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The NAVSTAR Global Positioning System is a satellite-based radio navigation system which will consist of 24 satellites, ground control equipment, and user equipment for a variety of Department of Defense applications. All military services are participating in the program with the Air Force acting as management executive. Program costs are estimated at $3.7 billion, including $1.5 billion for the Global Positioning System, $1.7 billion related to user equipment, and $0.5 billion for replenishment satellites. Findings/Conclusions: Delays due to technical problems in developing the satellite, control, and user equipment segments led to restructuring of the program in early 1977. In restructuring the program, the Air Force extended scheduled milestone dates, and since the restructuring, additional delays in satellite development increased the chance that Phase I completion might extend beyond the February 1979 timeframe. Since concept validation approval in December 1973, cost estimates have increased from $177.9 million to almost $400 million. The total program cost increased approximately $672 million more than originally estimated. This program cost estimate does not include costs for acquiring operational user equipment, replenishing satellites, space shuttle launches, and other related activities. The program's current phase could be delayed further. Any further slippage in satellite launches or a launch failure could lead to increased costs for the current phase and future program phases. (RRS)

6145

BY THE COMPTROLLER GENERAL

Report To The Congress

OF THE UNITED STATES

Status Of The NAVSTAR Global Positioning System

The Air Force is developing the NAVSTAR Global Positioning System for precise worldwide positioning or navigation. It will be used by the Air Force, Navy, and Army and possibly by military allies and civilians. Developmental problems have delayed the program about 1 year. Beginning in July 1978 through February 1979, the system will be tested to see how well it performs military applications.

PSAD-78-37
APRIL 25, 1978

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

B-163058

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

This report presents our views on the major issues of the NAVSTAR Global Positioning System. A draft of this report was reviewed by agency officials associated with the program and their comments are incorporated as appropriate.

For the past several years we have annually reported to the Congress on the status of selected major weapons systems. This report is one of a series of reports that we are furnishing this year to the Congress for its use in reviewing fiscal year 1979 requests for funds.

We made our review pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this report to the Director, Office of Management and Budget, and the Secretary of Defense.

Comptroller General
of the United States

COMPTROLLER GENERAL'S REPORT TO THE CONGRESSS

STATUS OF THE NAVSTAR GLOBAL POSITIONING SYSTEM

D I G E S T

The NAVSTAR Global Positioning System is a satellite-based radio navigation system. The system will consist of 24 satellites, ground control equipment, and user equipment designed for a variety of Department of Defense applications. Potential also exists for civilian and allied use of the system. Currently all military services are participating in the program with the Air Force acting as the management executive. Total program costs are estimated at $3.7 billion. This includes $1.5 billion for the Global Positioning System, $1.7 billion related to user equipment, and $0.5 billion for replenishment satellites. (See p. 23.)

The program, which was restructured in early 1977, is currently in the concept validation phase of the acquisition process. Testing to demonstrate system performance capabilities is scheduled to begin in July 1978, and is to be completed by February 1979. Initial operational capability is planned for 1985.

GAO's review included evaluations of system performance and testing, schedule milestones, and program cost estimates. The following matters were noted during the review:

--Developmental problems in ground control and user equipment delayed the anticipated completion of the concept validation phase by 1 year. (See pp. 7 and 8.)

--Since program restructuring, expected additional delays in satellite development and delivery dates of some critical user equipment have increased chances that the concept validation phase will not be completed by February 1979. (See pp. 8 and 10.)

Tear Sheet. Upon removal, the report cover date should be noted hereon.

--Since concept validation approval in December 1973, cost estimates have increased from $177.9 million to almost $400 million. Scope changes contributed largely to the increase. Total program cost increased to almost $1.5 billion, approximately $672 million more than originally estimated. (See pp. 18 and 19.)

--The program cost estimate does not include cost for acquiring operational user equipment, replenishing satellites, space shuttle launches, and other related activities. (See p. 23.)

The program's current phase could be delayed further. Performance of user equipment must be evaluated to support the recommendation to proceed into the next phase of the program, and the Air Force has experienced continual delays in the launching of satellites needed to perform the evaluation. Any further slippage in satellite launches or a launch failure would lead to increased costs for the current phase and future program phases.

The value of 4 years work and millions of dollars spent on the Global Positioning System will be determined during the coming year. Preliminary performance results for the one satellite in orbit and the one type of user equipment checked out are encouraging

The Global Positioning System should provide many advantages over contemporary positioning systems. What remains now is the need to continue and complete the concept validation on an orderly basis in order to demonstrate just how well the Global Positioning System works and to provide a baseline for future development.

