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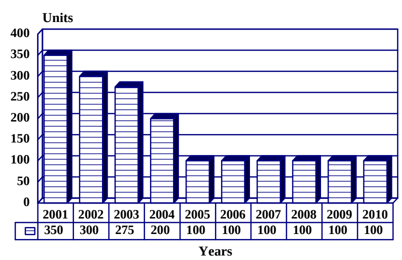
NAVSTAR GPS Naval & Maritime Terminals – Archived 12/2002

Outlook

- Consumer demand for NAVSTAR GPS Naval & Maritime Terminals should be strong over the next decade
- Look for Raytheon's JPALS to enter engineering and manufacturing development in 2002
- Expect the JPALS system to enter initial operating capability sometime in 2004
- New NAVSTAR satellites, Block III, to be produced and launched

10 Year Unit Production Forecast
2001 - 2010



Orientation

Description. The Navigation Signal Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a constellation of orbiting satellites that provides navigation data to military and civilian users all over the world. The system is managed by the United States NAVSTAR GPS Joint Program Office at the Space and Missile Systems Center, Los Angeles Air Force Base, Calif. This report primarily covers GPS terminals for sea applications, including military naval vessels, commercial maritime ships, and civilian maritime usage.

Sponsor

US Air Force - Materiel Command
Space Missile Systems Center
GPS Joint Program Office
Los Angeles, California (CA) USA
(US DoD Lead Agency and GPS Program Manager)

US Navy
Ocean Systems Center
San Diego, California (CA) USA
(Naval GPS)

Underwater Systems Center
Newport, Rhode Island (RI) USA
(GPS for submarines)

All US military services are involved, as well as the US Defense Mapping Agency, the US Department of Transportation, and 13 members of NATO.

Contractors

Boeing Co (formerly McDonnell Douglas Aerospace)
PO Box 3707, M/S 10-06
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Web site: http://www.boeing.com
(GPS satellites in Blocks II and IIA)

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(GPS-100MRN, GPS-100MIL, and GPSMAP-200)

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6801 Rockledge Drive
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Web site: http://www.lockheedmartin.com
(GPS IIR replenishment spacecraft)

Gauss Interprise Inc
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Web site: http://www.gaussvip.com
(NAV-1000/1000M handheld GPS receivers)

Motorola Inc
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(GPS receivers for land/sea/air navigation and all-weather capabilities, joint venture with Unisys for GZ-810 GPS airborne receiver)

Newport News Shipbuilding
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(GPS core module and 501TR/GPS navigator for commercial vessels)

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(US Prime for GPS user equipment, integration of user equipment, developing two-channel receiver for Tomahawk cruise missile)

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(Search and rescue GPS receivers)

Thales
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(Member of EURONAV Consortium and Magnavox licensee)

Trimble Navigation Ltd
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Web site: http://www.trimble.com
(TRIMPAK Manpack GPS receiver and TANS advanced GPS navigation sensor)

Status. A great number of receivers in different variations, are currently in production and development.

Total Produced. Through the year 2000, the US Navy and other maritime services had taken delivery of approximately 4,500 sea-based terminals and receivers.

Application. To provide users with worldwide, all-weather, three-dimensional position, velocity, and precise time data.

Price Range. The price of GPS receivers is getting lower and lower all the time. The drop is especially noticeable with civilian GPS units. One can expect prices to continue to fall as the system is developed and mass production manufacturer competition resurfaces. Raytheon TI's PSN-9 receiver (for both manpack and helicopter applications) originally cost about US$20,000, with the ship-based receiver originally costing about US$50,000.

Commercial GPS units currently being produced cost much less than their military counterparts. The receiver in a military configuration costs US$3,500. Magellan also introduced a GPS receiver priced at US$900. Trimble's Ensign GPS handheld receiver for maritime use originally sold for US$1,195. Magnavox's OEM GPS Engine receiver for integration into vehicle tracking systems, avionics suites, handheld radios, personal locators, and marine navigation systems initially sold for approximately US$500.

Technical Data

Satellite Segment Design Features. The NAVSTAR (Navigation System Time And Ranging) GPS (Global Positioning System) program is comprised of 21 active satellites and three spares in 12-hour, 55° orbits. The satellites are segregated into six equally spaced planes (60° separation) at 10,900 miles, with three active satellites evenly spaced (120° separation) in each of these planes. In addition, replacement satellites are planned for earlier units, bringing to over 50 the total number of GPS satellites expected to be produced. The system provides 24-hour positioning data accurate to 15 meters.

All GPS satellites are controlled over an S-band link; 2227.5 MHz for the uplink, 1783.74 MHz for the downlink. They transmit navigation data in spread spectrum using the L1 frequency band of 1575.42 MHz, and the L2 frequency band of 1227.60 MHz. The L2 band is encrypted and is intended for the sole use of the US Department of Defense (DoD) and authorized allies. Pseudo random noise techniques are used to encode the P (Precision) code for both the satellite and the receiver's encoders. However, in a cold start situation, when the operator turns on his GPS set, all the receiver hears is gibberish from the noise coding, thus necessitating auto correlation. To speed the matching of codes, each satellite sends a second, less accurate and lower resolution signal, but only on one of the frequencies because ionospheric correction is not needed. This signal is called the Coarse Acquisition or C/A signal. It serves to provide rough latitude and longitude data to the user's receiver. The less accurate C/A code will be available to all users. While a downgraded accuracy of 100 meters is claimed for the C/A signal, commercial receivers are able to get better accuracy.

