 nm.

(2) Minimum en route altitude of 500 feet above sea level or above obstructions.

(3) Accuracy adequate to support routes ±4 nm wide or narrower with 95 percent confidence.

(4) Minimum descent altitude to 100 feet in designated areas.

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

(1) Accuracy adequate to support ±2 nm route widths in both en route and terminal areas with 95 percent confidence.

(2) Minimum en route altitudes of 1,200 feet.

(3) Navigational signal coverage adequate to support approach procedures to minimums of 250 feet above obstruction altitudes at heliports and airports.

2.2.2 Approach/Landing Phase

This phase of flight is one of two types: (1) non-precision approach, or (2) precision approach and landing.

Phase	Sub-Phase	Altitude (Flight Level)	Traffic Density	Route Width (NM)	Accuracy 2 drms (meters)	System Use Accuracy 2 drms (meters)
EnRoute/ Terminal	Oceanic	FL 275 to 400	Normal	60		12.6nm*
	Domestic	FL 180 to 600	Low	16	2000	7,200
			Normal	8	1000	3,600
		500 - 18,000 ft.	High	8	1000	3,600
	Terminal	500 - 18,000 ft.	High	4	500	1,800
	Remote	500 - 60,000 ft.	Low	8 to 20	1000 to 4000	3,600 to 14,400
	Helicopter Operations	500 - 5000 ft.	Low (Off-Shore)	Not Determined	1000 to 2000	3,600 to 7,200
		500 - 3000 ft.	High (Land)	4	500	1,800
Approach and Landing	Non-Precision	250 to 3000 ft. above Surface	Normal	2	100	150
	Precision Cat I	100 to 3000 ft. above Surface	Normal	± 9.1 meters**	± 3 meters ***	
				at 100 ft. above Surface	at 100 ft. above Surface	
	Cat II	50 to 3000 ft. above Surface	Normal	± 4.6 meters	± 1.4 meters	
				at 50 ft. above Surface	at 50 ft. above Surface	
	Cat III	0 to 3000 ft. above Surface	Normal	± 4.1 meters	± 0.5 meters	
				at Surface	at Surface	

* The distribution of this error is detailed in the "Report of the Limited North Atlantic Regional Air Navigation Meeting," dated 1976; ICAO Montreal Canada

** This column is lateral position 2 sigma accuracy in meters for Precision Approach and Landing

*** This column is vertical position 2 sigma accuracy in meters for Precision Approach and Landing.

TABLE II-2.1 Controlled Airspace Navigation Accuracy to Meet Current Requirements

The general requirements of paragraph 2.1 apply to the approach/landing phase. In addition, specific procedures and clearance zone requirements are specified in TERPS (United States Standard for Terminal Instrument Procedures, FAA Handbook 8260.3B).

Altimetry accuracy requirements are established in accordance with FAR 91.170 (Federal Aviation Regulations, paragraph 91.170) and are the same as those for the en route/terminal phase.

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

A. Non-Precision Approach

Non-precision approaches are based on any navigational system that meets the criteria established in TERPS. Minimum safe altitude, obstacle clearance area, visibility minimum, final approach segment area, etc., are all functions of the navigational accuracy available and other factors. The unique features of Area Navigation (RNAV) for non-precision approaches are specified in FAA Advisory Circular No. 90-45A, "Approval of Area Navigation Systems for Use in the U. S. National Airspace System."

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

B. Precision Approach and Landing

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

OPERATIONAL PERFORMANCE OBJECTIVE FOR APPROACH AND LANDING

Landing Category	Decision Height (feet)	(meters)	Runway Visual Range (feet)	(meters)
I	200	(61.0)	2600	(792)
II	100	(30.5)	1200	(366)
IIA	0	(0)	700	(213)
IIIB	0	(0)	150	(46)
IIIC	0	(0)	0	(0)

Category	Minimum Guidance Height (feet)	(meters)	Accuracy Lateral (feet)	(meters)	Vertical (feet)	(meters)
I	100	(30.5)	30.0	(9.1)	10.0	(3.0)
II	50	(15.3)	15.0	(4.6)	4.5	(1.4)
IIIABC	0	(0)	13.5	(4.1)	1.8	(0.5)

2.2.3 Current System Requirements Summary

The system use accuracy criteria to meet the current route requirements are summarized in Table II-2.1. These route widths are based upon present capacities, separation requirements, and obstruction clearance requirements.

2.3 FUTURE AVIATION NAVIGATION REQUIREMENTS

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

2.3.1 En Route/Terminal Phase

A. Oceanic

New lateral separation specifications have been designed to allow a lateral separation of 60 nm. This was put into effect for certain areas of the North Atlantic in early 1981. The 60 nm separation requires a lateral track error of less than ±12.6 nm (2 sigma). Further lateral separation reductions are desirable.

