REPORT BY THE

Comptroller General

OF THE UNITED STATES

9983

Should NAVSTAR Be Used For Civil Navigation? FAA Should Improve Its Efforts To Decide

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The Federal Aviation Administration (FAA) is making an extensive evaluation of DOD's planned NAVSTAR satellite navigation system to determine if it should also become the primary civil air navigation system.

The Chairman, Subcommittee on Transportation, Aviation, and Weather, House Committee on Science and Technology, asked GAO to review the adequacy and timeliness of FAA's evaluation program. This report discusses the work FAA has done or plans to do as of this time.

Before a decision is made, reasonable assurance is needed that DOD will develop, test, and deploy NAVSTAR and allow the civil community full access to its signals under all conditions other than national emergency.

GAO recommends that FAA improve its NAVSTAR evaluation program if NAVSTAR's benefits to civil aviation are to be fully considered.

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APRIL 30, 1979

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

B-164497(1)

The Honorable Thomas Harkin
Chairman, Subcommittee on
Transportation, Aviation,
and Communication HSE 03510
Committee on Science and Technology
House of Representatives

Dear Mr. Chairman:

As requested in the April 1978 letter from your predecessor, we have reviewed the Federal Aviation Administration's NAVSTAR evaluation program.

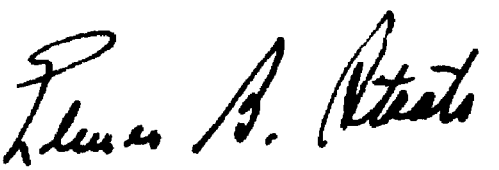
We obtained Federal Aviation Administration officials' informal comments and incorporated their comments where appropriate.

The report refers to the Department of Defense's consideration of diluting (or denying) the achievable accuracy of NAVSTAR's coarse signals for civil users and the possible referral of this matter to the National Security Council for a policy decision. It appears to us that such a decision should also involve the President's Domestic Policy staff to insure that civil interests, as well as security interests, are weighed. (See p. 13.)

We are sending copies of this report to the House and Senate Committees on Appropriations; the House and Senate Committees on Armed Services; the House Committee on Government Operations; the Senate Committee on Governmental Affairs; the House Committee on Public Works and Transportation; the Senate Committee on Commerce, Science and Transportation; the House Committee on Science and Technology; the House Committee on Merchant Marine and Fisheries; the Subcommittee on Transportation of the Senate Committee on Appropriations; and the House Committee on Ways and Means, Subcommittee on Oversight.

We are also sending copies to the Director, Office of Management and Budget; the Secretaries of Defense and Transportation; the Administrator, National Aeronautics and Space Administration; and the Assistant Secretary for Communications and Information, Department of Commerce.

Sincerely yours,



Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT TO THE SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND COMMUNICATION, HOUSE COMMITTEE ON SCIENCE AND TECHNOLOGY

SHOULD "NAVSTAR" BE USED FOR CIVIL NAVIGATION? FAA SHOULD IMPROVE ITS EFFORTS TO DECIDE

D I G E S T

NAVSTAR is a global satellite-based navigation system which the Department of Defense (DOD) plans to implement in the mid-1980s. The system is being designed to provide highly accurate position information anywhere in the world.

The Federal Aviation Administration is pursuing a ~~deliberate~~ program to determine ~~by fiscal year 1982~~ whether NAVSTAR could become the primary civil air navigation system. (See p. 5.)

If adopted for civil use, NAVSTAR could provide many benefits beyond those of current systems and also reduce Government costs through replacement of older systems. For example, NAVSTAR's expected high accuracy and coverage at any altitude would facilitate a nationwide system of area navigation, allowing aircraft to fly direct (shortest) routes and reduce holding times and pilot and controller workloads.

FIND/CON

According to a Federal Aviation Administration study, area navigation could save the civil aviation community some $780 million (in 1975 dollars), annually by 1984. This amount includes annual fuel savings of about 605 million gallons. (See pp. 2,3, and 22.)

But some uncertainties must be resolved before the Federal Aviation Administration and the civil community decide on NAVSTAR as the primary civil air navigation system:

--It must be clear that DOD will develop, test, and deploy NAVSTAR. (See p. 11.)

--The requirements of and potential benefits of NAVSTAR to the civil community must be clarified, and civil access assured to NAVSTAR's

high-accuracy signals under all conditions other than war or emergency when the President might close down U.S.-controlled radio emissions. (See p. 11.)

--Several cost, technical, and other questions need resolution. (See pp. 15 to 23.)

NAVSTAR's development and deployment is DOD's responsibility. FAA's program must resolve the problems of access to NAVSTAR's signals, cost, and various other technical questions. GAO believes the Federal Aviation Administration should improve its evaluation program by:

--Working as a team with DOD in defining unequivocal civil aviation requirements for all flight conditions. This should be done in a timely manner. (See p. 25.)

--Eliminating its alternative signal work and placing more emphasis on the radio frequency portion of the receiver, and (See p. 25.)

--Continuing efforts to reevaluate the cost of NAVSTAR, considering the potential benefits NAVSTAR would provide which current systems do not. (See p. 25.)

Until about mid-1978 it was widely assumed that DOD would always permit free access to NAVSTAR's signals. DOD is now considering techniques which would dilute one of the signal's accuracy.

GAO believes any significant dilution would greatly diminish, if not negate, many of NAVSTAR's benefits to the civil community. Therefore, the Federal Aviation Administration must make it clear to DOD what accuracies would be needed, not simply for enroute navigation, but for the whole range of flight conditions.

If the question of the dilution of NAVSTAR's achievable accuracy is adjudicated by DOD or a higher authority, the Secretary of Transportation should ensure that the Secretary of Defense or the President's Domestic Policy staff (as

appropriate) give careful consideration to the many potential benefits NAVSTAR could provide to the civil community and the impact any dilution of accuracy would have on such benefits. Also, the Secretary should ensure that position accuracies obtainable from other systems are fully recognized during deliberations. (See pp. 13, 25, and 26.)

NAVSTAR receiver costs will be a critical factor in whether a high percentage of the 180,000 general aviation aircraft owners accept NAVSTAR. However, growing congestion and rising fuel costs may motivate aircraft owners to procure more capable navigation equipment at higher costs if it can enhance both safety and operating economies. (See pp. 16 and 17.)

The Federal Aviation Administration needs to place a high priority on updating a cost study of alternative navigation systems. The study concluded that NAVSTAR, even though the least costly to the Federal Aviation Administration, is the most costly to users of systems as a whole.

GAO recognizes that the Federal Aviation Administration is beginning to expand the study to include other users and benefits. However, the initial study appears to overstate the cost of NAVSTAR to users because the Federal Aviation Administration did not consider the large number of potential marine and land users if NAVSTAR is made available to the civil community. Also, the Federal Aviation Administration did not consider the potential benefits NAVSTAR could provide which current systems do not. GAO believes that when the requirements of, and benefits to, all potential users are considered, NAVSTAR would be more appealing to the civil community. (See pp. 16 to 23.)

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ABBREVIATIONS

ARINC	Aeronautical Radio, Inc.
ATC	air traffic control
AVIONICS	A collection of electrical and electronic devices for use in aircraft. Examples: air-ground-air communications, navigation and instrument landing receivers, beacon transponders, radar altimeters, etc.
C/A	coarse component of NAVSTAR's signal
DME	distance measuring equipment
DOD	Department of Defense
FAA	Federal Aviation Administration
Loran	long range navigation
NASA	National Aeronautics and Space Administration
NAVSTAR	A DOD development of a navigation satellite system using timing and ranging. Also referred to as the global positioning system--GPS.
P	precise component of NAVSTAR's signal
SCI	Systems Control, Inc.
TACAN	Tactical Air Navigation
VOR	Very High Frequency (VHF) Omnidirection Range

CHAPTER 1

INTRODUCTION

The Federal Aviation Administration (FAA) is engaged in a program to evaluate the potential use of the Department of Defense's (DOD's) planned Navigation System Using Timing and Ranging (NAVSTAR) by the civil aviation community. In hearings on this subject before the House Subcommittee on Transportation, Aviation and Weather, House Committee on Science and Technology, FAA officials raised a number of uncertainties over eventual civil aviation use of NAVSTAR. As a result, the Subcommittee Chairman, in an April 12, 1978, letter asked us to review the adequacy and timeliness of FAA's NAVSTAR evaluation program. This report is our response to that request.