The satellites are equipped with four onboard atomic clocks (three rubidium and one cesium in the Block I satellites and two rubidium and two cesium in Block II) accurate to within one second every 300,000 years. To assure the proper workings of the satellites' clocks, the NAVSTAR ground stations compare the internal accuracy of the system to that of the US Bureau of Standards' hydrogen maser clock, the most accurate timepiece in the world (developed by the Naval Research Laboratory). NAVSTAR uses a receiver to monitor the signal produced rather than a constant, such as a mountain or star used in conventional navigational means.

NAVSTAR provides accurate, three-dimensional position, velocity, and timing information. The system is passive, has inherent anti-jam capability and is available continuously, regardless of weather conditions. This allows the NAVSTAR system to serve the entire spectrum of users, both civilian and military. Authorized military and civilian users can call upon accuracy of 2 to 15 meters, while other civilian and military users have to settle for 100 meter accuracy. Ironically, since selective availability cannot be applied to the satellites presently in orbit, civilian users have been able to call upon accuracy as good as 5-30 meters, versus that of the precise positioning accuracy of 2-15 meters. This has been gradually changing with the launching of the Block II GPS satellites in February 1989, which incorporate the selective availability feature.

Ground Element. Ground stations located in friendly nations act as the control segment of the NAVSTAR system. The master control station (MCS) was relocated at the Consolidated Space Operations Center (CSOC) at Falcon Air Force Station, Peterson AFB, Colorado Springs, Colorado, with the launch of the first Block II satellite in February 1989, marking the official transfer of control to the CSOC. The master control station maintains the accuracy of the atomic clocks housed within the satellites, ensuring all are synchronous. The Monitor Stations, which operate remotely without needing on-site staff, are located on Ascension Island, in Hawaii, on the Kwajalein Atoll, CSOC, and Diego Garcia. Uplink antennas are located at Diego Garcia, Ascension Island, and Kwajalein. Lockheed Martin (originally IBM which was acquired by Loral which in turn was later acquired by Lockheed Martin) is under contract by the US Air Force (USAF) Systems Command to manage the GPS control element.

User Equipment Design Features. The user equipment segment is composed of the antenna, antenna control unit, antenna preamplifier, receiver, and man/vehicle control display. The pseudo-random noise code must be known by the user for real-time processing. However, geologists have for many years been able to get GPS accuracy of approximately one centimeter by processing hours' worth of data for each location to be measured.

The receiver calculates pseudo-range and pseudo-range rate. Pseudo-range is the distance from each satellite to the receiver plus an offset due to clock bias. Because this distance is not perfectly measured, it is called a pseudo-range instead of simply range. Pseudo-range rate gives the velocity between receiver and satellite, again with a clock offset.

The basic calculation technique is to determine the time lag from each satellite's transmitter to the GPS receiver.

Then, the ephemeris of each satellite is calculated, giving the position of each satellite when it transmits each bit of data. From four satellites the receiver may obtain three-dimensional position and three-dimensional velocity data.

For high-accuracy operation, the data in the L2 band as well as the P/A code are also decoded. Comparison of the L1 and L2 bands enables the receiver to correct for signal errors caused in passing through the ionosphere and atmosphere. This gets the accuracy down into the three meter range.

Receivers. The three common groups of receivers are: single-channel, two-channel, and five-channel devices. A single-channel MAN/Vehicle (M/V) receiver takes the satellite signals in sequence. The critical dimension here is acceleration rather than velocity as one would expect. Satellites can use single-channel receivers since there is no acceleration. Also, with inertial aiding there is no problem with acceleration.

Dual-channel receivers need two channels at exactly the same time, but actually require four satellites for proper coverage. The two-channel receivers would be used by lower dynamic users such as helicopters or Army fixed-wing aircraft equipped with Doppler sensors. The higher channel receivers may receive data simultaneously from up to five GPS satellites. This is essential for high dynamics uses, such as fighter aircraft. The additional channels ensure a greater number of satellites being tracked, and therefore a more precise location and velocity value can be obtained. Logistics is the main driver, particularly if there is no aiding source or if alignment from sources such as an inertial navigation system (INS) is available. The higher channel receivers are more robust, and have anti-jamming benefits, especially for higher dynamic users. Small five-channel configurations will be available in later years as all the channels are put on a single chip.

Operational Characteristics. Based on tests conducted by the USAF, using an initial constellation of seven satellites, the GPS demonstrated accuracy in position to within 35 feet for aircraft and ground vehicles. Speeds have been measured to within 0.1 knot, and time transmitted with an accuracy to within millionths of a second. The accuracy indicated is achieved through the use of two satellite channels simultaneously. Although NAVSTAR is available to civil users, only one channel can be accessed, resulting in slightly reduced accuracy. Even so, position accuracy is expected to be within 100 feet, which is adequate for non-precision instrument approaches. Accuracy is not dependent on the number of channels. Rather, it is a function of the time it takes to gain a fix and re-acquire it.

There are six basic levels of navigational accuracy, with the highest level of accuracy being stationary survey. This is followed in descending order of accuracy by survey from moving platforms, differential GPS (improved accuracy within several hundred kilometers of a surveyed monitor station), precise positioning service (US military and other DoD approved users), standard positioning service (without the DoD selective availability degradation), and the standard positioning service for civil users with DoD degradation of the signal.

The users of the NAVSTAR system include all aircraft, armored and soft-skinned vehicles, surface and sub-surface vessels, and individual foot soldiers. The receiver processes the position and time signals produced by the satellites which are displayed on the readout equipment. The various types of receivers installed on military and civilian equipment will scan the skies for a satellite signal. The more channels that are scanning, the more precise the type of information available to the user. The receiver measures the time delay between the signals received from the satellites within range which gives the range of the satellite from the receiver. If a time measurement outside of the system is utilized by the user, and altitude is known, the signal from two satellites will provide longitude and latitude.

