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September 1987

SATELLITE ACQUISITION

Global ... ing System ... tion Chang... dent

GAO

United States
General Accounting Office
Washington, D.C. 20548

National Security and
International Affairs Division

B-228776

September 30, 1987

The Honorable Bill Chappell, Jr.
Chairman, Subcommittee on Defense
Committee on Appropriations
House of Representatives

Dear Mr. Chairman:

As requested in June 1986, we reviewed the NAVSTAR Global Positioning System (GPS) to determine how the Air Force modified its acquisition approach for this system following the space shuttle Challenger accident. We briefed your representatives on the status of our review on September 5 and December 9, 1986, and February 24 and August 6, 1987. This letter summarizes the information provided during the briefings. These issues are more fully discussed in appendixes I to IV.

GPS is a space-based radio navigation system which is expected to provide (1) highly accurate three-dimensional positioning (altitude, latitude, and longitude) and time information to authorized military users anywhere in the world, (2) nuclear detonation detection information, and (3) less precise positioning and navigation information to the U.S. civilian community and other nations. The system was designed to enhance any mission that requires precise navigation or timing, such as tactical or strategic weapons delivery. The three services have been developing GPS since 1973, with the Air Force as the executive service for the acquisition. It was scheduled to be fully operational by December 1988; however, with the Challenger accident on January 28, 1986, and subsequent launch delays, GPS is not expected to be operational until September 1990.

ALTERNATIVE LAUNCH CAPABILITY DEVELOPED

At the time of the Challenger accident, the GPS program had launched 11 developmental (Block I) satellites, was completely dependent on the space shuttle for launching 28 heavier operational (Block II) satellites, and planned to launch the first one in January 1987. Immediately following the accident, the Air Force began planning for an alternative launch capability. In October 1986, the National Aeronautics and Space Administration (NASA) issued a revised space shuttle launch schedule, which reduced the number of shuttle launches for GPS from 28 to 16, and slipped the date for the first shuttle launch from January 1987 to June 1989.

In January 1987, the Air Force awarded a contract to the McDonnell Douglas Corporation to build and launch 7 medium expendable launch vehicles (MLVs), with options to purchase up to 13 more. With the plan to use as many as 20 MLVs for GPS launches, the Air Force reduced from 28 to 8 the number of GPS satellites it planned to launch on the space shuttle. The Air Force plans to launch the first of the 28 GPS Block II satellites on an MLV in October 1988.

SOME PROCUREMENTS STRETCHED OUT

At the time of the Challenger accident, the GPS program was in the production and deployment phase and a number of major contracts had been awarded. Between May and August 1986, the Air Force began to review these contracts to determine which could be slowed or stopped. For example, it stopped work on a few items having limited life parts, such as orbit insertion subsystem motors, and batteries that would age once electrolyte was added. In April 1986, it also directed Rockwell International Corporation to minimize expenditures under the satellite production portion of the contract for launch and orbital operational support.

The Air Force has decided to stretch out the production of the 28 Block II satellites. This is the largest of the GPS Program Office contracts, valued at about $1.269 billion as of April 22, 1987, to produce the satellites and another $48.6 million for launch and orbit support services. This decision was based on an Air Force directed study, which began in June 1986, conducted by the GPS contractor, Rockwell, to determine how to best complete the production contract. Based on the results of this study, the Air Force reported to you in February 1987 that it had decided to stretch out production to make satellite deliveries more compatible with estimated launch dates.

Because the Air Force is stretching out production of the Block II satellites, it has begun steps to reduce funding on the existing contract by an estimated $59 million. It also has to decide what effect the stretch out will have on the need for $48.6 million in the contract for launch and orbit support services.

Work on another major GPS contract has been partially stopped and the contract will be restructured to buy fewer items. This was a $170 million contract for 28 upper stage boosters, called Payload Assist Module, Delta Class II (PAM-DII), used to lift the satellites from the space shuttle's 160-nautical mile orbit to GPS' required orbit of about 10,900 nautical

miles. The Air Force no longer needs as many PAM-DIIs because of the reduced number of satellites scheduled for launch on the space shuttle and because the MLV uses a different upper stage booster. At the time the contract was stopped, the Air Force had obligated funds for 16 boosters. GPS program officials told us that the Air Force has decided to take delivery of all 16 boosters. The Air Force intends to use eight for the planned space shuttle launches. It has not yet decided what to do with the other eight.

Because the contract was partially canceled, the Air Force is in the process of determining how to use the $19.8 million that was authorized in fiscal year 1987 to buy the canceled upper stage boosters and how much of nearly $27 million for launch and orbital support services will not be needed. In addition, the change to this contract means that $17.9 million which the Air Force budgeted for upper stage booster production during fiscal year 1988 will not be needed.

REPLENISHMENT SATELLITE PLANS POSTPONED

Delays in launching the 28 Block II satellites also means that the Air Force will postpone a planned buy of 20 Block II-R replenishment satellites needed to maintain the constellation.

The GPS Program Office's estimated need date for the Block II-R satellites has slipped 3 years. Before the Challenger accident, the Air Force planned to begin buying the 20 replenishment satellites in fiscal year 1988 in order to begin launching them 4 years later, in fiscal year 1992. After the delays in launch, the Air Force established a 6-year program with 3 years of satellite hardware development and testing starting in 1989, and it expects to launch the first Block II-R satellite in October 1994.

The launch date for Block II-R satellites was determined by a statistical model projection based on planned design life of 7.5 years, which has been extended to an estimated 10-year life because of Block I experience to date, and modified by expected operational and launch failures. The estimated 10-year life for Block II satellites would require a Block II-R satellite to be launched in October 1994, or only 6 years after launch of the first Block II satellite in October 1988. However, if the 28 satellites can maintain the 18 satellite Block II constellation for 10 years, the first Block II-R satellite would not be needed in orbit until October 1998, or 4 years after the October 1994 date the Air Force is projecting.

The Air Force plans to start Block II-R production in fiscal year 1990. By then, more current information on Block II performance will be available to program officials because the Air Force expects to have 10 Block II satellites in orbit before the end of fiscal year 1989. If early Block II satellites meet or exceed performance expectations, program officials will have time to reconsider the start date for Block II-R production to avoid acquiring them too soon and incurring unnecessary storage costs.

MINIMUM USER EQUIPMENT IMPACTS TO DATE

The user equipment segment of the GPS is intended to provide authorized military users with capabilities to receive precise, continuous, all weather, common-grid worldwide positioning, navigation, and time reference information. The user equipment consists of 1-, 2-, and 5-channel radio receiver sets that will be used on military platforms and by individuals to convert satellite transmitted signals into useful position, navigation, time, and weapon delivery information.

GPS user equipment is being developed and tested and a decision to move to full-rate production is scheduled for September 1989. At the time of the Challenger accident, the full-rate production milestone had slipped due to technical problems. Subsequently, the full-rate production milestone slipped further because the technical problems have not been solved. Testing must be completed before full-rate production can begin. The Air Force told us that it has implemented programs to address the technical development problems and that completion of user equipment testing also required a Block II operational satellite in orbit. Because development is almost 3 years behind schedule, the Challenger loss caused no further adjustment to user equipment production.