B. Domestic En Route

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

Traffic forecasts indicate that IFR traffic will increase by more than 60 percent by 1990. This may cause route capacity problems before 1990. A proposed solution* is more use of VOR/DME RNAV which will allow the implementation of random parallel routes with the use of current VOR/DME facilities. Present studies indicate that an RNAV environment based on use of current route width of 8 nm, can be achieved using the existing VOR/DME facilities. No increase in VOR/DME ground accuracy is required to meet the navigational requirements imposed by the air traffic levels estimated for the Year 2000. The current nominal VOR system signal-in-space accuracy that permits 8 nm route widths is ±1,000 meters (2 drms). Any replacement system must have an equivalent accuracy.

C. Terminal

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

D. Remote Areas

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

E. Helicopter Operations

Both offshore and onshore low-altitude helicopter operations will have navigational requirements at least as stringent as those in paragraph 2.2.1. E and coverage to 500 nm from shore. The accuracies are equivalent to 1,000 meters (2 drms) for offshore and 500 meters (2 drms) for over land.

2.3.2 Approach/Landing Phase

A. Non-Precision Approach

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

*FAA, Implementation of Area Navigation in the National Airspace System, December 1976, Report FAA RD-76-196 and FAA RNAV Policy Statement, January 7, 1977.

The requirement in the non-precision approach procedures is that the navigational system be able to perform as well as an on-airport VOR. This requirement has been selected for the following reasons:

- o Approximately 30 percent of the runways with non-precision approaches use on-airport VOR.
- o These are typically used at the busiest airports. Since they are in urban areas, they will have the most pressure for reduction of clearance areas for additional noise abatement and obstacle encroachment problems.
- o Any replacement navigational system must operate at least as well in all navigational phases as the system it is replacing.

The critical factor in the final approach segment of a non-precision approach is the size of the obstacle clearance area. This is determined by establishing an area defined by taking the 95 percent (2 sigma) lateral navigational system use error and adding a 1 nautical-mile buffer on either side of it from the VOR to the final approach fix. This is depicted in Figure II-2.1 for an on-airport VOR, where the VOR is the missed approach point (MAP). The critical dimensions in the figure are the widths at the VOR, the visibility minimum distance from the VOR, and at the Final Approach Fix (FAF).

The $\pm$100 m (2 sigma) system accuracy is based on a 0.7 nm visibility minimum distance from the VOR. This is the distance where the pilot should obtain visual cues of the airport and/or runway. Current RNAV equipments cannot meet this requirement; however, it seems feasible to provide improved RNAV systems that can meet this requirement.

B. Precision Approach and Landing

The requirements for precision approaches and landings are not expected to change by the Year 2020 and are presented in Paragraph 2.2.2. B.

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

Accuracy at 8 Feet (2.4 Meters) Above Surface (2 sigma)

Lateral	$\pm$13.5 feet ($\pm$4.1 meters)
Vertical	$\pm$1.8 feet ($\pm$0.5 meter)

2.3.3 Future System Performance Requirements Summary

Table II-2.2 represents the best estimate of future minimum accuracy and route criteria to meet the aviation navigational requirements up to the Year 2000.