A draft of this report was reviewed by agency officials and their comments are included as appropriate.

Contents

ABBREVIATIONS

DOD	Department of Defense
GAO	General Accounting Office
GPS	Global Positioning System
NASA	National Aeronautics and Space Administration
NDS	Navigation Development Satellite
NTS	Navigation Technology Satellite

CHAPTER 1

INTRODUCTION

Navigation systems are used to determine position, course, and distance to a destination. They are vital to air and sea travel and are used by the military for weapons delivery. The NAVSTAR Global Positioning System (GPS) is such a system.

SYSTEM DESCRIPTION

The GPS program is a multiservice, Department of Defense (DOD) program planned to meet the positioning and navigation requirements of the armed forces in the future. The GPS, a space-based radio positioning and navigation system, is being developed to provide accurate three-dimensional position and velocity information, together with system time, to suitably equipped users.

User applications include strategic, tactical, airlift, and helicopter aircraft; surface ships; submarines; land vehicles; and ground troops. Current projections of total needs within DOD exceed 27,000 units. Potential also exists for civilian and NATO/allied use of GPS.

The operational GPS system includes the following three major segments:

--A space segment consisting of 24 satellites which will broadcast position coordinates and timing information to users.

--A control segment to track the satellites and update position coordinates and timing information daily. It will include four or more monitor stations to track satellites, a master control station to determine signal accuracy, and an upload station to relay data to the satellites.

--A user segment consisting of devices to receive and process information from four satellites to obtain accurate position and velocity components for ground, aircraft, and ship users. The users' position and velocity are established by determining the distance from the known position of GPS satellites.

PROGRAM DESCRIPTION

The operational GPS is planned to evolve into three phases. Prior to each phase, DOD's Defense System Acquisition Review Council will review the program to determine whether sufficient progress has been made and achieved objectives warrant advancing the program into the next phase.

Phase I or concept validation is intended to be a minimum cost validation of the GPS concept. Overall Phase I objectives are to

--validate the GPS concept,

--select preferred equipment design,

--define system costs, and

--demonstrate military value.

The Phase I space segment is to consist of six satellites. This constellation is to provide (1) periodic (up to 4 hours a day), three-dimensional coverage over selected test areas in the western United States and (2) support to the Navy's Submarine-launched Ballistic Missile Improved Accuracy Program. The first satellite, launched in June 1977, is being used to investigate satellite survivability with respect to space radiation hazards and to determine the space stability of atomic clocks. The Naval Research Laboratory was responsible for the initial research and development effort to qualify advanced atomic clocks for possible use in GPS.

The remaining Phase I satellites, called Navigation Development Satellites (NDSs), are being developed and built by Rockwell International Corporation. Rockwell is under contract to build eight spacecraft; NDS-1 through 5 will be used in the initial Phase I network and NDS-6 through 8 will replenish primarily the first six spacecraft.

Phase I and II satellites will be launched from Vandenberg Air Force Base, California, using refurbished Atlas F launch vehicles acquired from existing Air Force inventories.

The Phase I control segment is being developed and fabricated by General Dynamics Corporation, Electronics Division, and will perform essentially the same functions described earlier for the operational system.

The Phase I user segment involves three contractors and several configurations of user equipment. Potential users were identified during GPS studies and were categorized in six classes based on operational needs. Some users require more precise navigation data and operate in more stringent dynamic environments than other users. Thus, the Phase I user equipment strategy is to investigate, test, and evaluate alternative design concepts to satisfy various user requirements.

Table 1 identifies Phase I user equipment, planned performance capabilities, potential military use, and development contractors.

Phase II, full-scale development, will involve (1) development, fabrication, and initial production of operational satellites to augment satellites launched in Phase I, (2) major development of the control segment, including the installation of a survivable, autonomous master control station in the continental United States, and (3) extensive development and initial operational test and evaluation of user equipment.

Phase III, production, will feature deploying the complete operational satellite constellation, upgrading and operating a back-up master control station, and producing and installing all classes of user equipment.

PROGRAM MANAGEMENT

On April 17, 1973, the Air Force was designated as the executive service for the GPS joint service program. The Air Force Systems Command supervises Phase I concept validation activities on the development and testing of the space, control, and user equipment segments. The Joint Program Office at the Space and Missile Systems Organization, El Segundo, California, manages the GPS program.

The program manager was delegated as the single manager to plan, organize, coordinate, control, and direct the GPS program. Within the Joint Program Office, the program manager is supported by deputy program managers from the Air Force, Navy, Army, Marine Corps, and the Defense Mapping Agency who represent their respective organizations.