Variants/Upgrades

Over the last few years, GPS technology has truly exploded. The current focus appears to be on down-sizing the unit and improving commercial receivers' precision. A partial listing of major known manufacturers of sea-based GPS receivers, with descriptions of their products, is as follows:

Garmin. Garmin International practically made its name on GPS; becoming a leading designer, manufacturer, and marketer of navigation and communications electronics equipment. Garmin has developed GPS products that serve the aviation, military, survey, and maritime markets. Many nations use Garmin products in aircraft that range from light helicopters to C-141s.

Garmin supplied its commercial GPS 100 receiver for use by US-led Coalition Forces in the Persian Gulf War and equipped several hundred aircraft (fighters, C-141 transports, and helicopters) together with ground vehicles and individual soldiers. Since that time, Garmin has introduced a military variant, the GPS 100 MIL, which can operate with a helmet-mounted antenna if required. Garmin's MultiTrac facility enables the unit to use information from up to eight satellites at a time, resulting in accuracy of 15 m RMS for position, 15 m RMS for altitude, and 0.1 kt steady state for velocity.

The company's commercial models available are the GPSMAP 200 Integrated GPS Navigator for US$2,495 and the GPS MRN Personal Navigator for US$1,795 (in 1993 dollars). In December 1992, Garmin released its handheld Trooper GPS receiver. Designed to be user-friendly, the Trooper was listed at US$1,340. At the same time, Garmin introduced the GPA 94 AVD, a powerful handheld GPS receiver with a moving map display intended for the aviation market. The moving display presents position, course flown, and nearby airports/waypoints in real time. Designed for handheld portability, the unit includes a convenient adapter for mounting it on the yoke of virtually any aircraft.

Raytheon Company. The Raytheon Company (formerly Magnavox, previously Hughes) developed its Parachute Offset Navigation System (PONS) to provide basic navigation assistance to troops in the field. The PONS is a very compact system weighing only 7.5 pounds. Another unit is the MX 4400 two-channel manpack receiver. Unfortunately, the MX 4400 may not do all that well, considering its weight of almost 30 pounds.

An additional Magnavox/Hughes/Raytheon system is the MX 5400, a two-channel receiver for sea, land, and low-dynamic airborne applications. The MX 5400 weighs just under 12 pounds and the airborne version sold for US$11,400 (1994 dollars). The company's SRN-25(V) integrated Transit/Omega/GPS two-channel receiver has been fitted to many US Navy ships.

In 1991, Magnavox/Hughes/Raytheon introduced a new high-performance, low-cost GPS receiver aimed at the OEM market. The OEM GPS Engine is designed to be integrated into vehicle tracking systems, avionics suites, handheld radios, personal locators, marine navigation systems, and similar applications. The GPS Engine is a six-channel receiver and initially sold for around US$500.

In 1992, the MX 9012 R 12-channel Differential GPS lightweight reference station was introduced. This station can be used in high-accuracy, real-time navigation systems for marine, air, and land-based requirements.

Rockwell Collins. Rockwell Collins has a wide variety of GPS products. The company received the 1988 Award for Outstanding Technical Achievement from the Defense Advanced Research Projects Agency (DARPA) for the development and demonstration of the first monolithic microwave integrated circuit (MMIC) chip designed in connection with a miniature GPS receiver. The chip has been used in the two-channel handheld (100-cubic-centimeter) GPS receiver that Rockwell Collins developed in a technology demonstration for DARPA. The chip set (also including very high-speed and very large-scale [VHS and VLS] integrated circuits) for the miniature receiver was formally demonstrated to DARPA in March 1989. The mil-spec receiver weighed 8 ounces. The development work done for the miniature receiver resulted in a generic set of chips that can be used without modification in virtually any type of GPS receiver, whether single- or multi-channel.

Rockwell Collins also developed a single-channel GPS receiver for the US Navy's Standoff Land Attack Missile (SLAM) and a two-channel receiver for the service's Tomahawk cruise missile.

The company's User Equipment family, developed under a US DoD contract, offers one-, two-, and five-channel receivers for tanks, vehicles, submarines, surface ships, submarines, and aircraft, as well as man-pack versions. Rockwell Collins has provided User Equipment for all three services, as well as several foreign customers. As part of a miniaturization effort, the company came up with a value engineering change proposal modification to the user equipment contract which resulted in a significant weight reduction of the processor assembly for the two- and five-channel receivers. One circuit board was replaced with an embedded processor chip which incorporates VLSIC/ CMOS technology. (In the family, the 3S receiver is the basic shipboard receiver, while the M/V GPS is the basic manpack/vehicular configuration.)

Signature Industries. Signature launched a GPS search-and-rescue beacon for civil and military aircrews in late 1994. The system is known as the SARBE-GPS. Although already used by the military, this is the first such unit intended for civilian use. The size of a transistor radio, the unit broadcasts a data stream that includes position information and a user-identification code. The transmitter operates over a range of at least 50 miles and can work with a variety of rescue homing systems. It is also waterproof and can be placed into a life jacket, survival pack or inflatable raft.

Trimble Navigation. Although it started as a relatively small company, Trimble has shown an excellent capability in the GPS arena, and its TRIMPAK receiver at the time of launching was claimed by the company to be the smallest, lightest, lowest power military manpack GPS receiver available. The two-channel receiver was privately developed after the US Army requested that a readout display be added to the TANS (Trimble Advanced Navigation Sensor), already used on the US Navy's Pioneer unmanned air vehicle. TRIMPAK's capabilities were demonstrated in December 1988 when the GPS Joint Program Office had to withdraw the Request for Proposals (RFP) for its Small Lightweight GPS Receiver (SLGR) program because of the lack of qualified competitors to the TRIMPAK. Since then, Trimble has delivered some 1,012 of the receivers under a US$4 million contract issued by the USAF Space Systems Division. Featuring a built-in antenna, the TRIMPAK weighed in at a maximum of 4.2 pounds (two D-cell batteries), was about the size of a pair of binoculars, and originally cost well under US$10,000.