Of the 27,157 user equipment sets the Air Force is buying from 1986 through 1999, only about 8 percent will be available by September 1990, when the GPS satellite constellation is scheduled to become fully operational.

The Air Force plans to spend about $1.43 billion on user equipment during fiscal years 1989 to 1992. The Air Force selected its user equipment design in 1985. Since then equipment has become available from other manufacturers that is advertised as smaller, lighter, and less costly. The Air Force plans to incorporate technology changes into user

equipment sets through a preplanned product improvement program over several years beginning in 1989. Program officials said that they are aware of the new technology but that significant per unit cost savings would have to be available in the newer sets to warrant a procurement change. However, they are starting an evaluation of commercially available 1-channel sets to determine if they can meet user needs and potential cost savings.

We discussed the contents of this report with program officials and have included their comments where appropriate. The objective, scope and methodology of our work are described in Appendix I.

Unless you publicly announce its contents earlier, we plan no further distribution of this report until 30 days from the date of the report. At that time we will send copies to interested parties and make copies available to others upon request. If you have any questions, please call me on 275-4841.

Sincerely yours,

Richard Davis
Associate Director

Contents

TABLES

ABBREVIATIONS

DSCS	Defense Satellite Communications Systems
DOD	Department of Defense
ELV	expendable launch vehicle
GAP	Generalized Availability Programs
GPS	Global Positioning System
MLV	medium expendable launch vehicle
NASA	National Aeronautics and Space Administration
PAM-DII	Payload Assist Module, Delta II Class

THE NAVSTAR GPS

BACKGROUND

The NAVSTAR GPS is a space-based radio navigation system which is expected to provide (1) highly accurate three-dimensional positioning (altitude, latitude, and longitude) and time information to authorized military users anywhere in the world, (2) nuclear detonation detection information, and (3) less precise positioning and navigation information to the U.S. civilian community and other nations. The system was designed to enhance any mission that requires precise navigation or timing, such as tactical or strategic weapons delivery.

The services have been jointly developing GPS since 1973, with the Air Force as the executive agency for the acquisition. It consists of:

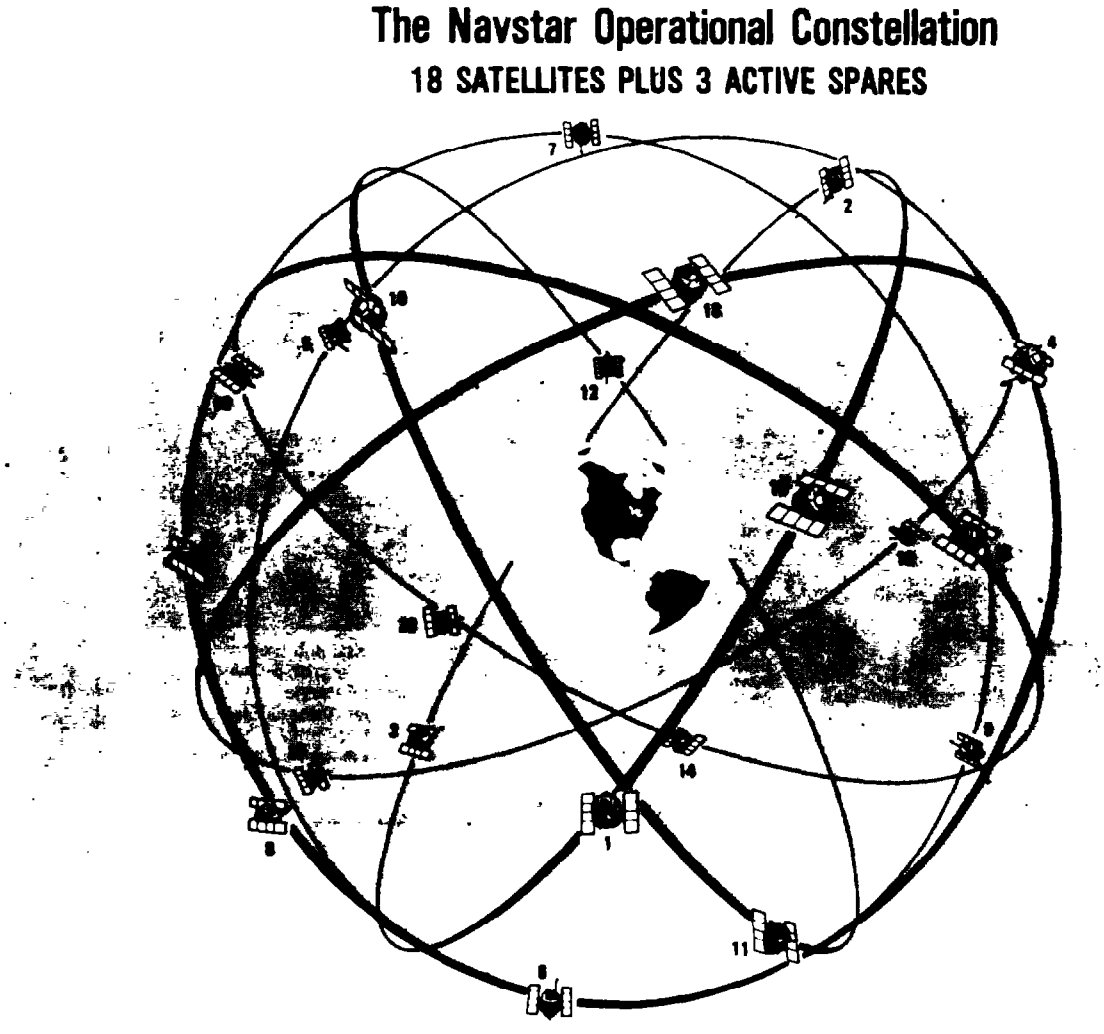
-- A space segment comprised of a satellite constellation which provides navigation, time and nuclear detonation signals back to earth, and upper stage boosters that move those satellites launched from the space shuttle from about a 160-nautical mile orbit to final circular orbit about 10,900 nautical miles above the earth. When fully operational, GPS will use an 18 satellite constellation operating in 6 orbital planes (3 satellites per plane). Figure I.1 shows a GPS Block II satellite.

-- A ground control segment involving a master control station in Colorado Springs, Colorado, and five monitoring stations located in Hawaii, Kwajalein Island, Colorado Springs, Diego Garcia, and Ascension. These stations track and control the satellites and ensure that their signals are accurate.

-- A user equipment segment consisting of devices to receive and process information from several satellites to obtain accurate position, time, and velocity measurements. A typical set includes a receiver, a standard control display unit, antenna electronics, and an antenna. Figure I.2 shows the GPS user equipment family. Appendix IV contains more information on the user equipment segment.

