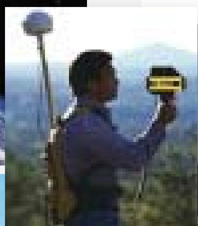
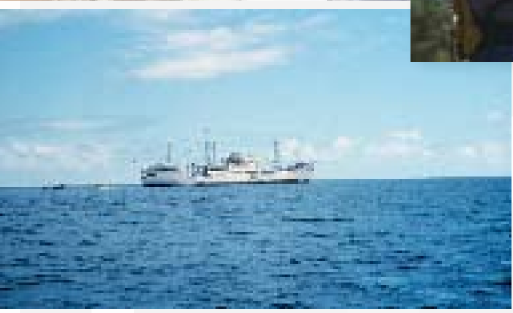
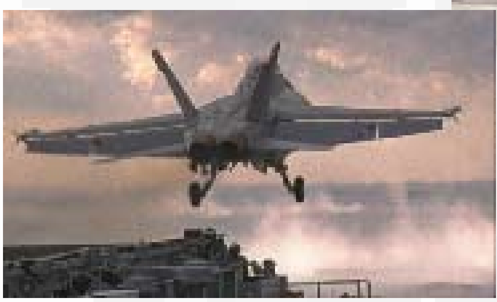
GPS

—an extraordinarily sophisticated technology with a remarkably simple operating principle…







For centuries, the only way to navigate was to look at the position of the sun and stars and use dead reckoning. Even after modern clocks were developed, which made it possible to find one's longitude, the most accurate instruments could yield a position that was accurate only to within a few miles. It wasn't until the study of relativity and Einstein's physics captured the minds of scientists that highly accurate clocks were created and later put to a unigue use, in combination with satellite tracking technology, to satisfy the basic human desire to know where we are and where we are going. That unique use led to GPS.

The history of GPS is an account of how basic research made possible first a vital defense technology and then a variety of important commercial applications. Many other technological advances also contributed to the development of GPS, among them satellite launching and control technologies, solid state devices, microchips, correlation circuitry, time-difference-of-arrival technology, microwave communication, and radionavigation.

Gunther Greulich, former president of ACSM, presents, on the following pages, another historical account—one that looks at GPS from the perspective of the ACSM community.

The Sky is the Limit—GPS and its roots

—by Gunther Greulich

Some 20 years ago, global positioning, a vital technology built by the U.S. Department of Defense primarily for military use, had reached a point when it became attractive to public and private commercial interests. Within ACSM, geodesists in particular had promoted the idea of a global positioning system (GPS), and they have been instrumental in advancing the civilian version of the technology through their work. Many land surveyors soon became aware of the enormous potential of GPS in their private practice, and, after some hesitation, embraced it as a new high-tech measuring tool. Today, there are few surveying companies in the U.S. that do not use GPS in some form or fashion.

The American global positioning system has its roots in the fierce competition between U.S. and the Soviet Union to be the first in space. On October 5, 1957, just one day after the Soviet Union launched Sputnik, researchers precisely determined the satellite's orbit by analyzing the Doppler shift of its radio signals—the frequency of the satellite's radio signal increased as it approached Earth and decreased as it departed. Frank McClure, the then head of the Research Center at the U.S. Navy's Applied Physics Laboratory in Maryland, went a step further by suggesting that if the satellite's position were known and predictable, the Doppler shift could be used to locate a receiver on Earth; in other words, one could navigate by satellite.

In the years that followed Sputnik's launch, the U.S. Navy experimented with a series of satellite navigation systems. One of the early systems was NNSS, the Navy Navigation Satellite System, better known to the public as Transit. Conceived at the Applied Physics Laboratory in the late 1950s, the system's first prototype satellite was launched in 1959; Transit entered Naval service in 1964. Navy's Transit positioning system consisted of six satellites orbitting the Earth at an altitude of 1,100 km, and its initial purpose was to provide passive, all-weather global navigation for submarines and surface ships carrying Polaris nuclear missiles. From 1967, certain bandwidths of the Transit signal became available for use on commercial ships and aircraft of all nations.