It should be recognized, as pointed out on page 10, that FAA's NAVSTAR evaluation program is still in its formulative stages. Therefore, this report should be considered a status report rather than a definitive evaluation of the adequacy of the program. We have included herein our observations and recommendations regarding the work that FAA has done or plans to do as of this time.

NAVSTAR is being developed primarily to enhance global weapons delivery. However, it will be able to provide highly accurate altitude, latitude, longitude, velocity, and time to users anywhere in the world. The system will allow positioning of air, sea, land, and space platforms prior to weapons launch, and may also provide midcourse corrections to missiles after launch. Additionally, NAVSTAR may be used for highly accurate worldwide positioning and navigation offering many benefits to the United States and the world community.

The NAVSTAR system is being designed to consist of 24 satellites and 6 or more ground control stations in the United States and its possessions. DOD estimates that about 27,000 U.S. military receivers of various models and complexities will be employed. Additionally, DOD expects that the North Atlantic Treaty Organization will also use NAVSTAR. Eight satellites will travel in each of three orbits. Each satellite will transmit two accurately timed ultrahigh frequency signals with one signal containing both a precise (P) and coarse (C/A) component and the other containing a precise signal component.

The ground control stations will track and control the satellites and determine the navigation data to be superimposed on the coded satellite signals. The ground segment will consist of four or more monitor stations, a master control station, and an upload station. Measurement data from each monitor station will be processed at the master control station and used to develop the satellite data which the upload station will send to each satellite for storage and transmission.

Air, marine, and land users of various classes will use the military receivers, depending upon user requirements, for navigation accuracy and relative immunity from jamming. Receivers picking up both the P and C/A signal components should be able to establish their 3-dimensional positions within about 10 meters, while those designed to pick up only the C/A component should establish user positions within 100 meters. User equipment for most civil applications would probably be functionally similar to the least sophisticated military receivers, referred to as the Z set, which sequentially acquires and tracks the C/A signal from four satellites.

CIVIL USE OF NAVSTAR

Although NAVSTAR is being developed as a military system, it may offer many cost and operational benefits to civilians. By eliminating some currently used systems, overall costs to civilians and the Government might be lowered. NAVSTAR could provide enough navigational accuracy to eliminate the need for FAA's Very High Frequency Omnidirectional Range (VOR), Tactical Air Navigation (TACAN), and distance measuring equipment (DME) facilities. These facilities provide the basic guidance for enroute air navigation in the United States. If coupled with a data link (a communications transfer facility), NAVSTAR has the potential, provided that safety is insured, to do the surveillance now done by FAA's enroute radar. This would eliminate the cost of this surveillance radar and give the added benefit of allowing nonprecision approaches to all airports.

The operational benefits of NAVSTAR primarily will result from its high accuracy, global coverage, and redundancy (high reliability). One benefit will be more efficient use of airspace, by permitting direct routes (termed "area navigation") instead of requiring the majority of controlled aircraft to fly in the currently established airways between

VORs. Other benefits may be increased safety, improved controller productivity, and improved airport utilization. Another feature is that NAVSTAR can give precise time which may be used to synchronize communications systems or collision avoidance systems.

Before FAA decides to designate NAVSTAR as the primary civil air navigation system, many potential problems must be resolved. In our March 1978 report, "Navigation Planning--Need for a New Direction," we addressed many of these problems and made recommendations to FAA for resolving them. FAA is pursuing an evaluation program to provide answers to these problems. However, FAA needs to improve its NAVSTAR program. The NAVSTAR program is described in chapter 2 of this report, and specific areas where we believe FAA needs to improve its NAVSTAR program are presented in chapter 3.

PREVIOUS RADIONAVIGATION STUDIES

We reviewed Government-sponsored radionavigation systems in four previous reports, which are summarized below to assist those seeking additional information on issues related to this report. On March 26, 1974, we issued "Summary of GAO Study of Radionavigation Systems: Meeting Maritime Needs." The study noted a proliferation of navigation systems has resulted from continuing to use old systems, even after new systems become available. This has happened because users do not want to replace their equipment and because Government planners have not reconciled 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 on September 13, 1974. The study described the uses of the radio frequency spectrum and emphasized the need for managing it prudently. 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.

The third report, "Navigation Planning--Need for a New Direction," was issued on March 21, 1978. The study noted that navigation systems continue to proliferate, adding to Government and user costs, and that NAVSTAR could replace numerous other systems at a savings. But, better Government-wide planning and management of navigation systems are needed if NAVSTAR is to benefit the Nation.

The fourth report was an October 23, 1978, letter to the Secretary of Transportation concerning FAA's planned modernization of its VOR, TACAN, and DME facilities. The report concluded that the Congress should provide FAA the fiscal year 1979 funds to proceed with the planned modernization program. The payoff date of the new equipment would be about the same time NAVSTAR would conceivably replace VOR-DME. The report also recommended that FAA should further evaluate the planned replacement of solid state DMEs, the replacement priority schedule, and the staff savings claimed due to the modernization program.

Our most recent report on NAVSTAR was issued January 17, 1979. It was entitled "The NAVSTAR Global Positioning System--A Program with Many Uncertainties" (PSAD-79-16) and concluded that a cohesive DOD cost/benefit justification is needed before the system is approved for advancement in the acquisition cycle.

SCOPE OF REVIEW

We reviewed FAA policies, procedures, reports, and records related to the VOR, TACAN, and DME modernization programs and studies on the civil use of NAVSTAR. We made our review at FAA headquarters, Washington, D.C., and obtained additional information from civil aviation user groups, Government contractors, and other Government agencies.

CHAPTER 2

FAA EFFORTS TO RESOLVE NAVSTAR ISSUES

FAA now sees potential benefits and problems associated with using NAVSTAR. The overall objective of FAA's NAVSTAR program is to determine, by fiscal year 1982, whether benefits outweigh limitations (or vice versa) and, if so, whether NAVSTAR should become the standard civil navigation system or an element of the system. The following sections discuss benefits and limitations of NAVSTAR as seen by FAA and are the subjects of FAA's NAVSTAR work.

BENEFITS AND PROBLEMS

FAA recognizes that NAVSTAR might provide a cost-effective navigation system over much of the Earth's surface and might be used by most civil aviation groups. One group which might use NAVSTAR is international air carriers. Since this group flys oceanic and low-density traffic areas, NAVSTAR would offer them more accurate navigation than currently exists and eliminate the need to carry inertial navigation systems which are costly to buy and maintain. A second group is special users, such as helicopters used in offshore oil exploration.

Another possible user of NAVSTAR is domestic air traffic. This group might use it in high-altitude routes to provide prescribed straight-line routing, much like that available from some systems today. FAA is examining the use of NAVSTAR for non-precision approaches. These approaches are landing approaches to airports using navigational aids which provide directional guidance and sometimes distance measurement but no angle of descent information. FAA does not see the use of NAVSTAR requiring changes to air traffic control (ATC) procedures. FAA notes that it is important that the navigation system does not put a constraint on the flexibility and procedures needed to serve users and achievable by the aircraft, the ATC system, and the airports.

Although FAA feels that NAVSTAR may meet the requirements of many civil aviation users, FAA believes that NAVSTAR must be examined to assure that it can provide an equivalent or better level of failure protection than current systems. FAA believes that NAVSTAR should not be considered as a replacement for VOR and DME until user equipment is available

for about $2,500 (in 1978 dollars). Other problems which FAA believes must be resolved if NAVSTAR is to form a part of its navigation system are discussed in detail on pages 6 and 7.

WORK SCHEDULED TO INVESTIGATE NAVSTAR BENEFITS AND LIMITATIONS

In our March 1978 report we recommended that the Secretary of Transportation defer unneeded spending on civil navigation systems which NAVSTAR might be able to replace. Since then, FAA has expanded its NAVSTAR program. FAA plans to spend about $1.9 million in fiscal year 1979 for the NAVSTAR evaluation program.

As initial efforts in the program, FAA defined the following technical, cost, and institutional problems which it believed needed to be resolved.

--Technical factors which relate directly to cost factors. Most of these factors and the cost factors are being considered in FAA's studies.

1. Accuracy and operational suitability of low-cost, single frequency user equipment.
2. Suitability for non-precision (instrument) approaches.
3. Radio frequency interference.
4. Multipath problems.
5. Suitability of aircraft antennas.
6. Time for initial acquisition of position.
7. Desirability of alternative signal formats.
8. Human factors which could result in errors.