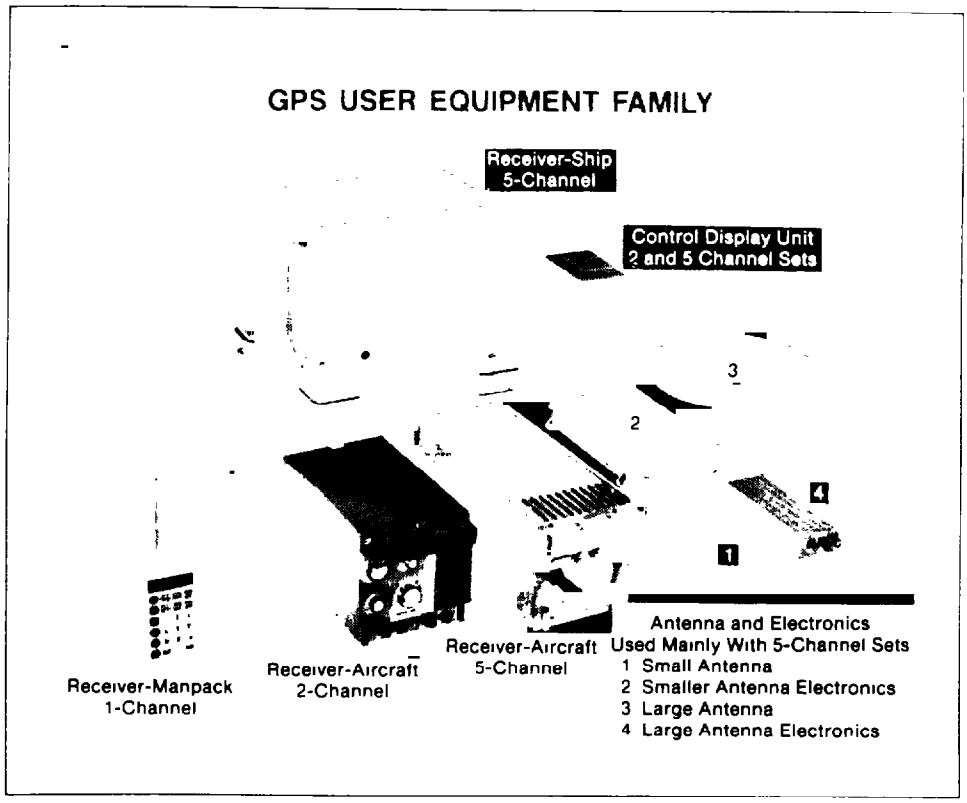
APPENDIX I

Figure I.1: The NAVSTAR GPS Satellite



APPENDIX I

Figure I.2: GPS User Equipment



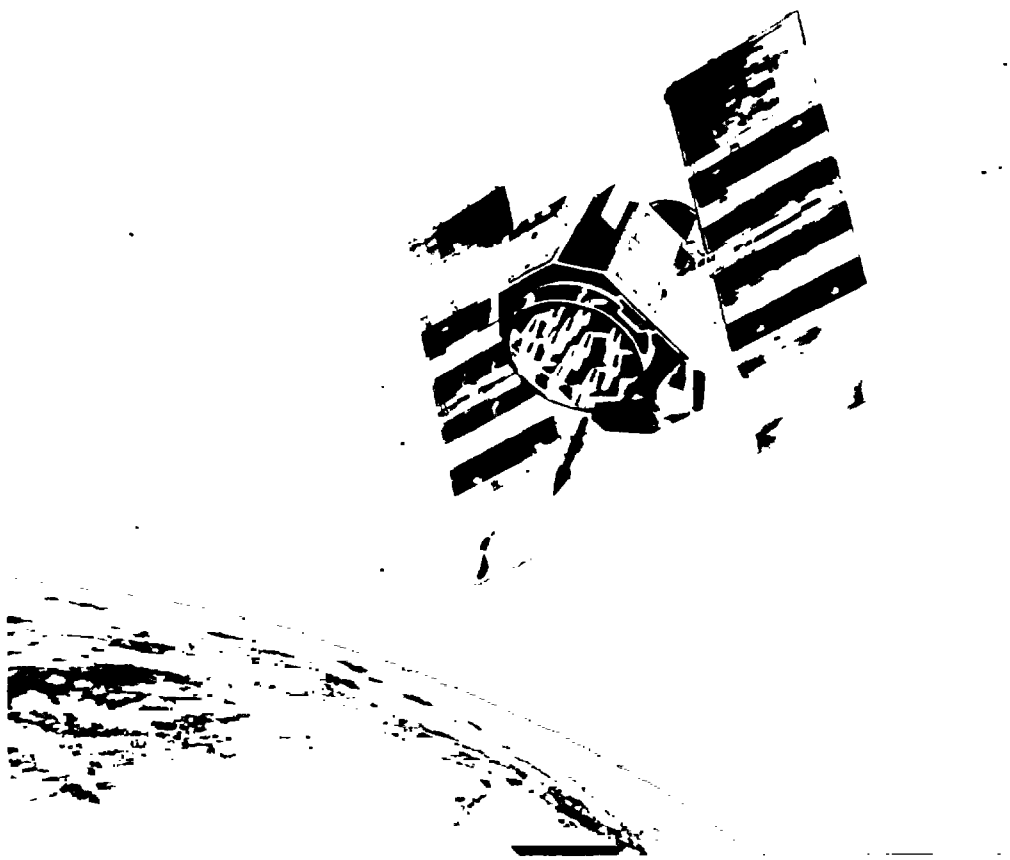
GPS is being developed using the Department of Defense's (DOD) major acquisition process, consisting of four phases: Phase I is concept exploration and selection which includes the identification and validation of the operational need for a new system. Phase II, demonstration and validation, involves identifying designs that will solve the problem at minimum technical risk and cost. Phase III is full-scale development, during which designs evolve into hardware and models are tested. In the final phase, full-rate production and deployment, equipment is produced, delivered, installed, and initial operating capability is established. In some cases, low-rate initial production is approved before full-rate production.

The GPS program is currently in the production and deployment phase. Between February 1978 and October 1985, 11 development (Block I) satellites were bought and launched, one of which failed to achieve orbit due to failure of the launch vehicle. The first operational (Block II) satellite was a qualification test vehicle and was not launched. It was followed by a buy of 28 additional Block II satellites, all of which are still in production. The Air Force plans that, as these 28 are used, the constellation will be replenished through a future contract for 20 more Block II-R satellites. The ground control segment is substantially complete, and the user equipment segment had established a final design and is in low-rate initial production.

The Air Force awarded the contract for the 28 Block II satellites at a cost of about $1.171 billion to the Rockwell International Corporation, Satellite Systems Division, Seal Beach, California, in May 1983. Launch and orbital support services under cost-plus-fixed-fee provisions of the contract totaled an additional $41 million. Rockwell also produced the Block I satellites. The 28 satellites will be used to establish an 18-satellite constellation, and provide 10 spare satellites, 3 of which will be in orbit. (See figure I.3.) Additional Air Force requirements for an enhanced nuclear detonation detection sensor and modifications to the orbit insertion system have increased the current cost of the contract to $1.269 billion as of April 22, 1987, to produce the satellites and another $48.7 million for launch and orbit support services.