Trimble GPS equipment was already in use by the US Geological Survey, probably the 4000 ST Field Surveyor GPS survey system. Other Trimble GPS products include the TransPak handheld receiver (civilian three-channel version of the two-channel TRIMPAK), Nav Trac graphic GPS receiver (maritime, three-channel) and the Nav Graphic II GPS/Loran navigation system (two-channel). A prototype naval system called the Loran/GPS 10X was tested onboard the CG 48 *Yorktown* in 1989. In February 1992, Trimble unveiled the Ensign, a 14-ounce handheld GPS receiver targeted at marine users and priced at approximately US$1,195.

In late 1989, Trimble formed a joint venture with Pioneer Electric Co of Japan, for production of mini GPS receivers for automobiles, small airplanes, and helicopters.

In July 1994, Trimble unveiled its MUGR (miniature underwater GPS receiver) unit for the military market. This small device is designed for naval and military operations, especially those conducted by special forces. The MUGR is currently fitted with a number of coordinate systems, including: USA Military Grid Reference System (MGRS); Universal Traverse Mercator (UTM); Universal Polar Stereograph (UPS); latitude, longitude, altitude; and Ordnance Survey of Great Britain. The MUGR is fully waterproof and can be immersed to depths of 10 meters (operational) and 20 meters (survival).

In late 1997, Trimble Navigation Europe was awarded a contract to supply the UK Defence Test and Evaluation Organization with six 7400 Si-based GPS units for use on the UK Royal Navy degaussing ranges. The GPS is used for precise positioning of vessels during their maneuvering across the electromagnetic range as part of the procedure to reduce the vessel's electromagnetic signature – important today with the increased emphasis on littoral warfare and the danger of sea mines and quiet, non-nuclear submarines operating off shallow coastal waters.

Program Review

Background. GPS can be traced back to the early 1960s, when the US Navy sponsored two navigation programs, Transit and Timaton. Transit became operational in 1964 and supplied navigation data to low-dynamic users such as the US Navy fleet. Timaton was a developmental program aimed at advancing 2D (latitude and longitude) navigation. The US Air Force (USAF) was also working in the same direction except that its program, called 621B, was 3D (added altitude). The 1973 Joint Chiefs of Staff master navigation plan called for a single, precise satellite-based positioning system to serve a variety of US DoD requirements. As the result of an Office of Secretary of Defense directive in 1973, the USAF was designated to consolidate the various efforts under the NAVSTAR GPS umbrella, with the USAF Systems command Space Division acting as the executive agency.

Rockwell received contracts to design, produce, launch, and operate three prototype GPS satellites and two flight-acceptance navigation development satellites, in 1974. The first GPS constellation was created in 1978, when four advanced development GPS satellites were launched. In 1979, Rockwell received contracts to build two operational GPS satellites, and to modify the space shuttle to use GPS for navigation. Due to cost concerns raised in 1980, the scope of the program was somewhat reduced, from 21 satellites to 18. By mid-1989 the total had been increased back to 21, with three backups. Deployment of the constellation was then delayed until 1991. Around then it was discovered that transmission of the GPS signal was not as good as originally thought when encountering obstacles such as dense foliage (particularly in moist environments); however, the difference is actually only about 0.5 dB. Another shortfall is that GPS signals do not penetrate deep water, but this is not isolated to GPS.

A full constellation of 24 NAVSTAR GPS satellites (21 operational with three spares) has been in place since March 1994. Block IIR NAVSTAR satellites were scheduled to replace Block II satellites starting in 1997, with Block IIF satellites becoming operational after the turn of the century.

<u>First Block IIR Satellite Lost</u>. The Delta II rocket carrying the first NAVSTAR GPS Block IIR spacecraft failed shortly after launch from Cape Canaveral Air Station, Florida, January 17, 1997. The USAF accident investigation board found that one of the vehicle's solid rocket motors catastrophically failed because its outer

composite layers were damaged by some type of impact to the outside of the case.

US Navy. The US Navy tends to procure five-channel receivers, and purchased the Rockwell Collins 3S (called the WRN-6) member of the User Equipment family. The US Navy completed testing the GPS receivers on board a variety of ships, including an AEGIS class cruiser, and found the five-channel user equipment exceeded reliability requirements by a factor of four. The US Navy declared it operationally suitable and effective, and OPTEVOR has recommended it for fleet use. Additionally, the US Navy applied FOT&E applications to 44 aircraft types through 1994. According to Rockwell Collins, it delivered 480 WRN-6s through 1990. Of this total, some have been provided to the German Navy. The US Navy also tested a Trimble Loran/GPS receiver on board the CG 48 Yorktown.

Two crucial applications became evident when the US Navy battle-tested GPSs during the Persian Gulf War. The GPS system was used to provide precise position fixing in minesweeping operations, with the accuracy being good enough to give the minesweepers exact data on the areas already swept. The GPS system was also used to fix datalink grid lock problems that occurred when interacting radar and communications systems became out of phase in basic parameters, resulting in multiple images and sharply higher false alarm rates. These operations pointed out the benefits of GPS over the present generation Transit system, especially in regard to accuracy.

PE 0604777N, Project X0921. Most of the US Navy's GPS work comes under Program Element 066477N, Project X0921. The name of Project X0921 is NAVTAR Global Positioning System (GPS) Equipment. Project X0921 develops user equipment and enhances the capability of each platform type through the integration and testing of equipment.