--Cost factors:

1. Responsibility for operation and maintenance cost, distribution among civilian and military users, and international agreements on cost sharing.

2. Feasibility of low-cost avionics equipment.

3. Comparison to alternative systems.

4. Area navigation capability savings.

5. Joint operation with VOR-DME during a transition to NAVSTAR or as an independent backup system.

--Institutional factors which FAA feels will have to be solved before NAVSTAR will be accepted.

1. Availability of signals in time of stress.

2. Availability of precision signal to civil users.

3. Acceptability of U.S. military system for international civil aviation use.

4. Reliability.

5. Need for independent backup system.

6. Transition plan.

7. Position on having U.S. taxpayers provide key navigation services for worldwide users.

What FAA now sees as NAVSTAR's benefits and limitations may change as FAA studies produce new information. FAA organized its NAVSTAR studies into the following four categories. (See app. I for a more detailed description of the studies.)

--Cost analysis of a combination of navigation systems for civil aviation use. Studies under this category will assess NAVSTAR's cost to the civilian community, including the cost of equipment for the general aviation user and operation and maintenance costs of the system.

--Investigations of low-cost NAVSTAR receiver equipment. Work under this category will address the following six areas which have potential for low-cost general aviation equipment.

1. Study, design, and development of a NAVSTAR test receiver.

2. Evaluation of an alternative signal structure.

3. Technology forecasts.

4. Antenna studies.

5. Radio frequency interference studies.

6. Receiver costs.

--Investigation of NAVSTAR performance and civil aviation navigation requirements. This work will be an analysis of the civil aviation requirements needed under NAVSTAR. It will analyze:

1. Current system performance.

2. NAVSTAR navigation error.

3. Future civil aviation navigation requirements.

4. Future ATC requirements.

--NAVSTAR simulation and equipment testing. Before deciding on the suitability of NAVSTAR, FAA will perform simulations of flight scenarios using NAVSTAR receivers and simulators. These simulators will then be validated by FAA flight tests. NAVSTAR receivers being tested will include one developed for FAA and two developed for the military. FAA will also test the receivers using four satellites.

These studies will be used to determine how NAVSTAR could be used, such as in the ATC system, and the results will be used in the decisionmaking process on new navigation systems. FAA has scheduled its studies to correspond to the following timetable, which leads up to the 1982 decision point.

	Target date (note a)
Cost comparison (initial) of various combinations of navigation systems	May 1978 (actual)
NAVSTAR avionics cost estimate for the civil version of the military "Z" set (receiver)	June 1978 (actual)
Study of low-cost NAVSTAR avionics equipment	Sept. 1978 (actual)
Cost comparison (updated) of various combinations of navigation systems	Oct. 1979
Obtain the military "Y" and "Z" sets for tests	Oct. 1979
Analysis, design, and tests of low-cost avionics equipment	Jan. 1980
NAVSTAR equipment cost estimate using results of low-cost design and technology forecast	June 1980
Determine NAVSTAR performance/civil requirements	FY 1981
Study civil aviation navigation requirements	FY 1981
NAVSTAR simulations	FY 1981
NAVSTAR hardware tests	FY 1981
NAVSTAR flight tests	FY 1982
FAA expected civil aviation decision date (public hearings will be required)	FY 1982

a/These dates may change depending on the availability of NAVSTAR satellites, receiver equipment, NAVSTAR simulators, and DOD schedules.

Depending on the results of the studies, FAA plans to accomplish additional work after the 1982 decision. For example, although FAA plans to begin testing NAVSTAR equipment about mid-1979, this testing will extend beyond 1982. However, FAA anticipates that enough information will be available by 1982 to allow it to decide what role NAVSTAR will have. Much of FAA's NAVSTAR work is still in the initial planning stages, and final detailed work statements, in many cases, have not been formulated. With this latter point in mind, our next chapter suggests some improvements which we think FAA should make in its NAVSTAR program.

CHAPTER 3

IMPROVEMENTS NEEDED IN FAA'S NAVSTAR PROGRAM

A number of uncertainties must be resolved before FAA and the civil aviation community decide upon NAVSTAR becoming the primary civil air navigation system.

--First, it must be clear that DOD will successfully develop and test NAVSTAR and that its deployment is reasonably assured.

--Second, the civil community must be assured of access to NAVSTAR's signals affording mutually acceptable accuracies under all conditions other than war or emergency (in which the President might close down any or all U.S.-controlled radio emissions).

--Third, several cost, technical, and institutional (other than the above) questions need resolution.

The first item is within the province of DOD. FAA's responsibility should be to keep abreast of NAVSTAR's development progress as it conducts its studies.

Although FAA's program addresses the second and third items above, we believe the program can be improved if FAA:

--Works more closely (as a team) with DOD in defining unequivocal civil aviation requirements for enroute navigation, area navigation, and separation assurance (in short, the whole range of flight conditions). This should be done before decisions are taken to dilute the achievable accuracy of NAVSTAR's signals.

--Redirects some of its technical efforts.

--Places a high priority on updating its cost and benefit evaluations.

NAVSTAR CIVIL AVIATION REQUIREMENTS NEED TO BE ESTABLISHED

Before proceeding into its NAVSTAR program, FAA developed several issues it wanted to study. (See p. 6.) One of

the most important issues was whether navigational signals of adequate accuracy would be available at all times to civil users. FAA cannot consider NAVSTAR as the civil navigation system unless this question is answered affirmatively. Since DOD is not responsible for civil aviation policy, FAA must work with DOD to define the signal accuracy civilians will need to use NAVSTAR and conditions under which its signals might be denied. 1/

As noted on page 1, DOD is developing NAVSTAR with two signal codes. Use of both the P and C/A codes will enable users to determine a position within about 10 meters, while use of only the C/A code will enable the user to fix a position within 100 meters. DOD has not yet stated what accuracy will be available to the civil community. DOD maintains that, before a national policy on the accuracy and availability of the NAVSTAR signal is established, an agreed-to-set of civil requirements must be established and the signal needs of civilians must be determined.

FAA should not be entirely faulted for not yet quantifying civil aviation accuracy needs. Until recently (mid-1978), it was widely assumed that DOD would permit free access to the C/A signals which would allow position accuracies of 100 meters (or better) for all users. It was also assumed that users having the need for the greater accuracies (and more costly receivers) from both the P and C/A codes (such as commercial aircraft) would be permitted their use in normal circumstances. However, FAA should now place a high priority on identifying civil navigational accuracy requirements.

In commenting on our draft report, FAA stated that it is working on a memorandum of understanding with the U.S. Air Force for NAVSTAR work. It also advised us that the Department of Transportation is formalizing a memorandum of understanding for NAVSTAR efforts. Although these will probably improve the coordination between FAA and DOD, we

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1/Section 606 of the Communications Act of 1934 empowers the President, in time of war or emergency, to suspend any U.S.-controlled radio emissions deemed inimical to our national security. The act specifically mentions radiations which could be used for navigation. These could include NAVSTAR, VORTAC, Loran, or broadcast stations, among others.

doubt that such coordination will result in a meaningful consolidation (and reduction) of overlapping navigation systems. As stated on page 37 of our March 21, 1978, report, we believe that the President should establish within one of his executive offices an authoritative management focus for navigation matters. (In response to that report, the Office of Management and Budget set up an interagency navigation planning team.)

DOD may reduce NAVSTAR's accuracy for civil users

DOD has become concerned that potential adversaries could exploit NAVSTAR's signals, even in peacetime, to the detriment of our national security. As a result, DOD is considering techniques to dilute, or selectively dilute, the achievable accuracies of the C/A signal. We believe any significant dilution would greatly diminish, if not negate, many of NAVSTAR's benefits to the civil aviation and maritime communities. This may also render FAA's efforts meaningless.

Because of its importance, we have been told that this issue may be referred to the National Security Council for a policy decision. This gives us two concerns. First, it is not clear that the National Security Council, alone, is the proper forum for such a decision which would so heavily affect the civil community. It would appear that the Domestic Policy staff and the National Security Council should jointly consider this issue to insure that civil interests as well as security interests, are weighed. Second, will the Secretary of Transportation or the Administrator of FAA oppose any significant dilution of NAVSTAR accuracy? FAA officials advised us that they will make the Council aware of the impact that dilution of achievable NAVSTAR accuracy may have on the potential use of NAVSTAR by civil aviation, but beyond that they will not oppose any recommendation or decision by the Council.