NOAA/NGS GPS station #60 at Culgora, New South Wales, Australia [http://www.photolib.noaa.gov/geodesy].

Eventually, the number of commercial, cruise, and sporting vessels using satellite-based navigation was in the tens of thousands—far outnumbering the military users. Transit proved essential for the recovery at sea of early manned space vehicles, and it became the standard for precision land surveying and the locations of platforms at sea. Fairly accurate, always available navigation improved the safety and efficiency of shipping operations around the globe.

Yet, despite its meteoric rise, Navy's brainchild, Transit, had, in the Pentagon's eyes, shortcomings; the most serious were time gaps in coverage resulting in navigational accuracies insufficient for defense purposes. A new direction was needed to develop a foolproof, highly accurate method of satellite navi-

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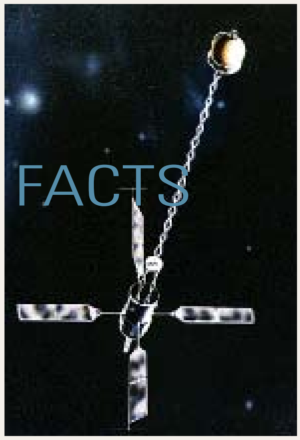
TRANSIT FACTS



The National Academy of Sciences- affiliated BEYONDDISCOVERY.com

The Transit constellation consisted of two types of spacecraft designated as Oscar (pictured left) and Nova (right). The final constellation consisted of six satellites (all Oscars) in a polar orbit with a nominal 600 nautical mile altitude, three ground control stations, and receivers (i.e., the system's users). Of the six satellites, three Oscars provided navigation service while three other Oscars were "stored-in-orbit" spares.

The Transit system spawned a number of space "firsts," including the two-frequency method for correcting ionospheric error. Additional improvements during the life of the system included development of satellite compensation for drag and radiation pressure, the use of pulsed plasma micro-thrusters, and hardening of the spacecraft against an enhanced radiation environment.

The development of Transit demanded great strides in many areas of space science and technology, including electronic devices, circuit and packaging design, advances in mechanical design, new materials, control of satellite operations, software development, and the use of modeling and simulation.

Today, the legacy of Transit may be seen in the application of many of its innovations and discoveries to scientific and engineering endeavors and to products that benefit mankind. These include the following:

Space Technology. Transit pioneered many areas of space technology, including stabilization systems, advancing time and frequency standards, multiple spacecraft launchings, and the first electronic memory computer in space. Each of these advances benefited America's space program.

Geodesy. Transit both required and made possible great advances in the knowledge of the Earth's gravitational field, thereby dramatically improving satellite tracking capabilities.

Space Science. Transit engineering and research satellites made the first measurements of low-energy protons in the polar regions, discovered auroral field-aligned currents, and detected and measured the artificial radiation belt created by the Starfish high-altitude nuclear test in 1962. This early work led to programs for NASA and other agencies.

Health. Transit technology spurred the development of many devices to improve our quality of life, including a rechargeable cardiac pacemaker, programmable implantable medication system, automatic implantable defibrillator, and a system to treat autistic children.

In October 1996, APL was cited by the Department of Defense for its achievements in the development of the Transit Navy Navigation Satellite System. The citation noted the Laboratory's innovations and achievements in developing the system and the fact that over 30 years of operation, hardware upgrades to the tracking system were required only three times."

At the end of 1996 Transit, the Navy Navigation Satellite System, was retired after more than 32 years of continuous, successful service to the U.S. Navy.


Sputnik, 1957 [www.celestiamotherlode]

gation. Following an intensive brainstorming session at the Pentagon over the Labor Day weekend of 1973, a new concept of a highly accurate spaceborne positioning system based on atomic clocks and a system of satellites was approved. GPS as we know it today was born.

ACSM in the GPS orbit

Given the enormous impact that GPS has had on surveying, and given that many of our members researched, built, or applied GPS in their work when it was being developed, perhaps an account of ACSM's involvement with GPS may be in order.