PARTICIPATION BY OTHER ORGANIZATIONS

A major relationship exists between GPS and the Navy's Strategic Systems Program Office which is responsible for

Table 1

Phase I User Equipment

Equipment nomenclature	Performance capabilities	Potential use	Contractor
X set	High accuracy High dynamic Simultaneous 4-channel reception Auxiliary sensor option (X-aided set)	Tactical aircraft Missiles Submarines Aircraft carriers Helicopters	a/General Dynamics (Magnavox)
Y set	High accuracy Medium dynamic Sequential single-channel Auxiliary sensor option (Y-aided set)	Naval combat ships Refueling aircraft Helicopters	General Dynamics (Magnavox)
Z set (low cost)	Medium accuracy Medium dynamic	Naval support vessels Search and rescue and cargo aircraft	General Dynamics (Magnavox)
Manpack	Portable High accuracy	Ground troops Land vehicles	General Dynamics (Magnavox) Texas Instruments (Alternate Design)
High dynamic set	High performance 5-channel reception (alternate design-similar to X set)	Airborne applications	Texas Instruments
Jam resistant set	High performance 5-channel reception Directional antenna Doppler velocity compensation	Environments requiring high antijam characteristics	Collins Radio

a/Magnavox Corporation is under subcontract to General Dynamics for user equipment development.

the Submarine-launched Ballistic Missile Improved Accuracy Program. This action was the result of a request by the Director of Defense Research and Engineering that GPS be used to support the missile accuracy improvement program in lieu of the dedicated satellite constellation planned as part of the Satellite Missile Tracking system. The Navy plans to use this information to determine potential accuracy improvements that can be used in future submarine-launched ballistic missile systems.

The Army will participate in the GPS program by developing manpack, vehicular, and airborne user equipment. In Phase I, the Army will conduct limited operational testing of the manpack and support the Joint Program Office test program relative to other user equipment testing.

The Defense Mapping Agency and the National Aeronautics and Space Administration (NASA) are funding an item of hardware called GPS-PAC, which is being developed to provide more accurate positioning data for future NASA and DOD satellites.

The Air Force Armament Laboratory is also involved in developing and testing a GPS receiver for missile midcourse guidance application. Additionally, the Air Force Minuteman Missile Program Office is funding the development of a GPS receiver set for use in planned guidance accuracy tests.

RESULTS OF PRIOR YEAR REVIEW

This is our second report on the GPS program. In our March 1977 report, we recommended that the Secretary of Defense should

--review the program to determine operational system performance required by the Air Force, Army, Navy, and Marine Corps;

--establish testing criteria for evaluating the adequacy of the development progress and the readiness to proceed into the next development phase;

--assess the time allotted for the Phase I test program relative to the scope of testing needed to demonstrate development progress;

--explore alternatives to the planned solicitation of contractor proposals before testing, as a means of accelerating operational capability;

--determine the total cost for the development and related activities and the total estimated cost to provide an operational capability for all the military services; and

--assure program visibility by including it in the Selected Acquisition Reporting system.

The Director of Defense Research and Engineering agreed with the general intent of our recommendations, and stated that several corrective actions had been taken and additional actions would be taken at appropriate times.

CHAPTER 2

PROGRAM SCHEDULE STATUS

Since Phase I concept validation approval in December 1973, the GPS program has undergone several changes. Due to developmental problems, the program was restructured in early 1977 and the anticipated completion of Phase I was delayed by approximately 1 year. Continued delays in the satellite segment and critical delivery dates of certain types of user equipment increase the chances that Phase I may not be completed by February 1979, as currently scheduled. As a result of program delays and budget constraints, initial operational capability was changed from 1984 to 1985.

SCHEDULE CHANGES DUE TO PROGRAM RESTRUCTURE

The GPS program was experiencing the following problems in early 1977

--a delay in user equipment deliveries due to technical problems,

--a delay in master control station system development due to technical problems, and

--a shortage of funds in fiscal years 1977 and 1978 due to increased program cost estimates. (See ch. 4.)

The cumulative impact of the delays and cost growth resulted in a decision to restructure the program. In order to remain within the fiscal year 1977 program funding limitations, a partial stop work order was issued to industrial contractors to (1) defer the development and delivery of the Y set, manpack, Z set, and monitor stations, (2) delay the build-up of satellites NDS-7 and 8 and respective launch vehicles, and (3) reduce contractors' formal testing and documentation requirements on control and user equipment. Fiscal year 1978 funds planned for Phase II were rebudgeted for Phase I.