Since DOD intends to resolve this question at an early date, we think it is important that FAA advise DOD of the signal accuracies civil aviation will need in a NAVSTAR (not VOR-DME) environment.

In this regard, we do not believe that DOD should overlook the high accuracies which an adversary could derive from signals not under DOD or U.S. control. For example, high 2-dimensional accuracies can be derived from two or more communications satellites in geostationary orbits.

Another important consideration

In August 1978 FAA gave DOD a draft of its projected civil aviation capability and requirements to be used in assessing civil navigation accuracy requirements under a range of flight environments. The draft was couched mainly in terms of existing capabilities as provided by VOR-DME. It should be noted that VOR-DME's accuracy is range dependent, and its coverage is altitude (user) dependent. The draft also stated some accuracies in terms of those being obtained by instrument landing systems and altimeters, which do not affect a comparison of capabilities of alternative navigation systems. The draft did not recognize benefits derived from NAVSTAR's accuracy and coverage as being independent of both range and altitude. Nevertheless, these parameters have led DOD to assume that the NAVSTAR C/A signals limited in accuracy to about 400 meters (versus an achievable accuracy of 100 meters or better) would satisfy a high percentage of civil aviation needs. Eventhough FAA advisory circular AC90-45A covers requirements for civil navigation, we believe that FAA's statement of requirements in VOR-DME terms is quite inappropriate in that with the 400-meter limitation, NAVSTAR can provide few capabilities beyond those of VOR-DME.

An FAA official said these DOD accuracy levels will probably be suitable for enroute domestic and oceanic navigation, but will not be acceptable for non-precision approaches because during these approaches the aircraft often maneuvers into a position which can cause one or more satellite signals to be lost or weakened, which can briefly degrade the accuracy. However, engineers knowledgable in NAVSTAR receiver designs said that proper filtering in the receiver could compensate for monetary losses of the signal. FAA believes that if a large error is injected into the signal and if an undetected failure occurs in the system, NAVSTAR may not provide a non-precision approach service. FAA plans to spend about $200,000 during fiscal year 1979 to answer this and related questions. FAA, however, does not plan to finish the signal requirements analysis until fiscal year 1981. Systems Control Inc. (SCI) is also doing a $36,000-study for FAA designed to refine the draft civil aviation navigation capability and requirements statements presented to DOD. This study was scheduled to be completed in February 1979.

FAA NEEDS TO REDIRECT SOME OF ITS NAVSTAR TECHNICAL EFFORTS

Some of FAA's technical efforts should be redirected if FAA is to determine whether NAVSTAR will be a suitable candidate for civil aviation.

FAA's study, design, and acquisition of a NAVSTAR receiver, which was listed as a low-cost receiver project, has recently been reoriented as a receiver analysis project. We see no basis to disagree with this project or FAA's technology forecast, antenna, and radio frequency interference studies. Each project will evaluate low-cost NAVSTAR receivers without getting into costing detail, which we feel should be deferred until FAA determines what features are needed in a range of acceptable NAVSTAR receivers.

FAA has identified several problems which NAVSTAR's use would inject into the existing ATC environment. FAA believes that a new navigation system should not be permitted to force changes to current aircraft operations and ATC procedures to overcome its own weaknesses (inability to perform like the existing system). We question the logic of this concern because the force-fitting of NAVSTAR into the mold of the limitations and procedures designed for the VOR-DME environment does not take advantage of the unique capabilities and added features which NAVSTAR may offer. Instead, FAA should evaluate NAVSTAR in its unique environment, with its enhanced technical capabilities, along with procedural changes which will be needed to exploit those advantages. An altitude-independent, highly accurate, area navigation capability would be an example. Once these evaluations are made, FAA should then analyze costs for a range of user equipment having the features needed under various flight demands.

We also feel that FAA should concentrate on developing those NAVSTAR components whose technology is relatively lagging. As an example, the microprocessing and software components of a NAVSTAR receiver need relatively little Government-supported technological efforts because they are being spurred by market demands. On the contrary, the L-band radio frequency receiver (analog) portion of the NAVSTAR receiver seems to be an area where the opportunities for Government-sponsored innovation and cost savings may be large, since market forces currently show little interest in this particular technology which is unique to NAVSTAR.

Although FAA agrees that work in this area should be done, FAA questions whether it is FAA's function to develop technology, or whether DOD, the National Aeronautics and Space Administration (NASA), or industry should undertake the technological development.

FAA's studies on alternative signal waveforms should be concluded at the earliest possible date. Although some studies have suggested that receiver costs might be reduced by changing the signal waveforms, we think that a recent 6-decibel gain in signal strength from the satellites (a four-fold improvement) will be of greater value in reducing receiver costs than could be realized from altering the signal structure. Furthermore, a change to the signals could lead to separate transmitters onboard the satellites (i.e., an exclusive civil transmitter). This, in turn, could create complications, such as additional power and weight and who would pay the added costs if a satellite had to be replaced because of failure in one segment, but not the other. FAA agreed and stated that its alternative signal waveforms study will not be extended beyond March 1979, as previously anticipated.

FAA SHOULD REEVALUATE ANTICIPATED NAVSTAR RECEIVER COSTS AND BENEFITS

Assuming that NAVSTAR is technically proven, will be deployed, and signals will be made available, FAA believes that the cost of user equipment will be the most important factor in determining whether the civil aviation community will accept the system. We agree with FAA that costs are important, but believe that user costs versus benefits--not necessarily costs alone--will be the determinant. For some users, cost might dominate for receivers which will do little more than current VOR-DME receivers. For others, added capabilities, such as area navigation, may offset some added costs. We recognize that a high percentage of the 180,000 general aviation aircraft (in 1978) are minimally equipped, and minimal performance receivers at minimal cost may appeal to many of their owners. However, growing air traffic congestion by the late 1980s may require that increasing amounts of national airspace be controlled. 1/ Also, rising fuel

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1/In late 1978, FAA announced its intent to lower the floor of controlled airspace from 18,000 feet to 10,000 feet in the east and California and to 12,500 feet elsewhere.

costs may motivate aircraft owners to procure more capable and more costly avionics to enhance both safety and operating economies.

In determining an acceptable range of NAVSTAR receiver costs by 1990, for example, we think that FAA should develop models of what typical civil aviation users' navigational needs will be by that time. These models should take into account equipment which might be mandated as well as those offering user economies. The models should then incorporate NAVSTAR receivers and components which duplicate or replace conventional equipment. When the results are compared in 1978 dollars, a range of NAVSTAR receiver cost objectives is derived. Although we have no basis to strongly disagree with FAA's assumption, we think some modeling, such as suggested above, may produce a range of receiver cost objectives in comparison to their technical features and added capabilities.

In an effort to compare Government, user, and total systems costs for a number of civil air navigation systems, including NAVSTAR, FAA had SCI make an analysis, "Economic Requirements Analysis of Civil Air Navigation Alternatives" (final report-Apr. 1978). The intent of the study was to develop a cost model and then enhance it to include benefits and a more sophisticated cost analysis. The conclusions, dependent upon costs, were quantified as being based upon the cost assumptions made in the report. Although we do not disagree with the methodology of the analysis, we believe that many of its conclusions are misleading because:

--It did not consider potential maritime NAVSTAR users.

--NAVSTAR receiver cost estimates might be overstated.

--NAVSTAR benefits over and above enroute navigation were not quantified.

All potential users not identified

The SCI study's conclusion that NAVSTAR would cost users more than other systems was based on a low cost NAVSTAR receiver costing $5,765. We believe this cost is misleading because the study did not consider the many non-aviation users who may take advantage of the system if and when it is available for civil use. The study's computer model is based on having 240,000 civil aircraft users by 1990. Using Loran-C

and Omega as a basis, we estimated that by 1990 NAVSTAR could have more than 396,000 U.S. maritime users. 1/ The study did not consider these 396,000 possible maritime users or the many probable foreign and potential land users. In short, the system could have well over 636,000 U.S. users by the 1990s.

As a result, the study did not fully consider a most important cost factor; namely production quantity and competition. FAA pointed out that (1) production quantity and competition are only two of the factors affecting price and (2) price evaluation can best be treated using sensitivity analyses. By this, FAA means that there will be a diversity of NAVSTAR receivers with varying capabilities. We agree but point out that any analysis of systems costs should consider all potential users of that system. FAA advised us that the study was to consider only the aviation users population; although the model was set up to do additional populations, if desired. The Department of Transportation's Research and Special Programs Administration is now expanding FAA's computer model to include other potential users, although it estimates that the study will take 2 years.