This involvement started as early as 1977, when a paper was presented at the 37th Annual Meeting of ACSM on "Satellite Positioning," which described the adaptation of the Transit system for civilian purposes. Eight years later, the National Geodetic Survey of the U.S. Department of Commerce, a sustaining member of ACSM, held, in conjunction with the Defense Mapping Agency "The First International Symposium on Precise Positioning with the Global Positioning System," in Rockville, Md. The symposium was attended by 600 participants, nearly 30 percent of whom came from foreign countries!

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The Navigation System and Ranging, NAVSTAR, and GPS were the main points of attraction.

In 1990, I presented a motion to the ACSM Board of Directors to appoint an ad hoc committee to document the research leading up to the development of GPS, identify the scientists involved in this innovative research, and submit their names and their great contribution to mankind to the Nobel Prize Committee for consideration. The motion failed.

This negative stance came as a surprise, and not only to me personally. Dr. Patricia Caldwell Lindgren, then president-elect, was "surprised that the Board did not find this project of interest." Capt. Sam Baker, ACSM president, was shocked into asking, "Why would the Board reject a motion that could only bring praise to our organization?" Still others proposed compromise solutions. One of them was Martin Menk, a surveyor board member from Minnesota, who offered to use his connections with the Gustavus Adolphus College, the seat of the annual Nobel Conference, to explore the options for nominating GPS innovators for the Nobel Prize.

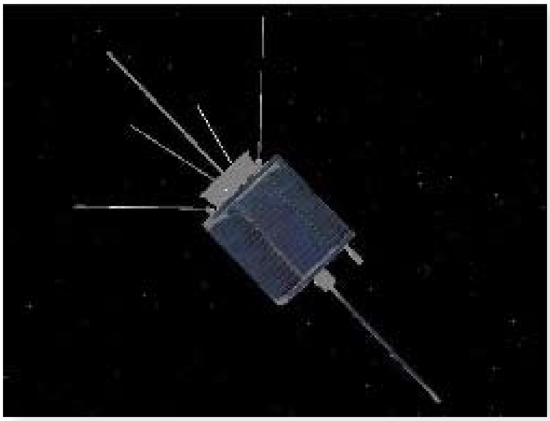

Explorer, an early U.S. satellite [www.celestiamotherlode]

With hindsight, the fate of my motion was not surprising. Awareness within ACSM of how profoundly GPS would change surveying and mapping was still rather limited in those days. However, Capt. Baker predicted, in a letter to the ACSM Board dated 12 April 1990, that "GPS will touch and benefit every living person on this Earth, for many years to come." He was right on the dot.

Sometime after the Board meeting, specifically on July 17, 1990, Lindgren acted, as President of ACSM and consistent with ACSM by-laws; she ignored the Board's earlier rejection and appointed an ad hoc committee. In her opinion, "No matter what the eventual results of the Committee's work (other prizes? National magazine coverage?), the efforts to recognize those who have made a significant contribution to our profession is, in itself, a worthwhile endeavor for ACSM to pursue."

Former president Sam Baker chaired the committee, which comprised former president Charlie Andregg, Board Member Martin Menk, and president-elect Gunther Greulich.

The appointment of the ad hoc committee resonated with some sections of the ACSM community. The New England Section of ACSM was one of them. In a letter to Capt. Baker on August 9, 1990, Richard F. Bastow, the Section's vice president, wrote that "The New England Section enthusiastically supports the idea."

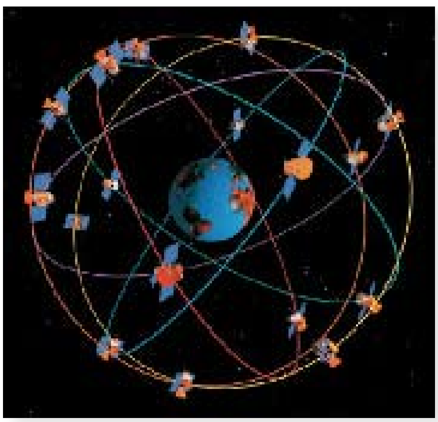


Terrier, longest-lived satellite ever; 1974- [www.celestiamotherlode]

During the course of the committee's work, several tips of who might have invented GPS came in from supportive ACSM members. The committee learned, however, that no single person had been the inventor of GPS.