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

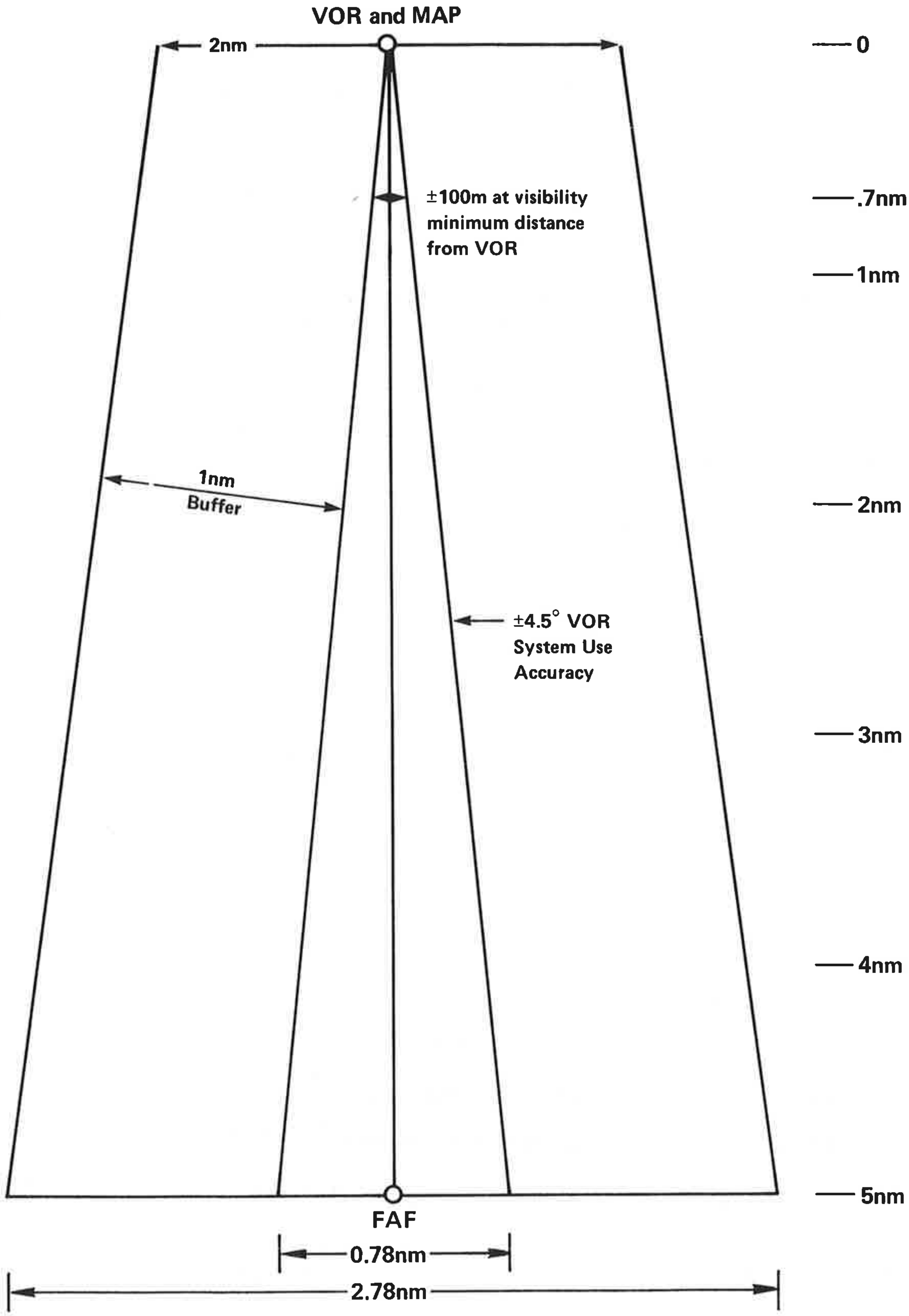

FIGURE II-2.1 Non-Precision Approach Obstacle Clearance Area for Current VOR with MAP at VOR Facility

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

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

Phase	Sub-Phase		Altitude (Flight Level)	Traffic Density	Route Width (NM)	Source Accuracy 2 drms (meter)	System Use Accuracy 2 drms (meters)
EnRoute/ Terminal	Oceanic		FL 275 to 400	Normal	less than 60		better than 12.6nm
	Domestic		FL 180 to 600	Normal	8	1000	3,600
				High	8	1000	3,600
			500 ft to FL 180	Normal	8	1000	3,600
	Terminal		500 ft to FL 180	High	4	500	1,800
	Remote		500 ft to FL 600	Normal	8 to 20	1000 to 4000	3,600 to 14,400
	Helicopter Operations		500 ft to 5000 ft	Low (Off-Shore)	8	1000	3,600
			500 ft to 3000 ft	High (Land)	4	500	1,800
Approach and Landing	Non-Precision		250 to 3000 ft. above surface	Normal	1 to 2	100	150
	Precision	Cat I	100 to 3000 ft. above surface	Normal	± 9.1 meters*	± 3 meters**	
					at 100 ft. above Surface		
		Cat II	50 to 3000 ft. above surface	Normal	± 4.6 meters	± 1.4 meters	
					at 50 ft. above Surface		
		Cat III	0 to 3000 ft. above surface	Normal	± 4.1 meters	± 0.5 meters	
					at Surface		

* This column is the 2 sigma lateral accuracy in meters
** This column is the 2 sigma vertical accuracy in meters

TABLE II-2.2 Controlled Airspace Aviation Navigation Accuracy to Meet Projected Future Requirements

VOLUME II

CHAPTER 3

CIVIL MARINE RADIONAVIGATION

3.0 MARINE RADIONAVIGATION REQUIREMENTS

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

The foregoing discussion of phases of marine navigation (paragraphs II-1.3.2) sets the framework for defining safety of navigation requirements. However, the economic and operational dimensions also need to be considered for the wide diversity of vessels that traverse the oceans and U.S. waters. For example, accurate worldwide navigation (beyond that needed for safety) is important particularly to the economy of large seagoing ships whose hourly operating costs are high. For fishing and oil exploration vessels, the ability to locate precisely and return to productive or promising areas and avoid underwater obstructions provides important economic benefits. Search and Rescue (SAR) effectiveness is similarly dependent on accurate navigation in the vicinity of a maritime distress incident.

For purposes of system planning, the Government seeks to satisfy minimum safety requirements for each phase of navigation and to maximize the economic utility of the service for users. Since the vast majority of marine users are not required to carry any navigational equipment, and will do so only if persuaded by "individual cost-benefit analysis," this Governmental policy helps to promote maritime safety through the "carrot" of economic incentive being provided simultaneously.