Projected receiver costs too much

We believe that the NAVSTAR receiver costs which were used in the study were too high. The predicted cost of the general aviation receiver is probably the most controversial issue related to NAVSTAR. With a potential NAVSTAR user population in the range of 636,000 units, it is obvious that user equipment costs will dominate any alternative systems costs comparisons, such as that done by SCI. For example, using the above population, a $1,000-change in NAVSTAR receiver costs will add or subtract $636 million to total systems costs (in constant dollars). Therefore, we believe FAA should place a high priority on identifying and using the most accurately predictable NAVSTAR receiver costs. We also believe, however, that any cost used should be for receivers whose performances will meet a range of civil aviation needs, as discussed on pages 16 and 17.

1/Our estimate was derived from the Coast Guard March 1978 Report "The Nationwide Boating Survey," plus figures obtained on commercial registry. See appendix II for derivation of this estimate.

FAA advised us that the $5,765 low-cost receiver was the best estimate that industry could give at the time of the study. Although we do not question this, it should be pointed out that the draft Aeronautical Radio, Incorporated (ARINC) research study, which estimated the cost of the low-cost NAVSTAR receiver to be $3,620, was provided to FAA only 3 months after the SCI study. We also realize that FAA intended the SCI study to give initial cost results and that it allowed FAA to reach conclusions about the significance of the transition period, the type of users affected, and the importance of the price of the low-cost receiver. However, as evidenced in congressional testimony and an FAA conducted seminar on NAVSTAR, we believe the SCI study caused a sense of aviation user rejection for NAVSTAR because of the huge user costs projected.

In July 1978, the ARINC Research Corporation prepared a draft report for FAA and estimated that a demilitarized Z set for civil application could be sold for $3,620. This cost was based on selling 3,000 units over 3 years and included a 100-percent distributor markup. FAA maintains that the $3,620 estimate may not be representative of a civil NAVSTAR receiver because the modified receiver used in ARINC Research's study may not meet FAA's instrument flight rule requirements.

A 1977 MITRE Corporation study projected an even lower cost. It concluded that a modified Z set could be built for about $2,800. As can be seen there are wide discrepancies in predicted receiver costs.

Distribution of operation and maintenance costs

One of the cost problems presented by FAA is the question of distribution of operation and maintenance costs between major system users. The following is taken from the Department of Transportation's National Plan for Navigation:

> "(k) To require users of Federally operated aids and services to bear their fair share of the costs for procurement, operation, and maintenance of navigation systems. For newly emerging categories of users, the aids and services will be provided without cost until it is determined that the following three conditions have been made:

(1) The growth in the number and diversity of the users of the system has stabilized, and,

(2) The number of such groups of users can be identified to permit the implementation of a procedure to collect the charges from all groups in a fair and equitable manner, and,

(3) The charges imposed upon each group will ensure the recovery of costs representing their individual fair shares of the total cost for procurement, operation, and maintenance of navigation systems."

Since NAVSTAR's coverage will be global, it would not seem equitable to tax U.S. users and equipment suppliers while foreign use could probably not be even measured, much less taxed. See paragraphs 2 and 3 above. In reply to a 1978 GAO letter on this subject, DOD stated that there is a precedent in the (free) use of U.S. military systems by the civil and international community. The Navy's Transit Satellite System, for example, has been used for many years by the world shipping community and others.

FAA maintains that at some future date, the Government may consider it viable to apply a user charge against users for the NAVSTAR space segment. In our opinion, some type of an international consortium would be needed if all users were obliged to pay for NAVSTAR in an equitable manner.

Other benefits not considered

Even though FAA realizes the problems of its present navigation system, it maintains that navigation is not one of the major problem areas and that most users are reasonably satisfied with current systems. Because of this, FAA feels that, even though NAVSTAR holds the promise of a single universal navigation system, NAVSTAR must provide better navigation service than present systems and provide it to as many users as possible at a cost no greater than present systems.

We agree that NAVSTAR should be able to provide a better navigation service than is now available. However, we do not agree that the cost of the system must not necessarily be greater than current systems. The cost of NAVSTAR should be weighed against the additional benefits it will provide. To compare the cost of NAVSTAR to the cost of VOR/DME without

considering NAVSTAR's many additional benefits offered is misleading. In our view, many users would purchase NAVSTAR because of its additional benefits over VOR-DME. FAA recognizes the potential benefits of a single universal navigation system, but to date it has been unable to identify the additional benefits to the full range of aviation users.

SCI's computer model cannot be used to quantify the benefits of the NAVSTAR system. However, the Research and Special Programs Administration's expansion of the model to include all users will also look at the additional benefits.

Among the aviation problems which NAVSTAR could potentially solve are

--better navigation and non-precision approaches to all airports,

--better navigation coverage for area navigation,

--precision navigation at very low altitudes where helicopters and short-haul aircraft operate, and

--a more accurate alternative for oceanic navigation.

Using current systems to correct these problems would require large additional system costs.

Better navigation and non-precision approaches to small airports

On March 22, 1978, FAA's Administrator noted that commuter aircraft service to small communities represented the most expansive growth trend in aviation and that it would be a major consideration in choosing the direction FAA takes in confronting aviation issues. FAA did not consider this factor in confronting the NAVSTAR issue.

Because NAVSTAR provides worldwide coverage and is altitude independent, it could give aircraft operating from many small airport areas the navigation and non-precision approach capabilities they do not have today. Using NAVSTAR for these functions could cost much less than expanding the VOR-DME system. Expansion would require leasing new facility sites, acquiring additional VOR-DME transmitters, and possibly replacing user equipment because of increasing congestion and the consequent need to convert to split channels. FAA acknowledges that this may be true; but states that the quality of

the NAVSTAR signal to be provided to the civil community will determine if and at what cost the non-precision approach capability can be provided.

Large potential savings from area navigation

In a January 7, 1977, FAA policy statement, FAA endorsed area navigation, recognizing the benefits that it offers to the aviation community. The statement also said, however, that FAA did not envision the mandatory equipping of aircraft with area navigation avionics in the near future.

A December 1977 FAA study noted that various aviation users would benefit from area navigation, primarily from the economic and operational advantages of using more efficient and ordered routes, both enroute and in the terminal area. The study noted that these benefits, which were heavily dependent upon the operational concept which was implemented, were derived through reducing route lengths, improving vertical flight profiles, reducing arrival holding delays, reducing pilot workload, and improving the availability and safety of instrument approaches. The study estimated total 1984 annual savings of $780.5 million (1975 dollars) for direct enroute and terminal areas. The annual savings were computed on the basis of fuel cost (605 million gallons), plus the flight time sensitive portion of direct operating cost and did not consider the worth of executive time in business aircraft operations.

FAA does provide limited direct clearances to fly, via prescribed area navigation routes, over the United States. These flights, however, are restricted to areas where VOR-DME coverage exists or at higher altitudes where inertial navigation is permitted.

In evaluating the costs associated with NAVSTAR, an FAA official noted, at an October 1978 seminar, that NAVSTAR, by definition, is an area navigation system and that the cost to provide that capability must be considered. What FAA fails to address, however, is that, with the predicted air-traffic growth, area navigation may be a future necessity. In addition, area navigation would result in economic and energy savings which may exceed the cost of NAVSTAR. It should be noted that the capabilities of area navigation and the potential savings are not attributable only to NAVSTAR but can be served by other systems if extended coverage were available.

However, if VOR-DME were to provide complete area navigation, the costs to the Government would increase.

Even though FAA has been working on area navigation since the early 1950s, no total area navigation plan, which is safe and economically feasible to both the user and Government, currently exists. We feel that FAA should develop the technology needed to adjust the ATC system to area navigation.

Precision-navigation at very low altitudes

According to the Helicopter Association of America, the U.S. civil fleet will include about 10,000 helicopters by the mid-1980s. The line-of-sight limitations for low-altitude flights and the unavailability of VOR stations in remote areas are deficiencies in the present VOR-DME system to which helicopter users are exposed. A representative for the Helicopter Association of America noted that "* * * to provide really reliable helicopter service to the many potentially desired landing-takeoff areas, all-weather or IFR 1/ capability is essential." NAVSTAR would provide all users with these capabilities at low altitudes worldwide.