In fact, two of our major military organizations, the U.S. Navy and the U.S. Air Force, had almost simultaneously conducted competing research programs for several years to develop GPS. The Air Force research program went under the heading "621-B" and the Navy's research program was named "Timation." This notwithstanding, by 1991, when I had the opportunity to speak to Col. Gaylord Green, one of the Air Force's GPS experts, the GPS concept and theory had been considered an "institutional endeavor" within the Pentagon.

Not so within ACSM. In that same year at the ACSM Convention in Baltimore, Md., for some strange reason, the GPS committee came under attack again. This time, the "kill" motion was defeated. Unfortunately, the administrative and political turmoil that befell ACSM after the convention did not bode well for the committee's continued work. Its members became discouraged, and the committee slowly faded away, without nominating a single GPS scientist or scientific organization for the Nobel Peace Prize. Nevertheless, some important information about the origin of GPS had surfaced as part of the committee's research.



Navstar GPS constellation; an early rendition with 18 satellites [www.aero.org]

The GPS race

As early as 1967, the U.S. Air Force had contracted with the famous Swiss instrument maker Kern-Wild Heerbrugg—now Leica—to conduct the first feasibility study for its GPS program "621-B." Four years later, in 1971, the Swiss manufacturer built the first prototype receivers for the program.

The Swiss also received a contract from the U.S. Navy in the same year to define, design and build early prototype receivers for the Navy's Timation program. It was this work that helped demonstrate the need of high-precision atomic clocks for accurate positioning, which were adopted for GPS.

Meanwhile the race among the Forces to be the first to build a highly accurate GPS surged ahead. The small Air Force research team, which was led by A.F. Colonel Bradford Parkinson and included Col. Green, Mel Birnbaum, Bob Rennard and Jim Spilker had, according to Col. Green, "put together the "GPS architecture in less than a month, back in 1972."

Richard Easton, son of a former head of Navy's Timation research team, tried to set the record straight on the Internet in May 2006. He claimed that his father Roger Easton had "invented GPS" and filed an enabling Patent, US #3789409, to that effect in 1974. Roger Easton was indeed the head of the Navy's GPS research team. Other members of the Navy team listed by Richard were James Buisson, Thomas McCaskill, Don Lynch, Charles Bartholomew, Randolph Zwirn and, "an important outsider," Robert Kern.

It so happens, that the important outsider was the founder of the Frequency and Time Systems company (FTS), a manufacturer of atomic clocks for GPS satellites, in Beverly, Massachusetts. He may or may not be a descendent of the famous Swiss instrument maker Kern A.G. But Kern's and his company's role in the development of GPS underlines Col. Green's characterization of the research as an "institutional endeavor"!

Ultimately, the Navstar GPS of the 1970s became the legitimate birth child of the U.S. Navy's Timation and the U.S. Air Force's 621-B programs, thanks, of course, to the authoritative midwiferly skills of the Department of Defense which brought the best features of both programs together.

The predecessors

The history of GPS development for military purposes

Navstar GPS [www.beyonddiscovery.com]

goes beyond the GPS race of the 1960s and 1970s. It goes all the way back to the 1940s, when the Massachusetts Institute of Technology developed a navigation system called LORAN. The system is still in use today by ships and boats.

Loran-C; installing a receiver [https://goby.nrl.navy.mil]

Among the LORAN researchers was Ivan A. Getting, whose research group at MIT also invented the first automatic microwave tracking radar, SCR-584. The radar was capable of tracking Germany's cruise missile V-1, which were deployed against England in in 1944.

A couple of years earlier, in 1942, two German brothers had developed and test-fired a submarine ballistic missile from a U-Boat into the Baltic Sea. Friedrich Steinhoff was the U-Boat captain. In May 1945, he became a POW at the Portsmouth, New Hampshire, Naval Base. His brother, Dr. Ernst Steinhoff, who was brought to Fort Bliss, Texas, under "Operation Paperclip" together with Wernher von Braun's German rocket team, played important roles in the U.S. Army's ordnance research and in the Air Force's Guided Missiles Development Program at Holoman AFB in New Mexico, and he was inducted in the International Space Hall of Fame in 1979.