To launch these satellites from the space shuttle orbit to the 10,900-nautical mile orbit, the Air Force awarded a $170 million contract to the McDonnell Douglas Corporation's Astronautics Company in July 1983. This was a fixed-price contract for about $143 million to buy 28 upper stage boosters, called PAM-DII; and a cost-plus-fixed-fee portion for about $27 million to buy launch and orbit support services.

Figure I.3: The NAVSTAR GPS Operational Constellation



To develop the ground control segment, the Air Force signed a $226.5 million contract with the International Business Machines Corporation in September 1980.

The Air Force also signed a contract in April 1985 for about $61.5 million with Rockwell International Corporation, Collins Government Avionics Division, to establish a final design and begin production of GPS user equipment. With additional costs for research and development and the exercise of some production options, this contract is currently valued at $233 million.

The Air Force had planned to use the space shuttle to launch its first GPS Block II satellite in January 1987 and, through subsequent space shuttle launches, to achieve worldwide, 24-hour a day, three-dimensional capability by December 1988. However, with the space shuttle Challenger accident on January 28, 1986, these plans were abruptly interrupted. As of January 1987, the Air Force had decided to launch 20 of its 28 GPS satellites from expendable launch vehicles (ELVs) rather than the space shuttle, was planning to launch its first satellite on an ELV in October 1988, and estimated it would achieve a three-dimensional initial operational capability by March 1991. In August 1987 program officials said a new fully operational (18 satellites in orbit) date of September 1990 has been identified based on GPS being able to successfully launch 6 satellites on the shuttle and 12 on ELVs by the end of September 1990.

The Air Force's current budget for the total acquisition cost of GPS through Block II is about $6.554 billion in then-year dollars for satellites, ground control, and user equipment segments, as shown in table I.1. Post Challenger adjustment costs are not included in the budget because they are still being developed by the Air Force.

Table I.1: GPS Acquisition Costs[a]

Appropriation	Current & prior yrs. (FY 74-87)	Budget year (FY 88)	Balance FYDP[b] (FY 89-92)	To complete beyond FYDP (FY 93-2000)	Total
	(then-year dollars in millions)				
Space segment:[c]					
Research, development, test and evaluation	$ 936.8	$ 23.1	$ 67.7	$ -	$1,027.6
Procurement:					
Satellites and ground control	1,066.4	92.6	199.7	-	1,358.7
Military construction	7.3	-	-	-	7.3
Total	2,010.5	115.7	267.4	-	2,393.6
User equipment segment:					
Research, development, test and evaluation	765.2	139.4	402.6	3.8	1,311.0
Procurement:					
Receivers	241.7	207.3	1,428.6	971.4	2,849.0
Total	1,006.9	346.7	1,831.2	975.2	4,160.0
Total	$3,017.4	$462.4	$2,098.6	$975.2	$6,553.6

[a]These costs do not include amounts for Block II-R satellites, enhanced nuclear detonation detection equipment, modifications to the orbit insertion system, launch vehicles, and planned contract adjustments due to the Challenger loss.

[b]GPS costs estimated in the DOD Five Year Defense Program (FYDP).

[c]According to GPS program officials, $358.9 million in ground control segment costs are included in the satellite segment.

OBJECTIVE, SCOPE, AND METHODOLOGY

As requested by the Chairman, Subcommittee on Defense, House Committee on Appropriations, we reviewed the GPS program to determine how the Air Force modified its acquisition approach for this system following the space shuttle Challenger accident and to provide information on the current status of GPS. We were also asked to determine the effect on GPS of an additional 1-year delay in the space shuttle launch.

We reviewed the GPS space and user equipment segments, but not the ground control segment. Most of the ground control segment procurement has been completed and most of the contract funds have been obligated.

We reviewed plans and schedules for launching GPS satellites before and after the Challenger accident, analyzed the GPS contract for 28 Block II satellites, the contract for 28 upper stage boosters, and the contract for user equipment design and production. We reviewed but did not evaluate a related Air Force study of options for completing the procurement of 28 Block II satellites because we did not have access to relevant data necessary to determine the reasonableness of the selection process and related cost assumptions. In addition, we evaluated plans for a follow-on buy of 20 Block II-R satellites.

Our work was performed primarily at the Air Force's Space Division, Air Force Systems Command, El Segundo, California; contractors' locations at Seal Beach, California, where the satellites are being produced; and Cedar Rapids, Iowa, where the user equipment is being developed and produced in limited quantities. At the contractor locations we received briefings and toured production facilities.

Program officials reviewed drafts of this report and their comments are included where appropriate. As requested, we did not obtain official comments on this report. Our work was performed from August 1986 to August 1987 in accordance with generally accepted government auditing standards.

EXTENSIVE CHANGES HAVE OCCURRED IN GPS LAUNCH PLANS

At the time of the Challenger accident in January 1986, the GPS program was completely dependent on the space shuttle for launching the 28 Block II satellites. By March 1986, the Air Force had begun planning for shifting to ELVs or unmanned boosters for launching GPS satellites. In January 1987, the Air Force signed a production contract for seven MLVs (ELVs with medium launch lift weight capability) capable of launching the first nine production satellites beginning in October 1988. This contract contains options to buy up to 13 more MLVs over the next 2 years.

THE SPACE SHUTTLE ACCIDENT AND RESULTING DELAYS HAVE HAD A MAJOR EFFECT ON GPS SATELLITE LAUNCHES

At the time of the Challenger accident, the space shuttle was scheduled to launch all 28 GPS Block II satellites between fiscal years 1987 and 1991. There was no provision or funding for a backup launch capability if the space shuttle was not available. An Air Force strategy to use ELVs for critical satellites existed, but at the time of the Challenger accident, only a limited number of ELVs were available, and GPS was not designated as a critical program for their use.

Initial plans to resume space shuttle operations were not realized. According to information available from the GPS Program Office, the initial estimate was that the space shuttle would be available about 6 months after the accident. However, by March 1986, the estimate for the space shuttle's first return flight was January 1987, 12 months after the accident. In May 1986, it was moved to June 1987, 17 months after the accident. In July 1986, it was extended to February 1988, 25 months after the accident.

In October 1986, NASA issued a revised space shuttle manifest which identified shuttle flights for major payloads. NASA observed in this manifest that a substantial backlog was developing for payloads needing launch, and most launches were being delayed more than 2 years. In May 1987, NASA announced still another delay, to June 1988, for the first space shuttle launch.

Under the revised manifest GPS satellite launches were reduced from 28 to 16 satellites. Before the accident the first GPS shuttle launch was set for January 1987, but the revised manifest moved the first launch to June 1989, a slip of almost 30 months, and the last or 16th GPS satellite launch to fiscal year 1994.

THE AIR FORCE MADE AN EMERGENCY ELV BUY TO HELP LAUNCH GPS

Almost immediately after the Challenger accident, the Air Force began planning for some GPS Block II satellites to be launched on ELVs. In June 1986, it announced an emergency need for an MLV to help launch the GPS satellites; in August 1986, it signed design contracts; and in January 1987, it signed a production contract. As a result, within a year after the accident, the Air Force had taken action to help overcome its dependency on the space shuttle for launching GPS.