Oceanic navigation

Currently, oceanic navigation is provided primarily by inertial navigation systems and the Omega navigation system, which are expensive. Also, these systems are less accurate than the predicted accuracies of NAVSTAR. Because of NAVSTAR's higher accuracy, its user community has the potential to be much larger than that of inertial systems or Omega, which could make it less expensive because of large production quantities as previously discussed.

1/Instrument flight rules.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

NAVSTAR may be able to provide civil aviation users with a better navigation and, ultimately, ATC system than is presently available. In addition, NAVSTAR has the potential to save Federal dollars by replacing other systems. However, before NAVSTAR can be adopted as a civil system, several events must occur. First, it must be clear that DOD will successfully develop and test NAVSTAR and that its deployment is reasonably assured. Second, the civil community must be assured of access to NAVSTAR's signals which will provide acceptable accuracies under nearly all conditions. Third, FAA must solve or reconcile the cost, technology, and institutional problems that it has identified for NAVSTAR.

Since DOD will determine the availability of the NAVSTAR signal for civil use, we believe that FAA should press DOD to make an early commitment on the system's availability and make sure that the navigational accuracy is acceptable. In order for DOD to make this commitment, it must know the NAVSTAR civil requirements. FAA is in the process of defining NAVSTAR civil requirements, but they will not be available until fiscal year 1981. Since DOD is planning to decide at an early date on civil aviation signal availability and accuracy, a 1981 decision from FAA may be too late. Therefore, we believe that FAA must accelerate its efforts to define NAVSTAR civil requirements and to get a commitment from DOD that they will be met.

Most of FAA's projects seem to be directed toward solving problems associated with NAVSTAR. One of these projects concerns the alternative signal waveforms to eliminate receiver complexity. This study should be terminated because recent unexpected increased signal strength from the satellites should help reduce receiver costs to a greater extent than changing the waveforms.

FAA appears to be taking a cautious approach in looking at the possibility of NAVSTAR for civil use. Even though FAA maintains that civil navigation needs are being met by VOR-DME, this system may not be suitable, considering the projected future increase in air traffic. The current ATC

system was designed around VOR-DME and is, therefore, constrained to structured routes except when limited high altitude area navigation routes are utilized. We believe that FAA should consider all of NAVSTAR's potential capabilities and develop an air-traffic system concept compatible with NAVSTAR, taking advantage of its inherent area navigation at all altitudes and other capabilities. Although NASA can contribute to this effort, we believe that FAA must take the lead role in this effort. It is most important, therefore, that FAA make its assessments in a manner which is completely impartial in appearance as well as in fact.

Probably one of the most important factors in determining if NAVSTAR will be acceptable to the civil community is the receiver cost. Although FAA made comparative analyses of the projected user costs of NAVSTAR, these costs appear to be overstated because FAA did not consider all users and the additional benefits of NAVSTAR beyond what VOR-DME offers. When these factors are considered, NAVSTAR may be more appealing to the civil community.

RECOMMENDATIONS

We recommend that the Secretary of Transportation direct the Administrator of FAA to intensify and redirect certain of FAA's efforts on the NAVSTAR program, specifically:

--Work more closely (as a team) with DOD in defining unequivocal civil aviation requirements for enroute navigation, area navigation, and separation assurance (in short, the whole range of flight conditions). This should be done in a timely manner.

--Redirect some of its technical efforts. Specifically, eliminate its alternative signal work and place more emphasis on the radio frequency portion of the receiver.

--Continue efforts to reevaluate the cost of NAVSTAR, as compared to the current systems, in light of the potential benefits NAVSTAR will provide above those of current systems.

Whether the question of the dilution of the accuracy of the NAVSTAR C/A signal is adjudicated by DOD or a higher authority, we recommend that the Secretary of Transportation ensure that the Secretary of Defense, or the President's

Domestic Policy staff (as appropriate), give careful consideration to the many benefits which NAVSTAR's high accuracy could provide the civil community and the impact upon such benefits which would result from any dilution or denial of its achievable accuracy; also that position accuracies obtainable from other systems are fully recognized in the deliberations.

AGENCY COMMENTS AND OUR EVALUATION

FAA's overall comments to our draft report were related to the signal availability for civil use, the requirements of any navigation system, and the capabilities of NAVSTAR, such as area navigation, which could be provided by other systems. FAA maintains that it cannot assume that the full capability of NAVSTAR will be made available to the civil community. FAA also feels that the accuracy of NAVSTAR is not the only consideration when evaluating it as a navigation system, but consideration must also be given to the requirements for safe navigation. FAA also emphasizes that area navigation is not unique to NAVSTAR and that many area navigation features can be provided by VOR-DME, Loran-C, and possibly other systems.

In addition, FAA agreed that NAVSTAR civil aviation requirements are needed and stated that it is trying to develop them. It also agreed that some of the technical efforts need to be redirected and advised us that the alternative signal work will be stopped. FAA also informed us that it is expanding the initial cost study of navigation systems to include other users and benefits.

If VOR-DME were to be used for area navigation by helicopters or fixed-wing aircraft operating at lower altitudes, a great many more stations would be needed. For example, aircraft at 10,000 foot altitudes can generally obtain VOR-DME coverage up to about 140 miles from the station, whereas at a 1,000-foot altitude, coverage is limited to about 45 miles (assuming no terrain obstacles). However, neither Loran-C nor VOR-DME can provide the high accuracies achievable by NAVSTAR.

We agree with FAA that there are valid economic, technical, safety, and institutional questions related to civil aviation use of NAVSTAR which need resolution. However, any significant dilution of NAVSTAR's achievable

accuracy for civil users would bring into question whether there would be sufficient value to the civil community for its adoption, and could make the other questions moot. Although we agree that DOD may be able to design a capability to vary the accuracies of the satellite signals, an early resolution of this matter may be vital to civil receiver design. In fact, receiver design itself can affect accuracies to users no less importantly than changes made to signals from the satellites. Since these matters are so interrelated, it seems essential that DOD and FAA reach a timely agreement on this key question of NAVSTAR signal availability and accuracy.

By its nature NAVSTAR is inherently an area navigation system. Its global coverage and its achievable high accuracies at any altitude can surpass any other system for such purposes. We agree that Loran-C could be expanded to provide total U.S. coverage for area navigation. Loran-C signals, like NAVSTAR's signals, are essentially altitude independent.

Because of the very large potential savings which an altitude independent area navigation system could provide, we believe that FAA should consider the potential of NAVSTAR for such a system and should also consider Loran-C for this purpose in the event it is determined that NAVSTAR will not meet civil needs. It appears that either system would be superior to VOR-DME for area navigation.

DESCRIPTION OF FAA NAVSTAR PROGRAM

Our review consisted of an analysis of the projects FAA has done or plans to do to determine if NAVSTAR can be used by the civil community. This appendix describes these projects.

COST ANALYSIS OF DIFFERENT COMBINATIONS OF NAVIGATION SYSTEM MIXES FOR CIVIL AVIATION

A full assessment of NAVSTAR's cost to the civil aviation community would include the cost of avionics for the general aviation user (the most significant cost) and operation and maintenance costs. To get this information, in fiscal year 1978, FAA had SCI analyze the cost to both FAA and the users of various combinations of civil navigation systems. The study concluded that NAVSTAR was the most costly alternative, even though NAVSTAR was the least costly to FAA.

FAA plans to spend about $230,000 in fiscal year 1979 on two NAVSTAR cost analyses. One is an $80,000 extension of the previous SCI study. The other is for a total civil NAVSTAR cost analysis to be performed by the Department of Transportation. FAA's share of this $400,000 project is $150,000. 1/ This study will differ from the 1978 work in that revised NAVSTAR receiver costs will be used and consideration will be given to benefits above the current VOR-DME system. This project will use the cost estimated by ARINC Research Corporation for a demilitarized NAVSTAR receiver--$3,620.

Low-cost receivers

The largest component of NAVSTAR costs to the general aviation user is the NAVSTAR receiver. Therefore, several of FAA's projects were intended to lower the projected cost of the NAVSTAR receiver. FAA anticipates spending $792,000 in fiscal year 1979 to study six low-cost receiver areas.

1/The remainder of this amount ($250,000) is being provided by the U.S. Coast Guard and the Research and Special Programs Administration.