In 1993 program accomplishments included continued integration of engineering on various platforms such as E-2C(UD), F-14D, and S-3B. Other 1993 activities included completion of the Miniaturized Airborne GPS Receiver (MAGR) test and evaluation (T&E) for Milestone III.

During 1994 and 1995, integration engineering on various platforms progressed and the development of the TAMPS software continued. Work also continued on integration with shipboard C^2 systems along with work on Navigation Sensor System Interface (NAVSSI) software design and integration.

In 1996 and 1997, the US Navy continued platform integration. In 1998 the integration engineering on various and numerous platforms continued. Other activities included continuation of NAVSSI upgrades and the continuation of logistics element development and testing. Evolutionary upgrades included the collection/distribution of precise navigation and time data from/to gun weapons systems, the Joint Maritime Command Information System, HAVEQUICK Radio, Ring Laser Gyro Navigator (RLGN) Combat DF, ATWCS, Battle Force Tactical Trainer (BFTT), Fiber Optic Digital Multiplexing System (DMS), Doppler Sonar Velocity Log (DSVL), and SQS-53 sonar.

Project X0921 activities in 1999 included the continued integration of upgraded GPS units into various naval and maritime aircraft, the continued NAVSSI upgrade, and the continued logistics element development. Other activities included the development of solutions to the GPS vulnerability problem and the development of complementary navigation prevention capabilities for incorporation on selected Naval air, surface, and subsurface platforms.

In 2000, Project X0921 continued NAVSSI upgrade work. Moreover, Project X0921 began the NAVWAR air integration study for the CH-60S and SH-60R. The study will determine the feasibility of integrating the GPS JPO production antenna (GAS-1) on various platforms. In 2001, the project continued the development of the Interactive Electronic Technical Manual (IETM). Once fully developed the IETM will meet the standards of the current NAVSSI Block.

In 2002, look for Project X0921 to initiate NAVWAR anti-jam antenna and receiver integration on the F/A 18C/D and the AV-8B. Also expect Project X0921 to begin evaluation of Navy platform GPS Modernization integration requirements.

Note: For more details on aircraft-based GPS, please see the report titled "NAVSTAR GPS Airborne Terminals" in the *Airborne Systems* or *Electronic Systems* book.

Shipboard GPS. In February 1995, the US Navy announced it planned to replace the WRN-6 GPS receiver on board its surface ships and submarines with one consisting of a single electronics card in the VME (Versa Module Eurocard) form factor. The GPS VME Receiver Card is intended primarily for integration into the NAVSSI which consolidates inputs from all navigation systems on board and provides position, velocity, and timing information to a variety of weapons and other users. The US Navy foresaw the procurement of some 800 units as non-developmental items between 1996 and 2001.

The US Navy awarded Trimble a US$2.972 million contract in January 1996 for an initial delivery of 25 receiver cards with an option for up to 1,250 additional units. The receivers provide Precise Positioning Service (PPS), including position, velocity, and time. The 25 units underwent qualification and integration testing during 1996.

Undersea GPS. Using GPS for underwater navigation tends to be a bit of a problem; however, it has been achieved by using buoys and incorporating GPS systems into submarine periscopes. Sagem offers a range of fits on its periscopes and non-hull-penetrating electro-optical periscopes. Spears Associates (USA) also produces compact GPS antennas for submarine refits.

Underwater combat swimmers such as the US Navy SEALs and the US Special Operations Command can procure the Miniature Underwater GPS Receiver, known as MUGR (mugger), jointly built by Trimble Navigation and Battel. MUGR is half the size of current portable GPS units and is waterproof. It is illuminated so it can be used in the dark, has a simple keypad, and achieves a very quick satellite fix. A special antenna that floats on the water's surface is also being developed for the system. Until the development of MUGR, SEALs typically had to hold the GPS unit out of the water in order to get a position reading.

Note: For full details on Sagem electro-optical GPS-equipped periscopes, please refer to the "SAGEM Periscopes" report in the *Electro-Optical Systems* book.

Related Activities. Related activities include PE#0603203F – Advanced Avionics of Aircraft, PE#0603601F – Conventional Weapons Technology, and PE#0305164F – NAVSTAR GPS User Equipment. These are USAF program elements that contribute to the development and test of GPS receivers and associated peripheral equipment.

UK Navy. The UK Royal Navy (UKRN) announced in April 1997 that it planned to equip six of its Hydrographic Surveying Squadron ships with commercially available differential GPS systems between April 1997 and April 2000. Although no additional information was made available, it is expected that this enhancement took place as scheduled.

US Coast Guard. The US Coast Guard initiated its DGPS service in 1996. It uses a network of 200 radio beacons to transmit the digital signal throughout the country in order to create a fixed grid of known reference points to improve the accuracy of the US DoD's signal. The Coast Guard has already installed a prototype DGPS system at Montauk Point, Long Island, that offers an accuracy of about 10 meters.

The push for the nationwide DGPS service came from overall Transportation Department policy to improve safety in the harbor approach areas of the US with a radio navigation system that provided from 8 to 30 meters of accuracy. By spring 1995, the Coast Guard already had expanded its DGPS service to three other sites: Whidbey Island and Robinson Point, Washington, and Sandy Hook, New Jersey.

In April 1995, the Coast Guard officially activated its new automated dependent surveillance system (ADSS) in Prince William Sound. ADSS automatically plots vessel positions on an electronic chart display using GPS. The system is manufactured by Raytheon Marine Co and is said to have an accuracy of less than 10 meters. ADSS was part of a six-year, US$17 million effort, hastened by the SS *Exxon Valdez* oil spill disaster in 1989. The system has audible instructions to alert a ship if it is too close to navigation hazards. Raytheon won the US$5.6 million contract from the Coast Guard for the VTS system which is a key component of ADSS. Raytheon also has a similar system operating in Malaysia and Indonesia.