Tables II-3.1, II-3.2 and II-3.3 identify system performance needed to satisfy current maritime user requirements or to achieve special benefits in four of the five phases of marine navigation. They are divided into two categories. The upper half are those related to safety of navigation. The Government recognizes an obligation to satisfy these requirements for the overall national interest. The lower half are specialized requirements or characteritics needed to provide special benefits to discrete classes of maritime users (and additional public benefits which may accrue from services provided by users).

The Government does not recognize an absolute commitment to satisfy these, but does endeavor to meet them if achievable at a cost that is justified by the benefits derived which are in the national interest. For the purpose of comparing the performance of systems, the requirements are categorized in terms of system performance characteristics which represent the minimum performance considered necessary to satisfy the requirements or achieve special benefits.

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Interval	Fix Dimension	Capacity	Ambiguity
Safety of Navigation — All Craft	2-4NM(3.7-7.4km) Minimum 1-2NM(1.8-3.7km) DESIRABLE	—	—	Worldwide	95% full cap. 99% Fix at least every 12 hours	**	15 Mins. or Less Desired; 2 hrs Maximum	Two	Unlimited	Resolvable with 99% Confidence

Benefits	Measures of Minimum Performance Criteria to Achieve Benefits									
Large Ships Maximum Efficiency	0.1-0.25NM (185-460m) *	—	—	Worldwide, except Polar Regions	99%	**	5 min.	Two	Unlimited	Resolvable with 99% Confidence
Hydrography Science, Resource Exploitation	10-100m *	10-100 m *	—	Worldwide	99%	**	1 min.	Two	Unlimited	Resolvable with 99% Confidence
Search Operations	0-25NM (460m.)	0.25NM	185 m.	National Maritime SAR Region (NPAC, NWLAN)	99%	**	1 min.	Two	Unlimited	Resolvable with 99% Confidence

* Based on stated user need.

** Dependent upon mission time.

TABLE II-3.1 Current Maritime User Requirements/Benefits for Purposes Of System Planning and Development - Ocean Phase

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Interval	Fix Dimension	Capacity	Ambiguity
Safety of Navigation – All Ships	0.25nm (460m)	–	–	U.S. Coastal Waters	99.7% Minimum	**	2 Min.	Two	Unlimited	Resolvable with 99.9% Confidence
Safety of Navigation – Recreational Boats & Other Smaller Vessels	0.25nm-2nm (460-3700 m)	–	–	U.S. Coastal Waters	99% Minimum	**	5 Min.	Two	Unlimited	Resolvable with 99% Confidence

Benefits	Measures of Minimum Performance Criteria to Achieve Benefits									
Commercial Fishing (including Commerical Sport Fishing)	0.25 nm (460 m.)	50-600 ft. (15-180m)	–	U.S. Coastal/ Fisheries Areas	99% Minimum	**	1 Min.	Two	Unlimited	Resolvable with 99.9% Confidence
Hydrography Science, Resource Exploitation	1.0-100 m *	1.0-100m *	–	U.S. Coastal Area	99% Minimum	**	1 Sec.	Two	Unlimited	Resolvable with 99.9% Confidence
Search Operations, Law Enforcement	0.25 nm (460 m.)	300-600 ft. (90-180m)	300 ft. (90m)	U.S. Coastal/ Fisheries Areas	99.7% Minimum	**	1 Min.	Two	Unlimited	Resolvable with 99% Confidence
Recreational Sports Fishing	0.25nm (460 m.)	100-600 ft. (30-180m)	–	U.S. Coastal Areas	99% Minimum	**	5 Min.	Two	Unlimited	Resolvable with 99.9% Confidence

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

TABLE II-3.2 Current Maritime User Requirements/Benefits for Purposes Of System Planning and Development - Coastal Phase

Requirements	Measures of Minimum Performance Criteria to Meet Requirements									
	Accuracy (2 drms)									
	Predictable	Repeatable	Relative	Coverage	Availability	Reliability	Fix Interval	Fix Dimension	Capacity	Ambiguity
Safety of Navigation – Large Ships & Tows	25-65 Ft (8-20 m) ***	–	–	U.S. Harbor & Harbor Approaches	99.7% Minimum	**	6-10 Seconds	Two	Unlimited	Resolvable with 99.9% Confidence (Minimum)
Safety of Navigation – Smaller Ships	***	***		U.S. Harbors, & Harbor Approaches	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% Confidence (Minimum)
Hydrography Science, Resource Exploitation	1-5 m *	1-5 m *		U.S. Harbors, & Harbor Approaches	99% Minimum	**	1 Second	Two	Unlimited	Resolvable with 99.9% Confidence

Benefits	Measures of Minimum Performance Critieria to Achieve Benefits									
Fishing Recreational, and Other Small Vessels	***	***	–	U.S. Harbor, & Harbor Approaches	99.7%	**	***	Two	Unlimited	Resolvable with 99.9% Confidence

* Based on stated user need
** Dependent upon mission time
*** Varies from one harbor to another

TABLE II-3.3 Current Maritime User Requirements/Benefits for Purposes of System Planning and Development - Harbor Approach and Harbor Phases

3.1 OCEAN PHASE

The requirements for safety of navigation in the ocean phase for all ships are given in Table II-3.1. These requirements must provide the master with a capability to avoid hazards in the ocean (e.g., small islands, reefs) and to plan correctly the approach to land or restricted waters. For operational purposes, repeatability is necessary to locate and return safely to the vicinity of a maritime distress, as well as for special activities such as hydrography, research, etc. Economic efficiency in safe transit of open ocean areas depends upon the continuous availability of accurate position fixes to enable the vessel to follow the shortest safe route with precision and, thus, minimize transit time.