Another forerunner was "Loon," a modified V-1 ballistic missile test-fired in 1947 by the U.S. Navy from a submarine. The V-2 ballistic missile developed in 1945 became the forerunner of Raytheon's Scud and the Patriot Missile of Desert Storm Fame in 1991.

That brings us to Ivan Getting. He left MIT in 1951 and became Raytheon's head of research and engineering in Waltham, Massachusetts. Under his leadership Raytheon developed "MOSAIC," a railroad mobile ballistic missile guidance system which was to work like the LORAN system.

When MOSAIC was cancelled, Getting envisioned a similar system, but based on satellites. This theory ultimately led to Navstar. Encouraged by the Air Force to create a non-profit military systems development organi-

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GPS policy reviews

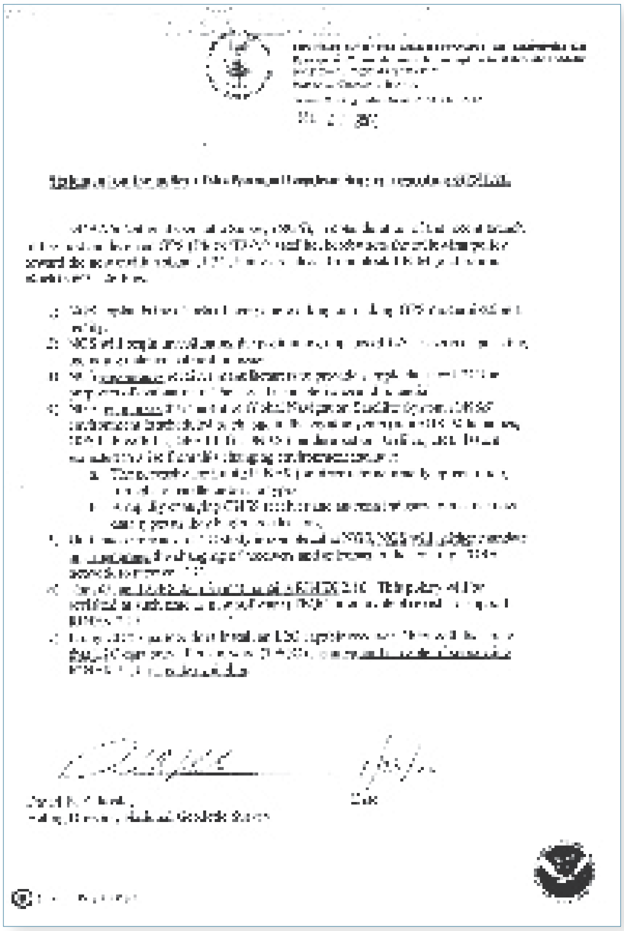
The Pentagon made the GPS system available for commercial use only after being pressured by the companies that built the equipment and saw the enormous potential market for it. Initially, a compromise policy was initiated, known as selective availability. The compromise revolved around an agreement that the most accurate signals broadcast by GPS satellites would be reserved strictly for military and other authorized users. Eventually, constellations were achieved where GPS satellites broadcast two signals: a civilian signal that is accurate to within 100 feet and a second signal that only the military can decode and which is accurate to within 60 feet. The Pentagon had also reserved the ability to introduce errors at any time into the civilian signal to reduce its accuracy to about 300 feet.

Partly due to the development of Europe's Galileo satellite navigation system and partly due to experience in Iraq I, another policy review of GPS use was initiated in 1996. A higher level of GPS accuracy was made available to everyone by Presidential Decision Directive, and the practice of degrading civil GPS signals was to be phased out within a decade. Clinton's Administration also reaffirmed the federal government's commitment to providing GPS services for peaceful civil, commercial, and scientific uses on a worldwide basis, and free of charge.