At the same time, but not directly associated with the cost growth, a change occurred in the method of developing Phase I and II user equipment. The original Phase II plan was to produce 1,000 Z sets to be installed in Air Force aircraft, thereby taking advantage of GPS 1981 limited operational capability. However, the Strategic Air Command, which

was to use 600 Z sets, decided not to install them due to a change in performance requirements. Therefore, due to the increased unit cost to the remaining users, the Z sets were not prototyped and operationally tested in Phase I, and Phase II Z set production was deleted. Additionally, this change eliminated the need for a 1981 limited operational capability, which enabled the Phase II satellite constellation to be reduced from nine to six satellites.

At the time of program restructuring, approval was granted to conduct a competitive user equipment predesign effort before full-scale development approval. By doing this, the Services plan to provide continuity between program phases, thereby avoiding the 6-month delay normally incurred after phase approval for soliciting and evaluating proposals and selecting contractors. The predesign effort is also intended to provide additional information on logistics concepts, modularity approaches, life-cycle cost estimates, and design-to-cost goals for the full-scale development decision.

Thus, in September 1977, requests were released to select four contractors for predesign efforts on Phase II user equipment. The objective was to increase competition and maximize alternative equipment designs for Phase II. Two competitive contracts will be awarded when Phase II is approved.

The program restructuring resulted in an increased estimate of program cost (see ch. 4) and extended schedule milestones. As shown in table 2 on page 9, the initial completion date of Phase I has been delayed from March 1978 to February 1979.

CHANGES TO PHASE I SCHEDULE REFLECT TECHNICAL PROBLEMS

Table 3 identifies the specific delays that have occurred in the Phase I schedule for the major milestones of the program.

Satellite segment

The NDS satellites have continued to experience significant schedule delays since program restructuring. The launch dates of the NDS satellites are currently the most critical factor in the GPS program. Until a four-satellite constellation is achieved, performance evaluation testing and demonstrations of GPS military value cannot be completed.

Satellite launches have been delayed because:

--Spacecraft subsystem and component manufacturers' technical problems resulted in late deliveries to Rockwell International, the prime contractor. Approximately 60 percent of the spacecraft effort was subcontracted.

--Rockwell identified poor workmanship and quality control in the manufacture of subsystems during assembly and integration testing.

Table 2

Comparison of Baseline Schedule Events with Current Schedule for the Overall Program

	Baseline schedule	Current schedule	Delay (months)
Phase I:			
Phase I approval issue	a/Dec. 1973	-	
Phase II user equipment requests (predesign)	Not planned	a/Sept. 1977	-
Acquisition Council's review for beginning Phase II	Mar 1978	Feb. 1979	11
Phase II:			
Production contract award for 2 sets	Jan. 1979	Deleted	-
Phase II user equipment (four contractors)	Not planned	Mar. 1978	-
Phase II user equipment final contract awards (two contractors)	Jan. 1979	Apr. 1979	3
Begin 2 set final operational testing	May 1980	Deleted	-
Begin field testing Phase II user equipment	June 1980	Mar. 1981	9
Begin operational master control and upload station operations	June 1981	June 1982	12
Issue Phase III user equipment proposal requests	Feb. 1982	Mar. 1982	1
Limited operational capability (nine satellites)	June 1981	Deleted	-
Acquisition Council's review for beginning Phase III	Jan. 1982	Aug. 1982	7
Phase III:			
Begin final operational testing of user equipment	Nov. 1983	June 1984	7
Initial operational capability (18 satellites)	Aug. 1984	Dec. 1984	4
24-satellite operation	Aug. 1985	Dec. 1985	4

a/Actual occurrence.

Table 3

Comparison of Baseline Phase I Schedule Events with Restructured and Current Schedule