In August 1986, the Air Force awarded contracts of about $5 million each to four different contractors to design an ELV that would accommodate GPS satellites and have the potential to launch commercial satellites. In these contracts, the Air Force specified that potentially at least 12 of the Block II GPS satellites would be launched on MLVs starting in fiscal year 1989 at a rate of at least 4 a year.

On January 20, 1987, the Air Force signed a contract with one of the design contractors, McDonnell Douglas Corporation, to build and launch seven MLVs at a cost of about $316.5 million. The contract contains options to purchase up to 13 more MLVs. The contract also states that because of the loss of the space shuttle, the Air Force has an emergency requirement to supplement its GPS launch capability, and the Air Force intends to modify GPS satellites to make them capable of being launched on either the space shuttle or an MLV. The Air Force has not determined how many satellites will need to be configured for dual launch and associated costs.

The Air Force plans to launch the first of the 28 Block II GPS satellites on an MLV in October 1988, 21 months after the MLV contract was signed.

GPS program officials told us that criteria for selecting the MLV contractor included how soon the first MLV would be available for launch and that there was a requirement for a first MLV launch of a GPS Block II satellite by early fiscal year 1989. To help achieve this launch date, the contractor will design the first 7 production and 2 optional MLVs with lighter lift capability than the next 11 optional MLVs. Program officials said this was done because the first 9 of the 28 satellites being produced do not weigh as much as the next 19. The satellite production contract calls for an enhanced and heavier nuclear detonation detection sensor to be developed and the Air Force anticipates it will be added to the last 19 satellites.

GPS program officials told us that satellites with these enhancements will need to be launched as soon as possible. The enhanced sensor is scheduled to be (1) on the 10th satellite, (2) delivered in December 1987 but has been rescheduled for delivery to December 1988, and (3) launched on the first GPS space shuttle flight in June 1989. However, if the space shuttle is not available for a GPS launch in June 1989 and if the Air Force must wait for the first MLV capable of launching the heavier satellites, the satellites with the enhanced sensors will not be launched until the 10th MLV is available in May 1990, if contract options to buy more than 7 MLVs are exercised.

Table II.1 is the latest available NASA manifest and it summarizes the changes that have occurred in the launch schedules for GPS since the Challenger accident. It shows that because of the availability of ELVs for launch the Air Force reduced the number of space shuttle flights for GPS from 28 to 8, and launch dates for many of these flights have slipped.

Table II.1: Changes in GPS Launch Schedules For Block II Satellites

Dates and type of vehicle	Fiscal years								
	1987	1988	1989	1990	1991	1992	1993	1994	Total
January 22, 1986:									
Space shuttle	6	7	7	4	4	-	-	-	28
March 13, 1986:									
Space shuttle	1	6	3	6	-	-	-	-	16
ELV	-	-	4	4	4	-	-	-	12
June 14, 1986:									
Space shuttle	-	2	6	3	1	4	-	-	16
ELV	-	-	4	4	4	-	-	-	12
July 7, 1986:									
Space shuttle	-	-	4	6	6	-	-	-	16
ELV	-	-	4	4	4	-	-	-	12
October 3, 1986:									
Space shuttle	-	-	4	2	5	2	2	1	16
ELV	-	2	5	4	1	-	-	-	12
January 22, 1987:									
Space shuttle	-	-	4	2	2	-	-	-	8
ELV	-	-	6	6	8	-	-	-	20

We asked the GPS Program Office what effect there would be on GPS if there was an additional 1-year delay in the first space shuttle launch. Program Office officials responded that they could not comment on the effects of any additional delay until there was an official change in the schedule. However, they said it would be unlikely that GPS launches would simply be delayed for a year. Instead, it would be more likely that a reassessment of program and launch priorities would occur, as has happened in response to past delays.

ACTIONS TO CHANGE

SPACE SEGMENT PROCUREMENTS

At the time of the Challenger accident, a number of major contracts were in process for the GPS program space segment. As of March 1987, the Air Force had modified several of these procurements by: (1) stopping some work on items with limited life, (2) deciding to stretch out its major buy of 28 Block II satellites, (3) partially canceling the contract for 28 upper stage boosters by not buying the last 12, and (4) delaying its need for the additional 20 Block II-R replenishment satellites. The Air Force is still determining how and when these actions will be completed and what effect they will have on program funding requirements.

REPLANNING SATELLITE ACQUISITION SCHEDULE DUE TO SHUTTLE LAUNCH DELAYS

At the time of the accident, the Air Force contracts for 28 Block II satellites and 28 PAM-DII upper stage boosters had been in process since 1983; contracts to buy 20 more replenishment satellites and PAM-DIIs were being planned. Between May and August 1986, the Air Force stopped work on a few items having limited life parts, such as orbit insertion subsystem motors and batteries that would age once the electrolyte was added. In April 1986, it also directed Rockwell to minimize expenditures under the contract for launch and orbital support.

The contracts for 28 satellites and 28 PAM-DIIs are multiyear procurements that call for the government to obligate funding each year toward the total value of the contract. For this amount, the contractor agrees to deliver a specified number of satellites or boosters. On these two contracts, the government has made obligations each year through fiscal year 1986, according to the terms in the contracts, but for fiscal year 1987, some funding was withheld at congressional direction and to adjust for less shuttle launches.

Multiyear procurement contracts allow the Air Force to realize savings as a result of efficiencies in production and purchasing. The Air Force estimated that the GPS multiyear procurement contract to buy 28 satellites saved about $212 million (then-year dollars) over annual buys for the same quantity.

The government also retained the right to terminate the contracts for the 28 satellites and PAM-DIIs at any time without being liable for more than the cumulative total of the funds obligated through the time of termination.

The funding and delivery schedule in the contract as of June 30, 1986, for the production of 28 Block II satellites is shown in table III.1.

Table III.1: GPS Block II Satellite Procurement Funding and Delivery Schedule

	Obligations		Delivery Schedule	
FY	By FY	Cum. total	By FY	Cum. total
	(dollars in millions)			
1982	$ 19.0	$ 19.0	-	-
1983	144.3	163.3	-	-
1984	310.1	473.4	1	1
1985	368.3	841.7	6	7
1986	221.6	1,063.3	9	16
1987	137.1	1,200.4	8	24
1988	54.0	1,254.4	4	28
1989[a]	10.1	1,264.5	-	28

[a]According to program officials, the $10.1 million in the contract for fiscal year 1989 will pay for dismantling equipment at the launch site and preparing final data and reports.

Table III.1 shows that for fiscal years 1982 through 1986, the Air Force had allotted about $1.063 billion to the contractor, enough to pay for 16 fully assembled satellites. This was also the government's maximum potential termination liability through the end of fiscal year 1986.

As of June 30, 1986, the total value of the contract for satellite production was about $1.265 billion. By April 22, 1987, the contract value had increased to $1.269 billion for enhanced nuclear detonation detection sensors and modifications to the orbit insertion system, and the total maximum liability was $1.127 billion through July 27, 1987.