3.1.1 Requirements

For safe general navigation under normal circumstances, the requirements for the accuracy and frequency of position fixing on the high seas are not very strict. As a minimum, these requirements include a predictable accuracy of 2 to 4 nm coupled with a maximum fix interval of 2 hours or less. These minimum requirements would permit reasonably safe oceanic navigation, provided that the navigator understands and makes allowances for the probable error in navigation, and provided that more accurate navigational service is available as land is approached. While these minimum requirements would permit all vessels to navigate with relative safety on the high seas, more desirable requirements would be predictable accuracy for 1 to 2 nm and a fix interval of 15 minutes or less. The navigation signal should be available 95% of the time. Further, in any 12 hour period, the probability of obtaining a fix from the system should be at least 0.99.

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

3.1.2 Minimum Performance Criteria

Economic efficiency in trans-oceanic transportation, special maritime activities and safety in emergency situations require or benefit from navigational accuracy higher than that needed for safety in routine, point-to-point ocean voyages. These requirements are summarized in Table II-3.1. The predictable accuracy requirements may be as stringent as 10 meters for special maritime activities, and may range to 0.25 nm for large, economically efficient vessels, including search operations. Search operations must also have a repeatable accuracy of at least 0.25 nm. As indicated in Table II-3.1, the required fix interval may range from as low as once per five minutes to as high as once per minute. Signal availability must be at least 95 percent and approach 99 percent for all users. These requirements are based on current estimates and are to be used for the purposes of system planning. There has not been sufficient analysis to establish quantitative relationships between navigational accuracy and economic efficiency. The expensive, satellite-based navigation systems used by ships engaged in science and resource exploration, and the increasing use of relatively expensive satellite navigation by merchant ships and larger, ocean-going fishing vessels are evidence of the perceived value attached to highly accurate ocean navigation by the vessel owners.

3.2 COASTAL PHASE

There is need for continuous, all-weather radionavigation service in the coastal area providing, at the least, the position fixing accuracy required to satisfy minimum safety requirements for general navigation. These requirements are delineated in Table II-3.2. Further, the total navigational service in the coastal area must provide service of useful quality, be within the economic reach of all classes of mariners, and be sufficient to assure that no boat or ship need be lost or endangered, or that the environment and public safety not be threatened, because a vessel could not navigate safely with reasonable economic efficiency.

3.2.1 Requirements

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

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

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

3.2.2 Minimum Performance Criteria

Government studies established that a navigation system providing a capability to fix position to an accuracy of 0.25 nm will satisfy the minimum safety requirements if a fix can be obtained at least every 15 minutes. As a secondary economic factor, it is required that relatively higher repeatable accuracy be recognized as a major advantage in the consideration of alternative candidate radionavigation systems for the coastal area. As indicated in Table II-3.2, these requirements may be relaxed slightly for the recreational boat and other small vessels.

In such activities as marine scientific research, hydrographic surveying, commercial fishing, and petroleum or mineral exploration, as well as in Navy operations, there may be a need to establish position in the coastal area with much higher accuracy than that needed for safety of general navigation. In many of these special operations which require highly accurate positions, the use of radiodetermination would be classified as radiolocation rather than radionavigation. As shown in Table II-3.2, the most rigid requirement of any of this general group of special operations is for seismic surveying with a repeatable accuracy on the order of 1 to 100 meters (2 drms), and a fix rate of once per second for most applications.

3.3 HARBOR AND HARBOR APPROACH PHASES

The pilot of a vessel in restricted waters must direct its movement with great accuracy and precision to avoid grounding in shallow water, and avoid collisions with other craft in congested waterways. Unable to turn around, and severely limited in the ability to stop to resolve a navigational problem, the pilot of the large vessel (or a tow boat and barge combination) may find it necessary to hold the total error in navigation within limits measured in tens of feet, while negotiating the straight channel segments and turns dictated by the configuration of the channel.

3.3.1 Requirements

To navigate safely, the pilot needs highly accurate verification of position almost continuously, together with information depicting any tendency for the vessel to deviate from its intended track and a nearly continuous and instantaneous indication of the direction in which the pilot should steer. These requirements are given in Table II-3.3.