Milestones	Baseline Dec. 1973	Restructure Apr. 1977	Current Nov. 1977	Delay (months) Since restructure	Delay (months) Total Phase I program
Satellite launches:					
NTS-2	Sept. 1976	a/June 1977	a/June 1977	-	9
NDS-1	Mar. 1977	Sept. 1977	a/Feb. 1978	5	11
NDS-2	May 1977	Dec. 1977	May 1978	5	12
NDS-3	July 1977	Feb. 1978	Aug. 1978	6	13
NDS-4	Sept. 1977	May 1978	Nov. 1978	6	14
NDS-5	Nov. 1977	July 1978	Feb. 1979	7	15
Control segments operational:					
Master control	Feb. 1977	a/Apr. 1977	a/Apr. 1977	-	2
Upload station	Feb. 1977	a/Apr. 1977	a/Apr. 1977	-	2
Monitor station	Nov. 1976	a/Dec. 1977	a/Dec. 1977	-	13
Begin user equipment deliveries:					
X set	May 1976	a/Mar. 1977	a/Mar. 1977	-	10
Y set	Nov. 1976	Sept. 1978	Sept. 1978	-	22
Z set	May 1977	July 1978	Aug. 1978	1	15
Manpack	Oct. 1977	June 1978	July 1978	1	9
Manpack (alt. design)	July 1977	Feb. 1978	June 1978	4	11
High dynamic set	Dec. 1976	Oct. 1977	Jan. 1978	3	13
Jam resistant set	May 1977	Feb. 1978	Apr. 1978	2	11
Testing program:					
Test range operating	May 1976	a/Mar. 1977	a/Mar. 1977	-	10
Begin field checkout of equipment	May 1976	a/Mar. 1977	a/Mar. 1977	-	10
Full performance evaluation tests (four satellites)	Oct. 1977	July 1978	Sept. 1978	2	11
Begin performance evaluation test (three satellites)	Not planned	Not planned	July 1978	-	-
TRIDENT support (six satellites)	Dec. 1977	July 1978	Feb. 1979	7	14
Phase I completion:					
Acquisition Council review for Phase II approval	Mar. 1978	Feb. 1979	Mar. 1979	1	12

a/Actual occurrence.

-New satellite testing standards imposed on GPS were more stringent than expected.

--Availability of test support equipment was limited.

As of November 30, 1977, NDS-1 satellite completed most testing and was being readied for shipment to Vandenburg Air Force Base. Officials stated that the current launch schedule is achievable, but it does not provide for any unexpected technical problems.

The testing program currently depends on the availability of the NDS satellites. Delays in beginning test range operations and field checkout of equipment were primarily related to problems with user equipment (X set).

Full system performance evaluation testing and military demonstrations cannot be completed until a four-satellite constellation is achieved. Based on the current schedule, an August 1978 launch of NDS-3 (the fourth satellite) would allow full performance evaluation testing to begin in September 1978. The current launch and testing schedule provides little room for further delay if all testing for Phase II is to be completed by the February 1979 time frame.

Studies by the Aerospace Corporation indicate that the probability of successfully launching three consecutive NDS satellites is only 53 percent. Because of the tight schedule and the risk of a launch failure, the Joint Program Office has developed a contingency plan whereby performance evaluation testing will begin when a three-satellite constellation is achieved. All navigation not requiring an altitude component can be done with three satellites. However, some of the most critical GPS demonstrations, involving airborne operations and demonstrating military value, require four satellites.

Despite the contingency plan, any delays in satellite availability will result in extending the Phase II decision date in order to complete all testing.

Although the satellites are the primary pacing items in the program, the delivery of user equipment is also critical to completing the scheduled testing. The delivery date of the Y set, scheduled for September 1978, is of particular concern. Program officials indicate that the schedule provides minimum time for field checkout and performance evaluation testing of the Y set.

OTHER SCHEDULE RISKS

Initially the GPS satellites were to be launched from two facilities at Vandenburg Air Force Base which would provide minimum turn-around time between launches. As GPS satellite launches slipped into 1978, they began to conflict with other DOD and NASA launches scheduled from the same facilities. As a result, GPS launches are now scheduled from only one of the two Atlas launch facilities. Turn-around time between launches is about 90 days.

GPS program officials do not expect launch conflicts to be a problem. However, beginning in May 1978 Vandenberg launch crews are to start a two-shift work schedule to meet the requirements of GPS, NASA, and other DOD launches. Thus, a delay in any of the launches appears to present some schedule risk to the GPS program.

In order to fully support the Navy's Submarine-launched Ballistic Missile Improved Accuracy Program, a six-satellite constellation was considered necessary by the end of Phase I. Based on the current launch schedule, the earliest the six satellites would be available is February 1979, some 14 months later than originally scheduled.

The current GPS launch schedule will not fully support Improved Accuracy Program desires for using the GPS-based Satellite Tracking system on the last few scheduled TRIDENT I land-launched flight tests. These desires were based on the fact that proving the capability of the Satellite Tracking system could be more easily accomplisned on these land launches than on subsequent launches from submarines where uncertainties in initial position and velocity would be much greater. The Director, Strategic Systems Projects, however, stated in November 1977 that verification of Satellite Tracking performance is believed to be possible in the submarine launch environment in the event that GPS satellites are not available to support the flat-pad (land) launches.

CONCLUSION

Delays due to technical problems in developing the satellite, control, and user equipment segments led to the program being restructured in early 1977. In restructuring the program, the Air Force extended scheduled milestone dates. Since the program was restructured, additional delays in satellite development has increased the chance that Phase I completion might extend beyond the February 1979 time frame.