As with any new technology, progress brings risks, and GPS extended to a multitude civilian uses could potentially be misused by hostile forces. There has also been the recurring problem of repeated threats to the GPS spectrum from other positioning systems. The U.S.eventually won an international battle to protect GPS frequencies from interference from, or reallocation to, mobile satellite interests. However,a similar confrontation threatened to emerge among various U.S. agencies over new ground-based augmentations to mobile satellite systems and emerging technologies such as ultrawide band. Thus the question on Americans' minds since 2003 has been on where our priorities lie; are they with the National Differential GPS System, or with Galileo and GLONAS? And, increasingly, are they with GPS that is the basis for computer networks, banking systems, and power grids, or are they with new communications technologies that could support entirely new, tax revenue-producing industries?

Some of these concerns have already been resolved. Galileo and GLONAS and GPS are mutually interoperable, the military has a new M-code to protect its operations from interference, and civilian uses of GPS stand to benefit even further by a new L2C signal broadcast from the modernized Block IIR-M GPS satellite. The policy statement issued by the Department of Commerce's National Oceanic and Atmospheric Administration/ National Geodetic Survey following the launch is reproduced on page 28.

Despite competing interests, the future of GPS appears to be virtually unlimited. The system provides a novel, unique, and instantly available address for every square yard on the surface of the planet—a new international standard for locations and distances. To the computers of the world, at least, our locations may be defined not by a street address, a city, and a state, but by a longitude and a latitude. With the GPS location of services stored with phone numbers in computerized "yellow pages," the search for a local restaurant or the nearest gas station in any city, town, or suburb will be completed in an instant. With GPS, people will always know where they are. And that's the ultimate benefit of a once secret basic research program being put within the fingertips of ordinary citizens. [Sources: Washington View: GPS World June 2003; BeyondDiscovery.com]



zation, Getting obliged in 1960 by establishing Aerospace Corp.

However, global satellite navigation continued to be Getting's passion even while planning new ballistic missile systems and developing high-powered chemical lasers. He became an "evangelist for Navstar," relentlessly promoting it and drumming up funding. Eventually, the U.S. Department of Defense approved $12 billion for the development of a global positioning system. In 1978, the first Navstar satellite went into orbit.

The GPS Hall of Famers

At the induction of Ivan Getting [posthumously] and Col. Parkinson into the National Inventors Hall of Fame in 2004, Getting was credited with "incubating" GPS in his mind. Roger Easton received the National Medal of Technology in 2006.

GPS satellite Block II

Most everybody agrees, however, that many others were part of the several inventors' teams and deserve much credit and our gratitude, as well.

The GPS as we know it today is a product of individual vision and tenacity which over three decades produced a mosaic of military piecemeal inventions, all coordinated and pulled together by the institutional wisdom and power of the U.S. Department of Defense. Its benefits to humankind are enormous, and the sky is the limit in taking advantage of GPS—both literally and figuratively speaking.

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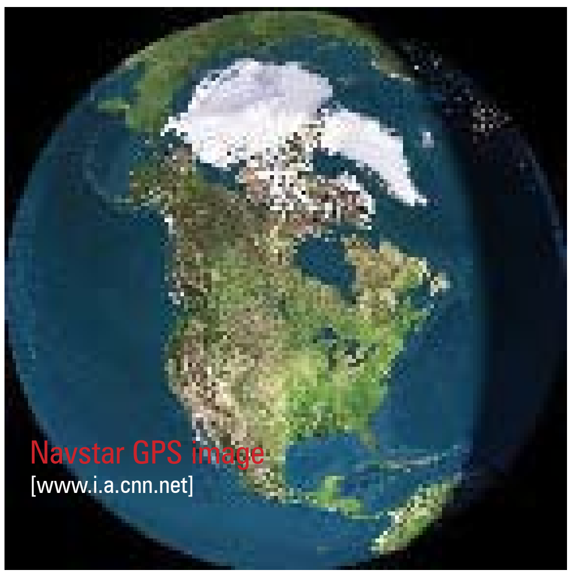

Navstar GPS image
[www.i.a.cnn.net]