3.3.2 Minimum Performance Criteria

The required accuracy varies from one harbor to another. In the most restricted channels, accuracy in the range 8 to 20 meters (2 drms) predictable accuracy is needed. The requirements for smaller vessels are currently under study but, in a given harbor, these requirements are somewhat less stringent than for large ships. For seismic surveying, the accuracy needs increase to one to five meters (2 drms) with a fix rate of one second.

3.4 INLAND WATERWAY PHASE

Very large amounts of commerce move on the United States Inland Waterway system, much of it in slow-moving, comparatively low-powered tug and barge combinations. Tows on the inland waterways, although comparatively shallow in draft, may be longer and wider than large seagoing ships which call at U.S. ports. Navigable channels used by this inland traffic are often narrower than the harbor access channels used by large ships. Restricted visibility and ice cover present problems in Inland Waterway navigation, as they do in Harbor Approach and Harbor navigation. The long, ribbon-like nature of the typical inland waterway presents special problems to the prospective use of precise, land-based area navigation systems. The continual movement of the navigable channels in some unstable waters creates additional problems to the prospective use of any radionavigation system which provides position measurements in a fixed coordinate system. The probable consequences of a grounding in inland waterway navigation, however, and thus the overall level of risk, are somewhat lower than for large, seagoing ships in restricted waters.

3.4.1 Requirements

Requirements from the consideration of practically achievable performance and expected benefits have not been defined. However, Research, Engineering & Development (R,E&D) in Harbor Approach and Harbor navigation is expected to produce results which will have some application to Inland Waterway navigation. Thus, no table or chart is provided for Inland Waterway navigation.

3.4.2 Minimum Performance Criteria

These criteria have not been determined. The R,E&D plans in Volume IV discuss the current and future efforts in the area of Inland Waterway navigation.

3.5 DISCUSSION OF FUTURE REQUIREMENTS

The marine navigational requirements presented in the preceding discussions and tables represent the best quantitative judgment of current performance that would satisfy a broad range of needs. However, they are the products of current technology and current operating practices, and therefore are subject to revision in an evolutionary and dynamic manner. The principal factors which will impact the formulation of future requirements are safety, economics, environment, and energy conservation.

3.5.1 Safety

A. Increased Risk from Collision, Grounding and Ramming

Cargoes of particular hazard (petroleum, chemicals, etc.) are being carried in greater volumes in U.S. coastal and inland waterways. For example, energy imports of bulk crude oil and Liquefied Natural Gas (LNG) are increasing to meet demand as U.S. domestic supplies are decreasing. Casualties involving vessels carrying these materials pose grave potential dangers to the enviroment and public at large.

B. Increased Size and Decreased Maneuverability of Marine Vessels

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

C. Greater Need for Traffic Management/Navigational Surveillance Integration

The foregoing trends foreshadow a growing governmental involvement in marine traffic control in order to assure reasonable safety in U.S. waters. Navigation systems are an essential component of such traffic management systems.

3.5.2 Economics

A. Greater Congestion in Harbor Approaches and Inland Waterways

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

B. Greater Emphasis on All Weather Operations

Low visibility and ice-covered waters presently impede full utilization of the marine transportation mode. Increasingly, joint government/industry efforts will be applied to remove these restrictions. An example is the Great Lakes Season Extension Program to allow year-round navigation in the Great Lakes and their harbors, which is dependent partially on improved radionavigational performance.

3.5.3 Environment

Greater Emphasis on Offshore Resource Exploitation: As onshore energy supplies are depleted, resource exploration and exploitation will move further offshore to the U.S. Outer Continental Shelf and to harsher environments, such as the North Slope of Alaska. Further, more intensive U.S. fishing activity is anticipated as the result of legislative initiatives and the creation of the U.S. Fishery Conservation Zone. In sum, both sets of activities may generate demands for navigational services of higher quality and for broadened geographic coverage in order to allow environmentally sound exploitations.

3.5.4 Energy Conservation

Increased Fuel Cost: Six percent of free world fuel consumption is devoted to marine transportation. The need to conserve energy resources and to reduce costs provides powerful incentives for increased transportation efficiency, some of which could come from better navigation systems.

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CHAPTER 4

CIVIL LAND RADIONAVIGATION

4.0 LAND RADIONAVIGATION REQUIREMENTS

Government studies have identified a number of areas in both the automatic vehicle monitoring (AVM) and site registration phases where productivity and operational improvements have been predicted. Since land application of radiolocation adopted systems has not been widely adopted by the civil community, no official requirements or systems have been recognized by the Government.

4.1 AUTOMATIC VEHICLE MONITORING PHASE

4.1.1 Preliminary Requirements

There is no definitive statement of requirements for AVM service since it is still under investigation. It appears that there are requirements in safety, transportation management and economic areas.

4.1.2 Preliminary Minimum Performance Characteristics

Study efforts and field measurements to date have led to some preliminary estimates of accuracies and costs required to make radiolocation service beneficial to various user groups. These data are shown in Table II-4.1. No other characteristics have been determined.