Due to the restructuring of the program and subsequent budget constraints, the original 1984 Initial Operational Capability date was changed to 1985.

CHAPTER 3

PERFORMANCE STATUS, PHASE I, AND CONCEPT VALIDATION

The overall objective of Phase I is to validate the GPS concept--that a space-based navigation system can provide highly accurate position and velocity information. Performance evaluation testing of the system has not occurred; consequently, results of actual performance of GPS are not available. However, initial field checkout of the user equipment X set and navigation with the NTS-2 satellite (currrently in orbit) have shown encouraging performance

PERFORMANCE REQUIREMENTS

The GPS program is currently addressing requirements stated in the Air Force's Military Airlift Command Required Operational Capability document for a navigation system. However, except for unique Army user equipment, specific operational requirements for GPS have not been established. A Navy operational requirement in the surface mine countermeasures mission area has been established and other Naval operational requirements are being developed. According to program officials, specific Air Force and Marine Corps requirements for GPS are in the approval process.

Although specific performance requirements have not been established, the GPS program office developed performance goals (i.e., predicted accuracies) for GPS user equipment. Performance evaluations of the Phase I user equipment relative to program office goals are planned to begin in July 1978. While these tests will primarily evaluate user equipment, they will also demonstrate the space and ground control equipment because all segments must operate together properly.

TESTING PROGRAM

The Phase I GPS test plan presents an orderly approach for the demonstration of test objectives. The plan calls for tests that realistically approximate the operational environments expected to be encountered by military users, specifies that test results are to be fully documented, and entails active involvement of user services.

Scope of testing versus schedule risk

The GPS field test plan estimates the number of test missions required to satisfactorily achieve a 95-percent confidence level for each test. However, officials have stated that they expect dispersion of results; therefore, the actual number of test runs could increase or decrease depending on the diversity of initial test results.

Additionally, the GPS program manager, in coordination with the deputy GPS program manager, has the authority to vary the number of tests to maintain emphasis on the highest priority item. Although such flexibility may be desirable, it can also lead to tradeoffs between the number of test missions and schedule considerations.

The GPS program's performance evaluation testing had always been scheduled to begin when four satellites became available. However, due to schedule slips in the satellites, and in order to meet the February 1979 Phase I completion date, program management decided to implement a contingency plan, whereby, performance evaluation testing will begin when three satellites are available. Tests where the altitude component is known, such as at sea level, can be conducted with three satellites. However, many critical GPS tests, such as precision weapons delivery, and all operational demonstrations require at least four satellites. Increased reliance may be placed on three-satellite test results to supplement reduced test missions flown with four satellites.

TEST RESULTS

Because performance evaluation had not begun, no statistically valid test results were available at the time of our review.

GPS field checkout testing began in March 1977 when the first X set was delivered to the Yuma test range. At that time, only three ground transmitters were operating at the inverted range and it was not until June 1977 that four ground transmitters were operating. Hybrid navigation, using three ground transmitters and a NTS-2 satellite (currently in orbit), began in September 1977.

As of November 30, 1977, field checkout testing of X sets was continuing and testing had begun on X-aided sets (auxiliary sensors). No other user equipment had been delivered for testing.

Test results--X set

As previously mentioned, performance statistics will not be determined until performance evaluation testing begins. However, some early assessments can be made from available field checkout test data on the X sets. The performance of X sets steadily improved from March to November 1977. Performance toward the end of the period was better than program goals. For example, on November 9, 1977, a test mission, flown on a jet transport, generated navigation data with a total mean position error of 2.66 meters (8.72 feet)--well within the program Phase I goal of 12 to 20 meters (39.4 to 65.6 feet). Other recent X set tests showed similar results. By comparison, current navigation systems, such as inertial sets, provide accuracy only within 600 feet per hour.

Results of NTS-2 satellite

The GPS objectives of the NTS-2 satellite, launched in June 1977, were to (1) demonstrate the feasibility of using a cesium (atomic clock) frequency standard in future GPS satellites, (2) initially demonstrate the GPS navigation payload, and (3) function as one of the satellites in the GPS Phase I constellation. The GPS payload on NTS-2 has been operating since July 1977 and has been used to conduct field checkout tests on user equipment at the inverted range.

At the time of our review it was too early to call NTS-2 results conclusive; however, the following are some of the significant observations thus far in the mission:

--The navigation signal being transmitted was 80 percent stronger than estimated--this provides a higher margin in a jamming environment.

--NTS-2 has been uploaded from the ground, and the GPS monitor station has verified the data.

--Ten GPS user sets have locked onto the NTS-2 navigation signals.

--NTS-2 is providing data on natural radiation levels.