US Marine Corps. The US Marine Corps (USMC) and the US Navy have worked toward the integration of the GPS system with the Position Location Reporting System (PLRS), used by the USMC to provide rapid position location information for all its units. Integration with GPS resulted in improved tactical awareness and a greatly enhanced capability to execute combined-arms operations. The interface unit automatically updates PLRS with data taken from GPS, thus anchoring the PLRS system and avoiding the time-intensive process presently required to determine the position of the PLRS node selected as the reference point for all the other PLRS nodes. The new capability is expected to be especially beneficial for maneuver control and fire support coordination.

Commercial Maritime GPS. Today's commercial off-the-shelf (COTS) GPS receivers, such as those used in recreational boating, have a large amount of computing power. They are capable of displaying latitude and longitude coordinates, and calculating course, bearing, and distance, speed, crosstrack error, and estimated time of arrival. This data is can be displayed graphically or numerically and some models can store up to 1,000 waypoints and dozens of routes.

For the vast majority of civilian boaters, the standard 100 meter accuracy available through GPS is quite adequate. For those who may need to navigate tight channels and narrow waterways, Differential GPS can compensate by bringing the accuracy to within a few meters.

GLONASS. The Commonwealth of Independent States (CIS) has deployed its own version of NAVSTAR, called GLONASS (Global Navigation Satellite System).

Like the American GPS system, GLONASS uses satellite transmitters to provide a position-locating service to mobile users on the ground, in the air, and at sea. Similarities include orbital altitudes, orbital periods, and orbital inclinations. Furthermore, both use two types of transmissions at the same time, as well as binary phase-shift keying, and both occupy the L1 and L2 bands.

GLONASS satellites originally tended to have a life-span of only one year; however, the Russians are claiming the satellites have been improved to last from five to seven years.

The GLONASS system draws a lot of interest due to its high precision, especially in determining aircraft position during final approach, and in the upper Northern hemisphere. The European Community sees GLONASS as an inexpensive way to enter the field of space technology that will be a major benefit to European air carriers.

The first launch was conducted in 1982, followed by launches in 1983, 1984, and 1985, with two launches of three satellites each year, resulting in a constellation of 21 satellites. In 1996, it was reported that all 24 constellations were in orbit and GLONASS was fully deployed. In November 1997, it was reported that only 14 or 15 satellites in GLONASS were operational. New launches were then scheduled, one to take place in 1997 and two triple launches in 1998. These would put GLONASS back in working order.

Unfortunately, before GLONASS can be considered a navigation system candidate alongside GPS, two questions have to be addressed: 1) Can GLONASS provide the levels of accuracy and integrity needed for a primary global navigation/ATC aid; and 2) How compatible is GLONASS with current/planned systems under development in the US and Europe?

In 1999, Russia reportedly announced that Spirit Corp is offering licenses for the hardware and software, which it had developed for receivers using GPS and its Russian equivalent, GLONASS. Spirit's plans tout a compact, low-power, and inexpensive all-in-view 24-channel (12 GPS and 12 GLONASS) receiver. The receiver has been described as providing a positional accuracy of 15-20 meters and velocity to within.02m/s. Additional plans/designs are reportedly available.

Miscellaneous. In January 1999 it was announced that the Australian DoD had awarded a contract to Rockwell Collins for the production of vehicular and non-vehicular Precision Lightweight Global Positioning System Receiver IIs (PLGR IIs). The PLGR IIs are expected to be installed in armored fighting vehicles and naval ships. Deliveries reportedly began in June 1999 and continued through 2000. (It has been reported that a total of 3,400 PLGR IIs were produced and delivered to Australia. It is estimated that an eighth of these units, about 425, will be allocated to naval applications.)

It was reported in June 1999 that the New Zealand Ministry of Defense issued an invitation to industry to submit bids for the supply of wide-area differential GPS units to the Royal New Zealand Navy. Five such systems appear to be scheduled for future procurement. Also in June 1999, it was declared that the US Navy received its first delivery of GPS receivers designed to make deck-mounted projectile guns "smart" through the use of GPS signals. Up to 300,000 short-range fire-support guns should ultimately be equipped with this system developed by Interstate Electronics Corporation.

Another GPS development in June 1999 was the Office of Naval Research contract, awarded to Potomac Photonics, for the construction of a complete work-station which is expected to include a GPS unit the size of a credit card. The workstation is scheduled to be delivered to the US Navy by June 2003.

Funding

US FUNDING - RDT&E

	FY00		FY01		FY02(Req)	
	QTY	AMT	QTY	AMT	QTY	AMT
RDT&E (US Navy)						
PE#0604777N						
Project X0921[(a)]		11.0		13.6		13.7

	FY03(Req)		FY04(Req)		FY05(Req)		FY06(Req)	
	QTY	AMT	QTY	AMT	QTY	AMT	QTY	AMT
RDT&E (US Navy)								
PE#0604777N								
Project X0921		Unknown		Unknown		Unknown		Unknown

All US$ are in millions.

Source: US Department of the Navy FY2002 RDT&E Descriptive Summary

Note: This administration has not addressed funding requirements for FY2003-2007.

[a]Project X0921 NAVSTAR GPS Equipment develops US Navy user equipment, integrates and tests this equipment on each class of application (aircraft, surface ship, and submarine), and does the planning necessary to support the equipment when introduced to the Fleet.

Recent Contracts

The following contracts focus on GPS terminals used at-sea. For contracts covering naval aviation and aircraft, please refer to the report "NAVSTAR GPS Airborne Terminals" in the *Airborne Electronics* and *Electronic Systems* books.