4.2 SITE REGISTRATION PHASE

4.2.1 Preliminary Requirements

There are no definitive statements of requirements for this service since it is still under investigation. It appears that there are requirements in both the safety and economic areas.

4.2.2 Preliminary Minimum Performance Characteristics

Study efforts and field measurements to date have led to some preliminary estimates of accuracies required to make radiolocation service beneficial to various user groups. These data are shown in Table II-4.1. No other characteristics have been determined.

MINIMUM REQUIREMENTS

APPLICATION	REPEATABLE ACCURACY (2 drms) *	COVERAGE	AVAILABILITY	FIX RATE **	FIX DIMENSION	CAPACITY	AMBIGUITY
Public Safety Urban Police, EMS Rural Police, EMS State Police	 250 ft. 1000 ft. 1000 ft.	 Urban Area County State	99.7%	 1 sec. 1 sec. 1 sec.	Two	Unlimited	Resolvable with 99.9% Confidence
Transportation Urban Buses Taxi Delivery Truck Truck (Hazardous Cargo)	 500 ft. 500 ft. 1000 ft. 10000 ft.	 Urban Area Urban Area Urban Area Nationwide	99.7%	 1 sec. 1 sec. 1 sec. 1 sec.	Two	Unlimited	Resolvable with 99.9% Confidence
Highway Safety Planning (Traffic Records, Highway Inventory, Highway Main.)	100 ft.	State	99.7%	1 sec.	Two	Unlimited	Resolvable with 99.9% Confidence
Resource Management	100 ft.	Nationwide	99.7%	1 sec.	Two	Unlimited	Resolvable with 99.9% Confidence

* Requirement under study, values noted are current estimates.
** Fix Rate of navigation system, user update rate dependent on application and characteristics of communication link.

TABLE II-4.1 Land Navigation Requirements

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CHAPTER 5

MILITARY RADIONAVIGATION

5.0 MILITARY RADIONAVIGATION REQUIREMENTS

Military forces must be prepared to conduct operations anywhere in the world, in the air, on and under the sea, on land, and in some cases, above the atmosphere. During peacetime, military platforms must conform to applicable national and international "rules of the road" in controlled airspace, on the high seas, and in coastal areas. However, military planning must consider the possibility of operations in a hostile environment.

5.1 GENERAL REQUIREMENTS

Military navigation systems should have the following characteristics:

A. Provide worldwide coverage

B. Be user passive

C. Be capable of denying use to the enemy

D. Have no saturation limit

E. Be resistant to meaconing,* interference, jamming and intrusion (MIJI)

F. Be resistant to natural disturbance and hostile attack

G. Provide effective realtime response

H. Be available for combined military operations with allies

I. Have no frequency allocation problem

J. Provide common grid for all users

K. Provide position accuracy not degraded by changes in altitude for air and land forces or by time of year or time of day

L. Retain accuracy while the user vehicle is employed in high "G" maneuvers

M. Be maintained by operative level personnel

N. Be continuously available for fix information

O. Be self-contained in the user vehicle.

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*Meaconing refers to imitative communications deceptions.

No single system or combination of systems currently in existence meets all of the approved military navigation requirements. No known system can provide a common grid for all users, be passive, and at the same time be self-contained and yield the world-wide accuracies required. The nature of military operations requires that essential navigational services must be available with the highest possible confidence that these services will equal or exceed mission requirements. This, among other considerations, requires that military operations use a variety of navigational techniques and redundant installations on the various weapon system platforms.

While general military requirements remain fairly constant, continuous review is required because of the impact of new technology, weapon system modifications, the dynamics of our national policy interests and non-military environment to which the military must respond. Current indications are that a navigation concept based on an advanced navigation satellite system with global precision coverage, incorporating supplementary self-contained special-purpose systems, will be the most effective combination of systems over the next decade. This system, NAVSTAR Global Positioning System (GPS), is currently in the Full Scale Development phase. NAVSTAR GPS will have a major impact on military operations. As this system becomes operational, the use of older systems will be constantly reviewed. In some cases, unique military requirements will also be affected. However, unique requirements will be considered as additional data and experience with NAVSTAR GPS become available.

5.2 SERVICE REQUIREMENTS

The JCS Master Navigation Plan provides specific Service and Defense Mapping Agency (DMA) requirements for navigation and positioning accuracy organized by primary missions and functions with specifically related accuracy requirements. These requirements are used for information and guidance in the development and procurement of military navigation systems.

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CHAPTER 6

SPACE RADIONAVIGATION

6.0 SPACE RADIONAVIGATION REQUIREMENTS

Several program areas within NASA are engaged in the evaluation of NAVSTAR GPS for precise position determination as a means of meeting space needs, for scientific studies, and for effecting economics in the use of space. These include the following uses of NAVSTAR GPS which are discussed herein:

A. For control and navigation of space missions, such as the Space Shuttle and automated spacecraft.

B. For determining in real time a position reference system for space platforms for in-orbit pointing of remote sensing devices.