- - - -

The successful launch and operation of the NTS-2 satellite and the favorable preliminary results of the X set field

checkout testing indicates that some of the program's technical problems may be solved, although it is too early to judge GPS performance.

This year will be the year to prove the GPS concept. ... atellites meet current dates and perform as desired, performance evaluation of user equipment will begin in July 1978. Satisfactory performance on the various user equipment produced by several different contractors will establish the GPS concept beyond question.

CHAPTER 4

PROGRAM COST STATUS

Since GPS Phase I program approval in December 1973, DOD has directed several scope changes which have increased program cost. Additionally, technical problems which delayed Phase I have had a major affect on estimated program costs. This chapter describes the original and current program cost estimates and the reason for increased costs.

INCREASE IN PROGRAM COST ESTIMATES

Since 1973 program cost estimates for all three phases have increased by about $672 million. Most of the increase was due to changes in the program's scope. The following table shows the current program office program cost estimate compared with the baseline estimate for the three phases.

Table 4

Current Program Office Program Cost Estimate Compared with Baseline (millions) (note a)

	Baseline estimate Dec. 1973	Current estimate Oct. 1977	Increase
Phase I:			
Air Force	$131.9	$ 292.9	$161.0
Navy	29.2	80.4	51.2
Army	16.8	26.0	9.2
Total	$177.9	$ 399.3	$221.4
Phase II:			
Air Force	$245.6	$ 557.4	$311.8
Navy	7.8	42.3	34.5
Army	-	54.8	54.8
Total	$253.4	$ 654.5	$401.1
Phase III:			
Air Force	$383.1	$ 433.2	$ 50.1
Navy	-	-	-
Army	-	-	-
Total	$383.1	$ 433.2	$ 50.1
Program total	$814.4	$1,487.0	$672.6

a/Then-year dollars.

The following sections discuss the reasons for the increased cost estimates for each program phase.

PHASE I COST ESTIMATES

At the time of program approval, the Phase I cost estimate totaled $177.9 million in then-year dollars (or $148.1 in fiscal year 1974 dollars). Since that time, program costs have increased to $399.3 million.

In early 1977, the GPS program was in a cost overrun condition and a funds shortage was predicted. To remain within the fiscal year 1977 budget, the Air Force restructured the GPS program. The Air Force System Command directed a "Grass Roots" evaluation of the cost to complete Phase I. The study was completed in February 1977 and reflected the restructured program funding requirement for fiscal years 1977 and 1978 and a revised cost estimate to complete Phase I.

Table 5 shows the cost increases from the original baseline through current estimates by program segment and the nature of the increases.

Table 5

Changes From Baseline Cost Estimate for Phase I

Segment	Baseline estimate Dec. 1973	Escalation	Added scope and tasks	Cost increase at restructuring	Current approved program Oct. 1977
	(millions)				
Spacecraft-support	$ 71.9	$13.4	$ 82.9	$ 3.7	$171.9
Launch vehicles	22.0	6.1	18.2	6.4	52.7
Control-user	40.3	7.6	46.7	36.5	131.1
Testing	9.4	1.9	.3	?	11.8
Technical support-studies-other	4.5	.8	10.8	12.2	28.3
1977 escalation index changes	-	-	-	-	3.5
Total	a/$148.1	$29.8	$158.9	$59.0	$399.3

a/$177.9 in fiscal year 1977 dollars.

The following sections explain the significant changes as shown in table 5.

Spacecraft/support

The scope additions are primarily attributed to (1) the procurement of four additional NDS satellites to support the Navy's Improved Accuracy Program, (2) the Navy's planned development of NTS-3, and (3) development of an advanced atomic clock having a higher level of stability to be used on NTS-3. The cost increase at restructuring represents the estimate to cover technical and schedule risks and incentive fees needed to complete the effort. The satellites are being procured under a fixed-price incentive contract with the Government sharing in 80 percent of the increase in target costs up to the contract ceiling price.

Launch vehicles

The scope change involved an additional four launch vehicles relative to the increased NDS satellite procurement. The cost increase involved improvements to the Atlas-F launch vehicle required by an Air Force reliability improvement program and a contingency for launch schedule delays.

Control/user equipment

The added scope changes involve contracts awarded to Texas Instruments and Collins Radio for alternate designs of user equipment. Additionally, the Navy increased the funding of user equipment integration efforts.

Approximately $19.8 of the $46.7 million increase in scope was held in reserve for expected cost growth in control/user equipment development. The realization that the reserve would not be adequate to cover increasing costs from delays in control/user equipment development was a major factor leading to program restructure. (See ch. 2.) Subsequently, an additional $36.5 million was added by transferring funds from Phase II to Phase I to insure completion of the effort.