The contract also contains a cost-plus-fixed-fee award for launch and orbital support services, with incremental funding each year. For example, as of April 1987, funding for fiscal years 1985 and 1986 was $3 million and $10.4 million, respectively, and for the 3 fiscal years 1987 to 1989 it was to be $12.4, $12.9, and $10 million, respectively, or a total of $48.7 million.

Air Force and GPS contractor officials considered it unwise for the government to terminate this contract after the Challenger accident because it was fixed price, most of the funds were obligated in the early years while delivery of satellites will be in later years, and many of the parts for all 28 satellites had been bought. They said that some provision would have had to be made for disposal or storage and future use of parts and components earmarked for 15 satellites in various stages of assembly (see table III.2), if the contract had been terminated.

GPS program officials described the production process as (1) assembling of parts and components into systems, (2) assembling of complete systems into a vehicle, and (3) final testing of an assembled vehicle. Even after system assembly, they said the satellites must be thoroughly tested before they are ready for launch. About 44 percent of the fixed price for the 28 Block II satellites is for testing after the satellite has been assembled. Table III.2 shows the level of work program officials estimated was completed on the 28 satellites.

Table III.2: GPS Program Office Estimate of Work Completed on 28 Block II Satellites as of January 30, 1987

Level of work completed	Satellites
Through systems assembly and in final test	4
45 percent to 80 percent through systems assembly	7
14 percent to 44 percent through systems assembly	4
No systems assembly started	13
Total	28

The most recent contract delivery schedule of January 1986 required Rockwell to deliver seven fully assembled satellites by December 31, 1986. But as of March 1987 only three satellites had been delivered and one of the delivered satellites was damaged by fire during testing in January 1987. GPS program officials said that the contractor is responsible for all required rework.

The PAM-DII contract is similar to the satellite contract in the way funds are obligated and vehicles are bought and delivered. GPS officials said that delivery dates for the PAM-DII boosters were made compatible with delivery dates for the 28 satellites. Table III.3 shows the scheduled obligations and delivery by fiscal year for the PAM-DII contract as of March 9, 1987.

Table III.3: PAM-DII Procurement Funding and Delivery Schedule

	Obligations		Delivery Schedule	
FY	By FY	Cum. total	By FY	Cum. total
	(dollars in millions)			
1983	$ 29.8	$ 29.8	-	-
1984	12.2	42.0	1	1
1985	35.2	77.2	6	7
1986	29.2	106.4	9	16
1987	19.8	126.2	8	24
1988	17.9	144.1	4	28

According to GPS program officials, the contract began in fiscal year 1983 with the purchase of parts requiring long lead times. Funds totaling $106.4 million have been obligated through fiscal year 1986 to buy 16 PAM-DIIs. According to program officials, none of the 16 boosters had been delivered as of January 30, 1987, when work under the production portion of the contract was stopped because the MLV uses a different upper stage booster. They said that the $19.8 million to be obligated for fiscal year 1987 was not provided to the contractor, and that the $17.9 million for fiscal year 1988 would not be provided either. The Air Force is now determining what will be done with these funds.

The Air Force plans to accept delivery of 16 PAM-DII boosters, and is negotiating partial termination of the contract after fiscal year 1987. During negotiations, they will decide how to restructure the delivery schedule for the 16 boosters. They said 8 of the 16 boosters would be needed for the planned space shuttle launches. The Air Force has not decided what to do with the other eight boosters.

This contract also includes about $27 million for launch and orbital support and other services. About $6 million of this has been obligated, and scheduled obligations for fiscal years 1987 through 1989 was $7.8 million, $7.1 million, and $6 million, respectively. The funding schedule has not yet changed to reflect the buy of 16 rather than 28 PAM-DII boosters.

THE AIR FORCE STUDIED THE BLOCK II CONTRACT AND DECIDED TO STRETCH OUT PRODUCTION

By July 1986, when the Air Force had estimated that the first space shuttle to be launched after the Challenger loss would slip to about 2 years after the accident, it tasked Rockwell to study how to best complete the production contract for 28 GPS Block II satellites. Rockwell began the study in July 1986, and provided the Air Force with a final briefing in October 1986. The cost to the Air Force for the study was about $90,000.

The House and Senate Appropriations Committees, in their conference report on appropriations for fiscal year 1987 (dated October 15, 1986), directed the Air Force to report to them on its plan for re-aligning the current GPS multiyear production contract to minimize storage costs due to delays in scheduled launches. They also directed the Air Force to obligate no more than $61 million of the $137.1 million budgeted for this contract during fiscal year 1987, until reporting to the Congress. In response to the congressional reporting requirement, the Air Force directed Rockwell to prepare a study based on the following options briefed to the Air Force earlier and to identify major factors and costs associated with each:

-- Continue to build all 28 satellites at the current rate, then store them until launch.

-- Stretch out the satellite production schedules to meet new launch dates.

-- Complete work on only 16 satellites fully funded by the contract through fiscal year 1986 and restart the production line for the remaining 12 in fiscal year 1989.

Rockwell's study objective was to determine an optimum way to complete the contract by (1) minimizing satellite acquisition costs to the GPS Program Office and (2) meeting a revised launch plan. Rockwell was to assume a 2-year slip in NASA launching the space shuttle, and that GPS Block II satellites would be launched on both the space shuttle and MLVs, at a rate of four MLVs a year starting in January 1989.

Rockwell's final briefing document to the Air Force in October 1986 stated that there were considerable uncertainties in its assessment related to such factors as launch dates, storage (location, maintenance, shelf life, etc.), the need to retest, and requirements for extending warranties. It also stated that certain assumptions were made to estimate costs. For example, Rockwell

assumed that satellites would have gone through final testing and were ready for launch at the time they were stored. Rockwell also assumed that if a satellite was stored for less than 6 months, no retesting would be required. However, if it was stored from 6 to 9 months, some retesting would be required, and if stored longer than 9 months, extensive retesting would be required.

Based on these assumptions, Rockwell estimated the rough-order-of-magnitude costs (see table III.4) for the three options and some alternatives to the options. However, it reported that although the costs were reasonable for planning purposes, they did not represent a firm commitment on price.

In late November 1986, the GPS Program Office decided to stretch out production and briefed the Air Force Systems Command on the three options and on its decision. On December 4, 1986, the Air Force Systems Command concurred. These three and another option were reported to the House Committee on Appropriations on February 9, 1987, along with the Air Force decision.

Under option 1 in the report to the Committee, satellites were to be built to the original contract schedule and stored. It assumed that all 28 satellites would be stored and launched on a first-in, first-out basis, the average storage time for each satellite would be 16 months, and there would be extensive retesting required. The total cost of this option was estimated at $332.1 million. This amount included $94.8 million in support and equipment the Air Force assumed would be needed for extensive retesting when satellites were stored for long periods. GPS program officials said this option showed what would happen if the current contract were completed without change.

Option 2, a variant of option 1, would also continue the original production schedule and would build and store satellites until the first launch is scheduled. However, satellites coming out of production would be launched whenever possible. If satellites in production were not available for a planned launch, the launches would be satisfied by taking satellites out of storage. Based on a need for retesting and a storage facility and a safety modification needed for launch on the space shuttle, the Air Force estimated that option 2 would cost $203 million.