Study, design, and brassboard

FAA had an interagency agreement with the Department of the Air Force, Space and Missiles Systems Organization, for a fiscal year 1978 preliminary design and performance analysis of a low-cost NAVSTAR receiver. The Air Force was to study and analyze the detection techniques of the NAVSTAR satellites' signals which would provide a capability equivalent to VOR-DME and area navigation. The initial results were published in a July 1978 report from Stanford Telecommunications Incorporated. The specific objectives of the report were to:

1. Analyze the C/A signal detection performance of a low-cost NAVSTAR receiver design.

2. Evaluate the potential position determination capability of the receiver design with respect to both 2D (latitude and longitude) and 3D (2D and altitude) navigational accuracy requirements for VOR-DME and area navigation.

3. Define experiments for validating the performance characteristics of the receiver design during the development phases of the NAVSTAR program.

The receiver used a single channel which acted in either a navigation or data mode. In the navigation mode, the receiver tracked the NAVSTAR C/A signal code and provided position update at a rate of 1 per second. The data mode would be used for 1 to 5 minutes every 0.5 to 2 hours to acquire navigation data from the satellites, for transitioning to new satellites, and/or updating the data for those satellites currently in use. Since position updates would then occur at a slower rate (1 per minute), a user would be provided with an override option for controlling entry into this mode.

The results of an analysis of receiver performance indicated that:

1. The basic design could provide excellent latitude and longitude positioning accuracy during level flight which more than meet the minimum area navigation and VOR-DME accuracy requirements.

2. Satisfactory performance could also be maintained during typical aircraft maneuvers in terminal areas

by tracking five satellites and/or temporarily using a receiver clock.

3. The accuracy required for fully satellite-based latitude, longitude, and altitude area navigation does not appear to be achievable with a low-cost receiver design.

FAA is concerned whether a one-channel receiver would be suitable for all general aviation operations in terminal areas. Indications are that the basic design would be suitable for visual flight rule operations, but the slower position update rate, while operating in the data mode, is a potential concern for instrument flight rule operations. Because of this, FAA has a $92,000-contract with Stanford Telecommunications Incorporated to extend its study and to modify its model by adding a second channel. Stanford will develop the hardware implementation concept and perform a navigation analysis. The navigation analysis is to provide the comparison over the same flight scenarios for four combinations of NAVSTAR receiver augmented equipment.

1. NAVSTAR receiver and encoding altimeter.

2. NAVSTAR receiver and encoding altimeter, airspeed, and leveling or turn rate.

3. Single strapdown inertial system and altimeter and NAVSTAR receiver for updating.

4. High quality inertial system and altimeter and NAVSTAR receiver for updating.

In a two-channel receiver, one channel is dedicated to sequential, high update-rate code tracking, and a second is devoted to satellite data gathering. The two-channel receiver will be used to track six satellites. The first channel will track five satellites, four of which will be acquiring and gathering data to get a horizontal position. The fifth satellite will be used to avoid position loss during a banking and turning maneuver by replacing any satellite whose signal is lost during the maneuver. The second channel is to gather the data and track a sixth satellite which it transfers to the first channel when one of the five satellites can no longer be used in the solution.

FAA also intends to build, based on the two-channel design, a receiver in fiscal year 1979. FAA will test the

receiver to determine whether it will operate under instrument flight rule requirements. To test the receiver, FAA will use a NAVSTAR simulator and, when available, the actual satellites.

Alternative/additional signal structure

Because NAVSTAR was developed solely for military operation, many of NAVSTAR's features were designed to enforce security and to be detectable in a hostile environment. These features add to the complexity and cost of user equipment. The use of alternative/additional signals for NAVSTAR transmission has been suggested many times. It has been said that lower cost avionics might result from the use of a different type of signal and that this saving might more than compensate for any increased satellite costs.

The Massachusetts Institute of Technology's Lincoln Laboratory is doing a NAVSTAR alternative/additional signal structure study for FAA. This is a 1-year study scheduled to end in March 1979. The study's objective is to assess whether the laboratory can identify alternative/additional signals which would greatly simplify signal processing and better fit the needs of civil aviation by lowering the cost of user equipment.

Initially, the study looked at a number of various approaches. The first-cut design effort showed the feasibility of a pulsed waveform approach and its suitability to a sequential NAVSTAR receiver. It was noted that considerable receiver simplification is possible and that some desirable operational features can be demonstrated. A drawback noted, however, was the potential of high-peak power interfering with the NAVSTAR signal which will be used by the military.

During fiscal year 1979, FAA plans to have Lincoln Laboratory continue the study and to focus on a few promising signal formats. FAA also anticipates having Lincoln Laboratory determine whether these alternatives/additional signals would be compatible with the military's NAVSTAR signal especially since an analysis is not being done in the present study. 1/

1/In commenting on our draft report, FAA officials stated that the alternative signal study will not be extended beyond March 1979 as previously anticipated.

Study of advanced technology for satellite-based navigation for civil aviation

FAA and NASA entered into an interagency agreement in June 1978 to develop advanced technology for use in satellite-based navigation for civil aviation. NASA's task is to develop the advanced technology for civil aviation user equipment, which includes:

1. Establishing a technology data base for cost/performance tradeoff studies.

2. Developing advanced technology user equipment to meet cost and performance goals.

3. Performing laboratory and flight tests, as necessary, to evaluate equipment performance.

Under the agreement, both FAA and NASA are responsible for:

1. Coordination with DOD and its elements involved in NAVSTAR and other interested Government agencies.

2. Plans for joint activities based on program needs and resources.

3. Experimental flight test programs, using both of their facilities to examine system performance in existing and proposed ATC environments.

Also, under the agreement, FAA must make sure that NAVSTAR is safe and effective and can be implemented and maintained within the basic requirements of the air transportation system at a reasonable cost.

FAA believes that the highest priority technology development efforts needed for this joint satellite program should include

1. Higher radiated power, lower cost satellites.

2. Advanced receiver technology.

3. Advanced aircraft antenna technology.

Antenna studies and design

FAA has assigned to the Department of Transportation's Transportation Systems Center the NAVSTAR antenna studies and design work to be done in fiscal year 1979. Under a previous contract with Ball Brothers Research Corporation, the Center had Ball Brothers' Aerospace Division (when developing a microstrip antenna for receiving and transmitting) consider the problem of simultaneous reception of the NAVSTAR signals. As a result, Ball Aerospace prepared a July 1978 paper on a low cost NAVSTAR antenna for general aviation.

The Ball Aerospace paper described a proposed study to determine electrical and mechanical characteristics of a NAVSTAR antenna for general aviation, especially for small aircraft. Ball Aerospace noted that it had developed more than 150 different antennas using microstrip technology, several of which were specifically designed for NAVSTAR users. One of the most important features of the microstrip antenna is its low profile which allows it to be mounted on the surface of an aircraft with hardly any additional drag. The antenna is rugged and reliable because it is a solid laminated structure with only one solder joint.

Ball Aerospace feels that the microstrip-crossed slot in the microstrip antenna is best suited for NAVSTAR. The advantage of the microstrip-crossed slot for NAVSTAR is that its radiation pattern is much broader, which eliminates the the need for complementary devices.

Another feature of the microstrip-crossed slot is the low cost process by which it is manufactured. Fabrication of the microstrip-crossed slot begins with the drilling of holes into circuit boards. (In large production these holes would likely be punched.) The holes are later plated and an antenna circuit is etched on the board using standard printed circuit techniques. Then a connector is mounted and a cover laminated to the top surface of the antenna. Ball Aerospace notes that these stages are all completed with minimum labor, making it possible for low production costs for the commercial market.

Even though the microstrip-crossed slot has been developed and preliminary testing completed, Ball Aerospace feels the following list of unanswered questions must be answered before the microstrip-crossed slot is ready.

1. How does the antenna perform on different aircraft, skin materials, wing positions, etc.?

2. Can performance generalizations be made to cover virtually all aircraft?

3. Will the received signal be modulated by the propeller?

4. Can performance be improved by finding an optimum location for the antenna?

5. What is gained by using two antennas?

6. What are the typical mechanical problems or are the mechanical problems unique to each aircraft?

7. How can costs be reduced and what will the final price realistically be?

The Center recently asked Ball Aerospace in its fiscal year 1979 contract to develop and test the microstrip-crossed slot for general aviation. Tasks required of Ball Aerospace include:

1. Complete development of a prototype microstrip-crossed slot antenna, including alternative mounting arrangements.

2. Fabricate and test two full-size NAVSTAR microstrip-crossed slot antennas.

3. Fabricate and test three-scale-model-microstrip antennas (1/7 scale) and compare pattern performance with that of the full size antenna in order to modify the model to match the performance of the full sized antenna.