Phase I cost outlook

Program officials stated that the current budget adequately covers all contracts and planned activities. As of November 1977 the budget contained about $9.[illegible] million in an unallocated risk reserve in the event of further delays caused by unanticipated problems.

The largest program risk is satellite launches. Each successful NDS launch will release a portion of the reserve for use in other risk areas. Program officials advised us that the current budget could support up to a 90-day delay in satellite launches. However, if the program is delayed beyond that or a launch failure is experienced, additional funding may be needed.

PHASE II AND III COST ESTIMATES

The following table provides a summary of program office Phase II baseline and current cost estimates.

Table 6

Changes From Baseline Cost Estimate for Phase II (millions) (note a)

Segment	Baseline Dec. 1973	Current Oct. 1977
Satellite	$126.2	$256.9
Launch vehicle	44.3	49.4
Control	19.7	87.3
User equipment/testing	55.4	136.5
Technical support/other	7.8	-
Military construction	-	25.8
Service unique user equipment development, integration, and testing:		
Navy	-	42.3
Army	-	54.8
Total	$253.4	$654.5

a/Then-year dollars.

The increased Phase II cost estimate is primarily due to (1) developing a space shuttle optimized prototype satellite with increase life from 4.5 to 7.8 years, adapting the satellite for space shuttle launch, nuclear and laser hardening, and survivability and vulnerability evaluation, (2) redesigning user equipment, more extensive testing, and involving two rather than one contractor in the development of user equipment, (3) developing an autonomous GPS communication and control facility because existing systems,

originally planned to be used, cannot handle the extensive workload anticipated by the GPS system, (4) constructing military facilities, and (5) increasing unit price of satellites due to procurement of two less satellites.

Additionally, the original Phase II program did not include funds for other services' participation; however, the Army and Navy decided subsequently to fund unique development, integration, and testing to assure that GPS user equipment will meet their needs.

The following table provides a breakout of program office Phase III baseline and current cost estimates:

Table 7

Changes From Baseline Cost Estimate for Phase III (millions) (note a)

Segment	Baseline Dec. 1973	Current Aug. 1977
Satellite	$219.2	$408.3
Launch vehicle	110.6	-
Control	23.6	21.9
Testing	23.5	-
Technical/other	6.2	-
Military construction	-	3.0
Total	$382.1	$433.2

a/Then-year dollars.

Generally the cost increase in Phase III is attributed to (1) increased unit prices of satellites due to the improvements in Phase II (see p. 21), (2) the addition of two satellites to the planned procurement, and (3) final modification of the control segment.

Originally the Phase III satellites were to have been launched by a conventional launch vehicle, however, present plans call for them to use space shuttles. GPS program officials stated that they were directed to remove approximately $81.8 million for space shuttle launches from the Phase III cost estimate, and that launch funding will be included in a newly established Defense Space Shuttle Program budget.

Funding for testing was deleted from Phase III and was included in the Phase II current estimate to support a planned increase in the testing effort.

Phase III cost estimates reflect Air Force participation only. Army and Navy funding for Phase III would add to total program cost. Additionally, Phase III estimates excluded the costs to produce user equipment, primarily because the quantity of user equipment cannot be accurately determined at this time.

TOTAL PROGRAM COST

Current estimates indicate that the total GPS Phase I, II, and III costs are approaching $1.5 billion. (See table 4.) Total program cost estimates do not include (1) acquisition, installation, and operation of Phase III user equipment, estimated at about $1.7 billion for a DOD user population of 27,000, (2) acquisition of satellites needed to replenish a 24-satellite constellation, estimated at $483 million through fiscal year 1995, and (3) the space shuttle launch cost estimate of $81.8 million. Considering all of these factors, the total cost of GPS could exceed $3.7 billion.

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The Phase I cost estimate to validate the GPS concept has increased from $178 million to almost $400 million. Additionally, some potential exists for further cost increases. In the event of significant delays in the satellite launch dates, a launch failure, or a delay in user equipment deliveries, the date of Phase I completion may have to be extended, thus increasing costs.

Both Phase II and Phase III of the program have already shown large increases in cost estimates although they are in the planning stages.

Total Phase I, II, and III cost estimates increased to almost $1.5 billion, approximately $672 million more than originally estimated.

The above cost estimates do not include all costs to have an operational GPS. We believe that the program cost estimates should include the significant costs of acquiring operational user equipment and replenishing satellites, launch services, and other related activities.

Without complete program cost information, officials cannot assess the impact their decisions will have on the future of the program and funding outlays for an operational system.

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