Under option 3, the stretch out chosen by the Air Force, work would continue on the first four satellites being produced to meet current launch schedules. Final testing on the next five would be rephased to begin in time to meet new launch dates. According to GPS program officials, work would continue on the remaining 19 satellites to meet revised delivery dates. The cost of this option

was estimated at $140.3 million, mainly for schedule and warranty revisions and extensions.

Under option 4, the contractor would finish building and testing the first 16 satellites. All work for subsequent satellites would stop for 2 years and begin again in fiscal year 1989. However, there would not be a total work stoppage because work would continue on the 16 satellites that are already fully funded through fiscal year 1986. Work on the remaining 12, currently at the subassembly level, would not progress further until fiscal year 1989. The cost of this option was estimated at $462.3 million.

Table III.4 compares the prices of the final four options. The amounts shown are in addition to the $201 million in funding scheduled to be provided in fiscal years 1988 and 1989 under the existing contract.

Table III.4: Estimated Additional Costs of GPS Production Restructure Options

Requirements	Options 1	2	3	4
	(dollars in millions)			
Storage	$ 5.0	$ 7.0	$ 0.7	$ 2.0
Retesting[a]	180.3	41.0	10.5	27.0
Production extensions[b]	94.9	105.6	89.7	379.0
Launch support	51.9	39.4	39.4	54.3
Shuttle safety modifications	-	10.0	-	-
Total	$332.1	$203.0	$140.3	$462.3

[a]These amounts include costs for support and equipment.

[b]These amounts include Rockwell's costs for retraining, schedules, and warranties and the subcontractors' costs for materials and warranties.

Table III.5 shows the planned obligations to Rockwell by fiscal year under the existing contract, and an estimated increase or decrease each year to fund the different options, except options 2 for which data was not developed. For example, Rockwell was scheduled to receive $137.1 million for fiscal year 1987 under its existing contract. In option 3, to stretch out production, it would need an estimated $59 million less. However, in fiscal year 1988, it would need the $54 million from its existing contract and $42 million more.

Table III.5: Estimated Cost by Fiscal Year of GPS Study Options Compared to Existing Contract

	Fiscal years								
	87	88	89	90	91	92	93	94	Total
	(dollars in millions, rounded)								
Existing Contract Amounts	$137	$54	$10	$ -	$ -	$ -	$ -	$ -	$201
Study Option Amounts									
No. 1: Build and store all satellites	98	54	36	42	42	42	18	-	332
No. 2: Build and store early satellites	no data developed								203
No. 3: Stretch production	-59	42	64	31	24	22	16	-	140
No. 4: Stop work	-122	-33	136	209	157	79	33	3	462

The GPS Program Office selected option 3 as the best way to restructure the contract because this option best fit the study criteria of minimizing satellite acquisition costs and meeting the revised launch plan, and has begun steps to reduce planned funding on the existing contract by an estimated $59 million. In addition, it has to decide what effect the stretch out will have on

the need for about $48.6 million in the contract for launch orbital support, and other services. Storage and retesting requirements and costs were not certain at the time the Air Force report was released and are still being evaluated in another study Rockwell is performing for the Air Force.

THE NEED DATE FOR REPLENISHMENT SATELLITES HAS BEEN REEVALUATED

Because of delays in launching the 28 Block II satellites, the Air Force will postpone a planned buy of 20 Block II-R satellites needed to maintain the constellation. Depending on what assumptions are made about launch failure probabilities, operating life of the satellites and other factors, estimates of when these Block II-R satellites will be needed can be quite different.

Before the Challenger accident, the Air Force was planning to begin buying Block II-R satellites in fiscal year 1988 in order to have a first replenishment satellite ready for launch in fiscal year 1992, or 4 years later. Because of the launch delays, it has now established a 6-year program, with 3 years of hardware development and testing to begin in fiscal year 1989, to have satellites ready for launch beginning in fiscal year 1995, a slip of about 3 years.

However, the Air Force faces a complex problem in estimating how many and when satellites will be needed. For example, if the 28 Block II satellites are launched and perform as well as the development satellites in providing a constellation that exceeds its design life, the first replenishment satellites might not need to be launched until April 1996 or later.

The Block I development satellites have lasted longer than the Program Office estimated. GPS program officials told us that the Block I satellite constellation exceeded an overall average design life goal of 5 years in August 1987. As shown in table III.6, through April 1987 one Block I satellite failed on launch; three are now nonoperational although one of them lasted longer than the design goal of 5 years; and seven are still operating, three for 7 years or more.

Table III.6: GPS Block I Satellite History

Satellite	Date launched	Date nonoperational	Number of years operational as of April 1987
1	2-78	7-85	7 yrs. 5 mos.
2	5-78	9-80	2 yrs. 4 mos.
3	10-78	Operating	8 yrs. 6 mos.
4	12-78	Operating	8 yrs. 4 mos.
5	2-80	11-83	3 yrs. 9 mos.
6	4-80	Operating	7 yrs. 0 mos.
7	12-81	Failed on launch	0 yrs.
8	7-83	Operating	3 yrs. 9 mos.
9	6-84	Operating	2 yrs. 10 mos.
10	9-84	Operating	2 yrs. 7 mos.
11	10-85	Operating	1 yrs. 6 mos.

GPS program officials said they used a group of computer tools, called a Generalized Availability Program (GAP), developed by the Aerospace Corporation to help estimate how many and when the Block II-R satellites should be ready for launch. GAP takes into account the predicted life of the hardware, production schedules, replenishment strategies, launch vehicle reliability, and other factors. However, according to Aerospace, GAP is only one of many possible decision tools, at best a mixture of science and art, and there is no sound procedure for estimating how long satellites will operate. Aerospace states that some of the GAP's potential pitfalls are errors in the failure rate data for parts used in the satellites and in the assumptions being used as input to the model.

In another program, the Defense Satellite Communications System (DSCS) where GAP has been used since the mid-1960s, Aerospace found that GAP's predictive ability has been poor. For example, GAP predicted DSCS I satellites would last 1.5 years but they have actually lasted more than 5 years; and GAP predicted DSCS II satellites would last 3 years, but program officials now estimate these satellites will last 10 years.

GPS program officials said they used the GAP to perform two analyses of when Block II-R satellites should be ready for launch. One analysis identified needs based on a planned design life of 7.5 years for Block II satellites, which is its performance goal. The other was based on an estimated life of 10 years, which was constructed from their experience with the Block I development satellites.

With the 7.5-year life, the GAP projected that, if the first Block II satellite is launched in October 1988, the first replenishment satellite would need to be launched in March 1994, or 5 years and 5 months later. Based on the 10 years of estimated life, the model projected the first replenishment satellite would need to be launched in July 1995, or 6 years and 9 months after the first Block II satellite.

According to GPS program officials, the shorter operating time projected by GAP results from the estimated probabilities for launch failures, replenishment strategies, and other factors used in the model. They said that the model yields conservative results which were not unrealistic, and that when planning to keep an operational, worldwide, constellation healthy, it is better to err on the conservative side. They said they anticipate a need for the first Block II-R satellite to be launched in October 1994. Program officials said that they selected the October 1994 launch date as the approximate midpoint between the dates GAP estimated. They also told us that a later date was being considered.