4. Investigate potential mounting locations on typical aircraft.

5. Coordinate and assist in installing scaled antennas on the NASA-scale model aircraft at NASA's Langley Research Center. Scale model pattern tests shall be planned to yield maximum information about aircraft effects.

6. Provide four staff-weeks maximum of technical support during the testing at Langley Field, Virginia.

7. The results of the above tasks shall be incorporated in a final technical report, deliverable under the existing contract.

Radio frequency interference studies and measurements

Radio frequency interference of a NAVSTAR receiver in an aircraft includes aircraft-generated interference (e.g., spark plugs, radio transmitters, etc.) and interference produced by sources around an airport and during typical flight patterns and maneuvers (e.g., radio stations, radar, etc.). This internal and external interference is critical to receiver design but it should be noted that these noise problems have been prevalent in past development of radio navigation systems.

FAA's fiscal year 1979 plans include doing these studies for about $142,000 and having the Center make a 4-month study to address this subject. Most test equipment needed is in the Center's inventory, but the Center plans to lease a single engine general aviation aircraft and pilot to make a variety of flights (e.g., open country, large and small cities, airport vicinity, etc.) to cover the range of radio frequency interference expected. The Center plans to mount a NAVSTAR antenna at an optimum position on the aircraft and connect it to interference measuring and recording equipment in order to measure the radio frequency interference in the scenarios mentioned above.

The results of this study will provide information needed in the study design and brassboard work being performed by FAA. (See p. 29.)

Receiver costs

The most significant cost of NAVSTAR to civil aviation is the cost of the receiver. Assuming that technical and political problems are resolved, FAA believes that the receiver cost will determine whether the civil community accepts NAVSTAR.

In fiscal year 1978, FAA had ARINC Research Corporation, a subsidiary of ARINC, study costs of a modified military

NAVSTAR receiver for civil use. The study developed costs which, were reportedly, based on a uniform approach to cost estimating with the assistance of a pricing model. Packaging modification of the military receiver to meet the requirements of air carrier avionics standards and the less stringent environmental and packaging requirements of general aviation resulted in a navigation system that ARINC claims will perform similar to the military Z set.

In July 1978, ARINC released a draft report which estimated the cost of general aviation user equipment at $3,620 in 1977 dollars with zero inflation. The cost was based on a total production quantity of 3,000 units over a 3-year period. The estimated cost included a 100-percent distribution markup. The table below shows the major avionics equipment and related costs included in the draft ARINC study.

Equipment	Estimated user acquisition cost
Receiver	$2,746
Control and display	724
Antenna with preamplifier	150
Total	$3,620

During fiscal year 1979, FAA plans to have ARINC perform additional NAVSTAR work. ARINC will (1) determine the effect of alternative navigation systems on the ATC system by evaluating the accuracy of existing and proposed navigation systems (including NAVSTAR) to determine the effect of the expected system errors of each alternative on position accuracy during level flight and when maneuvering, (2) evaluate the impact of each alternative on separation standards, controller workload, and ease of operation, (3) identify systems which will work together without modifying ATC procedures, (4) develop minimum requirements for each class of users, and (5) develop proposed ATC procedures that could permit all alternatives that meet minimum aviation navigation requirements to be used.

Another task is to develop detailed estimates of the proposed avionics costs of Loran-C and NAVSTAR. Also, the probable costs of avionics, as a function of varying

predicted levels of technology advancement and production, are scheduled to be developed.

NAVSTAR requirements

Definition of performance factors

FAA currently has SCI making a study to define and quantify, if possible, those operational, procedural, and equipment (receiver, satellite, and ground system) performance factors which are currently undefined and which are a major factor in the overall definition of navigation performance. The factors used are to pertain to those parameters other than accuracy and shall be defined to enable their use in a comparative performance analysis in other than the VORTAC and non-direction beacon systems.

SCI is also required to accumulate a comprehensive data base on the quantitative performance of existing air navigation systems. The data resulting from this is scheduled to be used to complete a cost-benefit study of various present and future navigation systems.

Tasks being performed include

--a general statement of air navigation requirements,

--pilot navigation information requirements,

--a VOR-DME system error study, and

--a VOR-DME and non-direction beacon non-precision approach survey and tabulation.

Use of NAVSTAR in ATC

An evaluation of the potential impact of NAVSTAR on future oceanic aeronautical system improvement will be performed by Aerospace Corporation as an input to the international oceanic study program in which FAA is participating.

For the continental United States efforts, Aerospace is investigating NAVSTAR performance in the areas of signal/satellite availability and the effects of terrain shadowing and aircraft banking. In addition, Aerospace will provide technical support related to the operational evaluation of NAVSTAR receiver associated hardware.

The MITRE Corporation was contracted by FAA to investigate some satellite-aided ATC system concepts employing NAVSTAR, and in January 1978 MITRE submitted a draft report to FAA. The objective of the report was to investigate both technical and economic aspects of several alternative concepts for providing surveillance, navigation, and data communication functions in a future continental United States ATC system, involving the NAVSTAR. The effort was comprised of

--an identification of potential system alternatives and a definition of corresponding configurations for the air, space, and ground segments;

--technical analyses to assess preliminary requirements and performance capabilities; and

--a "first-cut" economic analysis to estimate whether potential benefits might be achieved in terms of Government and/or user avionics costs.

GAO ESTIMATE OF POTENTIAL

NAVSTAR USERS BY 1990

CENSUS AND 1990 PROJECTIONS

AVIATION (Table was taken from FAA records and forecasts.)

	1978	1990
Air carrier	2,500	3,700
Air taxi	8,000	13,500
Exec business	51,000	90,000
Personal/other	97,000	133,000
Total	158,500	240,200

(Note: Figures are for aircraft equipped with at least a single VOR receiver.)

A 52-percent growth in 12 years or an annual rate of nearly 4 percent.

SHIPS AND BOATS (Figures were taken from most recent Coast Guard report for fiscal year 1973 and 1976-77.) Growth projections are based upon recent trends, but factored downward to be conservative.

Type	1973	1976	1990	Annual increase	Annual assumed increase
	(in thousands of vessels)			(percent)	(percent)
Commercial (over 5 tons)	54.4	68.7	126.5	7	5
Pleasure boats					
Class A (under 16 ft.)	5,680	7,000	12,473	8-1/2	6
Class I (16 ft.-25 ft.)	3,550	5,257	12,780	17	10
Class II (26 ft.-39 ft.)	293	418	1,338	16	9
Class III (40 ft. and over)	68	78	132	6	4
Total	9,645	12,822	26,849		

APPENDIX II

ESTIMATE OF VESSELS CARRYING ELECTRONIC NAVIGATION EQUIPMENT

The chart below was taken from the U.S. Coast Guard March 1978 report "The Nationwide Boating Survey." (See p. 59 of the Coast Guard report.)

Table 33: Electronic Navigation Equipment

Type of navigation equipment	Do carry 1973 (note a)	Percent (note b)	Do carry 1976 (note a)	Percent (note b)
Radio direction finder	163	1.7	294	2.3
Loran A automatic	20	.2	48 ±18	.4
Loran A manual	39	1.4	97 ±26	.8
Loran C	3	.03	25 ±13	.2
Loran A-C	1	.01	25 ±13	.2
Omega	26	.3	35 ±15	.3
Radar	35	.4	114	.9
Total	287		638	

a/Entries in thousands.

b/Percent of that year's total boats.

Annotated to the right of the 1976 column are the statistical error probabilities associated with the sample size. The 1976 total of 638,000 boats so equipped represent 5 percent of the 12,750,000 recreational boats for that year.

If the direction finders and radars are deleted, 230,000 vessels (1.8 percent) carried Loran or Omega. To be conservative, let us assume that the census for Loran and Omega was errored on the high side by one-half the statistical probabilities. In such cases, the total population of boats using Loran and Omega would be reduced to 188,000 or 1.47 percent.

If we apply this 1.47 percent to the projected 1990 population of vessels, namely 26,849,000, 1/ 396,000 vessels could carry Loran or Omega (or transit).

Of the total projection of 396,000 vessels, it is estimated that by 1990 some 10,000 (including off-shore platforms) would be using transit (versus 4,000 users in 1978).

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Recap of users (1990)

Aviation	240,000
Maritime	396,000
Total	636,000

1/It should be noted that this figure includes some 126,000 commercial vessels not covered by the Coast Guard survey. It is likely that a high percentage of these vessels, which include fishing craft, would carry Loran.

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