Contractor	Award ($ millions)	Date/Description
Trimble	unknown	Sep 1997 – Trimble Navigation Europe supplied the UK with six 7400 Msi-based GPS units for use on the UKRN's degaussing ranges.
SCI Technology	6.2	Mar 1998 – FVI to an FFP contract for 176 3A receivers applicable to the NAVSTAR GPS system and associated engineering services, in support of the F-15, F-16 and E-3 aircraft. Completed March 2000.
Rockwell Collins	18.0	Jan 1999 – Contract awarded by Australia's DoD to produce vehicular and non-vehicular PLGR IIs for use in armored fighting vehicles and naval ships. Deliveries began June 1999 and continued through 2000.
Potomac Photonics	7.8	Jun 1999 – Contract to construct a complete workstation which will be able to more effectively fabricate advanced circuitry of use to the US Navy. System demonstration will consist of production of a credit-card-size GPS unit. Work is scheduled to be completed by June 2003. (N00014-99-C-0236)

Timetable

Year	Major Development
FY 1973	Milestone I - concept validation
FY 1974	Initial space segment contract to Rockwell; General Dynamics receives control user contract
FY 1978	NAVSTAR 1, 2, 3, 4 launched
FY 1979	Phase 2 development contract; Milestone II; Block 1 replenishment satellite contract
FY 1980	First Minuteman 3 with NAVSTAR receiver launched; NAVSTAR 5 and 6 launched
FY 1981	NAVSTAR 7 launched, destroyed in booster failure accident
FY 1982	Rockwell awarded long-lead parts contract for Block 2
FY 1983	Rockwell receives Block 2 NAVSTAR contract, 1st transatlantic flight using NAVSTAR; NAVSTAR 8 launched; Congress asks for civilian use of NAVSTAR
FY 1984	NAVSTAR 9 launched via an Atlas-E; NAVSTAR 10 launched
FY 1985	McDonnell Douglas contract for 28 PAM-D11 upper stages; Rockwell Collins awarded initial user equipment contract; 1st NAVSTAR launch via the Space Shuttle; NAVSTAR 11 launched
FY 1986	Collins manpack approved for LRIP; program delayed due to failure of Delta and Titan 34D rockets; EURONAV announces Milestone IIIA – limited-rate initial production achieved
FY 1987	1st Collins GPS and 3S 5-channel receiver user equipment delivered to USAF and US Navy
FY 1988	Negotiations to merge GPS and GLONASS announced

Year	Major Development
FY 1989	1st Block II GPS satellite launched; Milestone IIIB – full-scale production originally scheduled
FY 1990	SCI awarded user equipment contract
FY 1991	DEM/VAL for GPS/PLRS interface unit for Marine Corps
FY 1992	Contract awards for GPS/PLRS interface units; USAF user equipment Milestone III; US Navy MS IIIB delayed; Launch of 13th, 14th, 15th, 16th, and 17th NAVSTAR GPS
FY 1993	Launch of 18th, 19th, 20th, 21st, 22nd, and 23rd NAVSTAR GPS
FY 1994	Launch of 24th NAVSTAR GPS
1995	Final operations capability of 24 satellites
1996	Initial Block IIR deliveries, Launch of 25th, 26th, and 27th NAVSTAR GPS
1997	C4ISR analyses and studies conducted; 1st Block IIR GPS satellites orbited
1998	Design/development/testing of GPS antenna for Navy tactical aircraft and helicopters begun
1999	Continued NAVSSI upgrade
2001	Final Block IIR deliveries; initial deliveries and launches of Block IIFs
2002	Raytheon's JPALS to possibly enter engineering and manufacturing development stage
2004	Potential IOC for JPALS system

Worldwide Distribution

In lieu of **US-**made military-capable GPS receivers, many nations are purchasing commercial models which are proving to be highly efficient at a fraction of the cost. Still, many nations are developing their own GPS receivers.

In April 1978, an MoU was signed with nine **NATO** allies and with Australia to permit **NATO** and **Australian** participation in developing GPS user equipment. The MoU created an international team at the US Joint Program Office. Nations involved were **Australia**, **Belgium**, **Canada**, **Denmark**, **France**, **Germany**, **Italy**, the **Netherlands**, **Norway** and the **UK**. In 1987, **Spain** became the tenth NATO signatory to the MoU. In 1991, Australia signed an agreement for 20 years in duration that allows access to PPS and the purchase of production user equipment. In 1991, a new NATO MoU which expired at the end of 1993 added **Greece**, **Portugal** and **Turkey**. A new MoU with a duration of 20 years is under negotiation with NATO countries to cover the operational phase of GPS, access to PPS, security of PPS, and development, production, and marketing of PPS user equipment.

Australia. The Australian Navy awarded Magnavox a US$1.1 million contract in 1988 for the company's GPS upgrade for existing Magnavox MX 1100 SATNAV receivers. A total of 37 ships received the upgrade kit. In February 1989, a notice appeared in the *Commerce Business Daily* that the Australian Defence Forces were seeking high-dynamic GPS receivers for their ships and aircraft, and low-dynamic GPS receivers for manpack applications. Collins is apparently involved in four different GPS programs for the Australians, including the S-70 Seahawk and the new submarine class. In early 1992, GEC-Plessey Avionics (now BAE Systems) was awarded a contract to supply the ANZAC frigate program with its PA9154 GPS receiver. In January 1999, Rockwell Collins was awarded a contract for approximately 3400 PLGR IIs – about 425 are anticipated to have naval applications.