If different assumptions are made, however, the date estimated for launching the first replenishment satellites could be quite different. For example, the Block I development satellite constellation has exceeded its average design life goal of 5 years. If the 28 Block II satellites can maintain the 18-satellite constellation for the 7.5-year average design life, and the first Block II satellite is launched in October 1988, then the first Block II-R satellite would not be needed for 7.5 years, or April 1996. This would be over 2 years after the March 1994 date GAP projected, and 18 months after the October 1994 date selected. For a 10-year average design life, it would mean the first Block II-R satellite would not be needed until October 1998, or over 3 years after the July 1995 date GAP projected, and 4 years from the October 1994 date selected. If the 10 GPS Block II spare satellites are used to maintain the satellite constellation for the average design life, the Block II failure rate would be 36 percent. The Block I failure rate to date computed on the average design life of 5 years is 27 percent which is considerably lower than the 36 percent failure rate assumed by the need for 10 spare Block II satellites.

GPS program officials said that we used a simplistic analysis which did not consider how many satellites are required to provide world-wide coverage and that they used GAP analysis which they believe is appropriate for this program. Given the experience to date with the use of the GAP model, we have initiated an assessment of the utility of the model as a predictive tool.

The current plans for the start of Block II-R production are that a long lead contract would begin in fiscal year 1990. As the Air Force plans to launch the first Block II satellite in October 1988 and expects to have 10 GPS satellites in orbit before the end of fiscal year 1989, more current information on the Block II satellite launches, launch failures, and satellite performance will be available to GPS program officials before Block II-R production starts. If the early Block II satellites meet or exceed projected performance expectations, program officials will have time to reconsider the start date for Block II-R production to avoid acquiring them too soon and incurring unnecessary storage costs.

IMPACTS OF LAUNCH DELAYS ON GPS USER EQUIPMENT PROCUREMENTS

The user equipment segment of the GPS procurement is intended to provide authorized military users with capabilities to receive precise, continuous, all-weather, common-grid, worldwide positioning, navigation, and time reference information. The user equipment consists of 1-, 2-, and 5-channel radio receiver sets which will be used on over 200 different types of aircraft, land vehicles, surface ships, submarines, and by individuals to receive and convert satellite transmitted signals into useful position, navigation, time, and weapons delivery information.

TECHNICAL PROBLEMS HAVE DELAYED USER EQUIPMENT PRODUCTION AWARD

The GPS program, including user equipment, passed milestone II (full-scale development) in 1979. Dates established at that time to award a user equipment production contract slipped by up to 33 months due to technical problems. Because development is almost 3 years behind schedule, the Challenger loss caused no further adjustment to user equipment production.

Although there were reliability problems with the GPS user equipment, the low-rate initial production contract was awarded in June 1986. Program officials told us that these problems are being addressed by a DOD-directed reliability program.

As of April 1987, GPS officials estimated that a March 1989 milestone date for a full-rate production decision will slip to September 1989 to allow additional time to complete adequate testing. This estimate may be optimistic, however, because some significant events must occur before the full-rate production decision can be made. For example, a Block II satellite needs to be successfully launched and tested. The earliest date planned for such a launch is October 1988, and testing requires several months. This would be followed by user equipment operational field testing which requires the integration or installation of low-rate initial production user equipment on test vehicles. This is expected to take at least 1 year. Then, any problems identified during satellite or user equipment testing will need to be resolved. Therefore, it may be fiscal year 1990 or later before a full-rate production contract can be awarded. The Air Force told us that most of the testing will be parallel, not sequential, and that the schedule is tight but achievable.

LIMITED AMOUNTS OF USER EQUIPMENT WILL BE AVAILABLE FOR GPS INITIAL OPERATING CAPABILITY

The Program Office as of March 1987, is procuring 27,157 user equipment sets with deliveries starting in 1986 and ending in 1999, and plans to integrate them on over 200 types of aircraft, ships, and vehicles at a cost of about $4.160 billion. This includes 18,857 5-channel sets for high priority, tactical aircraft and submarines. Our review of procurement plans and time required to produce, install, and deliver user equipment indicates that about 8 percent of the 27,157 sets to be procured will be available by the September 1990 system operational date, and about 6 percent of the 18,857 5-channel sets to be procured will be available then. The Air Force said that early deliveries of user equipment will be installed on high priority military platforms, and for this reason the Air Force feels that although production quantities are limited, system coverage will be adequate.

Table IV.1 shows the types and amounts of user equipment the services are planning to procure. Currently, each of the services has selected only two classes of user equipment each, with the Air Force and Navy buying most of the 5-channel sets.

Table IV.1: GPS User Equipment Procurements Through 1999 by Military Service

Receiver type	Air Force	Navy	Army	Total
1-channel	1,182	827	2,162	4,171
2-channel	-	-	4,129	4,129
5-channel	11,658	7,199	-	18,857
Total	12,840	8,026	6,291	27,157

According to the Program Office, it takes an average of about 30 months from the time user equipment sets are ordered until they are delivered and installed. This means that only those sets purchased by October 1988 will be available at the time the satellite constellation is scheduled to be fully operational in September 1990.

Table IV.2 shows the number of user equipment production sets the GPS Program Office currently plans to buy each year through fiscal year 1988.

Table IV.2: User Equipment Procurements Planned For Fiscal Years 1986 to 1988

Type of set	Fiscal years			
	1986	1987	1988	Total
1-channel	176	277	262	715
2-channel	67	133	107	307
5-channel	87	365	716	1,168
Total	330	775	1,085	2,190

During fiscal years 1989 through 1991, the services plan to acquire 2,344, 3,973, and 4,238 user equipment sets, respectively.

PLANS TO INTEGRATE NEW TECHNOLOGY INTO THE CURRENT GPS USER EQUIPMENT DESIGN

In 1985 the Air Force selected the user equipment design of the low-rate initial production contractor as the baseline configuration. Technological changes are to be incorporated through a preplanned product improvement program over several years, beginning in 1989. A competitive procurement is planned for a second source in fiscal year 1990; however, the design for this follow-on production will be the same as that selected in 1985.

The user equipment technology is changing rapidly and sets which are advertised as being equivalent in performance to GPS user equipment but miniaturized and less costly are currently available from several manufacturers.

GPS program officials are aware of the new technology, but believe that substantial additional costs could be incurred if the decision were made to change to the new equipment. They said that the new equipment on the market does not meet military specifications and that the costs associated with integrating newer user equipment into existing vehicles would have to be repeated. They said it takes as long as 6 years from the time a vehicle integration project starts until the first operational vehicle is ready. Consequently, in their view, significant per unit cost savings would have to be available in the new sets to warrant a change in

their strategy. However, they are starting an evaluation of commercially available 1-channel sets on the market which essentially have no integration costs to determine if they can meet user needs and potential cost savings. For the 2- and 5-channel receivers the Air Force is reviewing requirements, assessing available technology, and will develop a plan to systematically take advantage of new technology when it becomes available.

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