C. For real-time spacecraft position data to ± 1 km to be incorporated in the telemetered data stream of geophysical (solar-terrestrial) spacecraft or Spacelab payloads.

D. For further post-pass refinement of orbit data for data analysis when greater accuracy is required.

6.1 NAVIGATION AND CONTROL

NASA is considering use of the NAVSTAR GPS as the primary basis for navigation of the Space Shuttle in the future. This is to include the launch phase, in-flight position determination, and the reentry phase. Other methods (range and range rate tracking, inertial navigation Tracking and Data Relay Satellite System (TDRSS), etc.) will be backup modes. This assumes that NAVSTAR GPS determined positions will be within the 10-meter Circular Error Probable (CEP) design point.

Beginning in 1982, the Shuttle will be transporting free-flyer payloads into orbit. Many of these payloads, after release, will transfer to other earth orbits or will be placed in escape trajectories. For some of these missions, NAVSTAR GPS would be useful to assure proper orbit insertions or would be useful in minimizing ground control.

To minimize the cost of operating in space, NASA is planning for Shuttle to retrieve and return payloads to earth. This requires that free-flyers be capable of adjusting orbit to rendezvous with Shuttle. The free-flyer must be brought within close proximity of the Shuttle to permit capture by a crew-operated Remote Manipulator System. Obviously, the safety of the Shuttle crew and successful retrieval depends on an accurate knowledge of the realtime position of the satellite and of the Shuttle. Here again, it is anticipated that NAVSTAR GPS would be useful in simplifying satellite rendezvous procedures.

6.2 REAL-TIME POSITION REFERENCE SYSTEM

Many experiments to be flown on the Space Shuttle or free-flyers would benefit from knowing precisely the platform location as a reference for pointable observing systems. Payloads aboard the orbiter will receive ephemeris data of the orbiter with no reduction in accuracy. The importance of this information derives primarily from the efficiencies achievable by acquiring optimized data for a particular study. For instance, Lidar and limb scanning sensors intended to measure atmospheric aerosols and particulates, imagery of specific locations on the earth's surface, and direct narrow-band communication experiments would all benefit from an accurate knowledge (5 to 10 meters) of the three-dimensional location of the platform. With less accurate information, more data would have to be collected to assure that the primary area is covered.

Geophysical payloads need to know the positions where measurements are made. Generally, a precision of ± 1 km in realtime is adequate, but more accurate data are sometimes needed for special studies. In those cases, post-flight determinations are acceptable.

In 1983, NASA plans to initiate the TDRSS service. This is to be followed by the closing of most of the currently existing network of ground stations for satellite communication and tracking. The TDRSS (two satellites at synchronous orbit) is capable of realtime satellite positioning to 30 to 50 meters in cross track and 150 to 250 meters in a long track. Precision, non-realtime, orbit determination via TDRSS is expected to yield 20-meter CEP. While these capabilities will meet most of NASA tracking requirements for near-earth missions, they are not adequate for direct registration of multispectral scenes acquired using Landsat.

6.3 POST-PASS PRECISION ORBIT DETERMINATION

At present, missions requiring precise orbital data make use of Doppler tracking, range and range rate tracking, and laser ranging. Computation of the orbit is achieved at considerable expense using complicated modeling which incorporates satellite frontal area as a function of orientation (for drag, radiation pressure, and earth albedo), gravity field to degree and order 32, and all available tracking data. For missions such as GEOS-3 or Seasat final orbits are accurate to a few meters (GEOS-3 orbit calculations were adjusted using altimetric data for ascending and descending orbits).

Altimetric measurements of the ocean, radar and optical imaging of land areas and geopotential field measurements must be related to points on the earth. In the case of Landsat multi-spectral data, it is required that successive images be registrable to one-half of a pixel (minimum detectable spatial resolution). For Landsat-D (1983), registration is required to 15 meters. Later missions will require registration to 0.1 pixel or better than 2 meters. This is beyond the current NAVSTAR GPS capability. It is apparent that for long-life missions (3 to 5 years), which require this accuracy, significant economies could be achieved by replacing post-pass determinations with actual NAVSTAR GPS data. Hence, for remote sensing missions, it is particularly important that the precision-coded signal from the NAVSTAR GPS be available to NASA for onboard satellite tracking. Otherwise, expensive ground processing of intermittent range and Doppler tracking samples from the Ground Satellite Tracking and Data Network (GSTDN) or TDRSS must be accomplished. These tracking samples are normally used to determine spacecraft position many days, weeks, or even months after mission sensor images of interest are transmitted from the NASA spacecraft. With the availability of Precise Positioning Service (PPS) NAVSTAR GPS signals, accurate position estimates would be available every 100 milliseconds for transmission with the telemetry stream from the satellites directly to image users instantaneously.

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