China. Leica Navigation and Positioning Division (US) won a contract from the Chinese Maritime Safety Administration for a DGPS beacon system at Qinhuangdao in March 1995. The system provides positioning accuracy throughout the Bohai Sea and parts of the northern Yellow Sea.

France. The French Navy adopted Thomson-CSF's SNNS 90 receiver, which it builds under license from Magnavox, to equip ATL2 maritime-patrol aircraft, nuclear-powered submarines, and large surface ships. In March 1993, Sextant Avionique was awarded the contract to build the first European GPS receiver for a satellite.

The French Navy's Service Hydrographique et Oceanographique de las Marine (SHOM) ordered Racal Positioning Systems (UK) SkyFix DGPS, in April 1994, for surveying in the Mediterranean and French coastal waters and in the Pacific Ocean around New Caledonia.

Germany. In 1987, the German Navy awarded Collins a US$1.98 million contract for shipboard GPS sets (WRN-6s), with deliveries beginning in late 1988. The user equipment contract awarded to SCI in September 1990 also included an unspecified amount of FMS deliveries of WRN-6s to Germany.

Indonesia. Indonesia is reported to have begun installation of a Differential GPS network (summer 1996) in order to improve offshore navigation of ships and helicopters (both civilian and military). According to defense industry media sources, the Norwegian company Seatex is supplying Indonesia with six Searef reference stations that are linked via dedicated satellite to a central control and monitoring station in Jakarta, with differential corrections being distributed to mobile users through Indonesia's PAS geostationary satellite system.

Japan. The Japanese appear to be making their major effort for GPS in the commercial area. Pioneer Electronics Corp and Trimble Navigation announced in late 1989 the forming of a joint venture company to produce GPS mini-receivers that would be used in cars, small airplanes, and helicopters. Production began in Japan in fall 1990.

The Netherlands. In late 1989, the Royal Netherlands Navy awarded GEC-Plessey Avionics (now BAE Systems) a contract for five-channel Precise Positioning Service receivers for the entire Navy fleet. Deliveries began in 1990 and continued through 1995. In 1991, Trimble Navigation supplied a Royal Netherlands Marine battalion, on deployment to Cambodia with 50 Spartan GPS receivers; these are civilian versions of the military TRIMPAK.

Norway. The Royal Norwegian Navy awarded a US$736,000 contract to Collins in 1988 for GPS shipsets (based on the 3S receiver) to equip its ULA submarine class. In mid-1990, the Royal Norwegian Navy awarded GEC-Plessey Avionics a contract for 14 sets of differential GPS receivers.

Sweden. In August 1996, it was reported that the company FFV Aerotech had been selected to integrate 117 units of the Trimble Pro DGPS receiver with the onboard surveillance radar on the Royal Swedish Navy's Combat Boat 90-H craft. Such a combination is expected to enhance the vessel's navigation in the archipelago islands off Sweden's east coast.

UK. In 1988, the Ministry of Defence announced that it was seeking a single contractor to equip all UK Royal Navy ships with GPS receivers. In 1989, it was revealed that the British government had decided to fund its own technology for domestic GPS needs. The British company GEC-Plessey Avionics has developed the PA9000 family of GPS receivers which includes airborne and naval variants. The Royal Air Force had deployed the PA9052 onboard Tornados and Nimrods during the Persian Gulf War. The equipment had also been selected for prototypes on the Royal Navy's EH-101 helicopters. In January 1993, Cossor Electronics Ltd was awarded a contract to supply military GPS to the RAF's Nimrod maritime reconnaissance aircraft fleet. This is the first Mod procurement of unclassified military avionics GPS. Previous orders were met by more limited systems and the Mod sought to rectify known shortfalls as soon as possible.

On the civil front, Next Destination Ltd (UK) won a contract in March 1995 from the UK's Fisheries Department for automatic position recording systems using GPS. The system is used for vessel tracking. The company reported that most European Union countries are testing GPS systems for ship tracking. The European Union will decide if satellite-based or terrestrial-based position recording systems will be installed on board Europe's fishing fleets.

US. The US appears to be the largest GPS user, with orders for Collins and Garmin receivers of various types, Raytheon TI Systems (formerly Texas Instruments) manpacks, Magellan handheld units, and Trimble small receivers. There are a wide variety of developmental programs for various specific applications.

Forecast Rationale

The Navigation Signal Timing and Ranging (NAVSTAR) Global Positioning System (GPS) is a constellation of orbiting satellites that provides navigation data to military and civilian users all over the world. The system is managed by the United States NAVSTAR GPS Joint Program Office at the Space and Missile Systems Center, Los Angeles Air Force Base, Calif.

As indicated by the Ten-Year Outlook chart, Forecast International expects consumer demand for NAVSTAR GPS Naval & Maritime Terminals to be strong over the next decade. This healthy purchasing behavior is driven by the superior navigation capabilities of the NAVSTAR Global Positioning System.

The NAVSTAR constellation, and thus the terminals that use it, are expected to be operational for some time to come. The need for modern, smaller, and more efficient GPS terminal and receiver systems is also expected to continue. That said, Forecast International expects consumer demand for NAVSTAR GPS Naval & Maritime Terminals to be healthy.

Note: The following forecast figures are for worldwide military/governmental naval applications. Commercial and civilian maritime uses are not included in these figures.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR PRODUCTION

			High Confidence Level				Good Confidence Level			Speculative		
Designation	**System**	**Thru 00**	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**Total 01-10**
NAVSTAR GPS	GPS (VARIOUS)	4075	350	300	275	200	100	100	100	100	100	100	1725
NAVSTAR GPS	Prior Prod'n:	425	0	0	0	0	0	0	0	0	0	0	0
Total Production		4500	350	300	275	200	100	100	100	100	100	100	1725