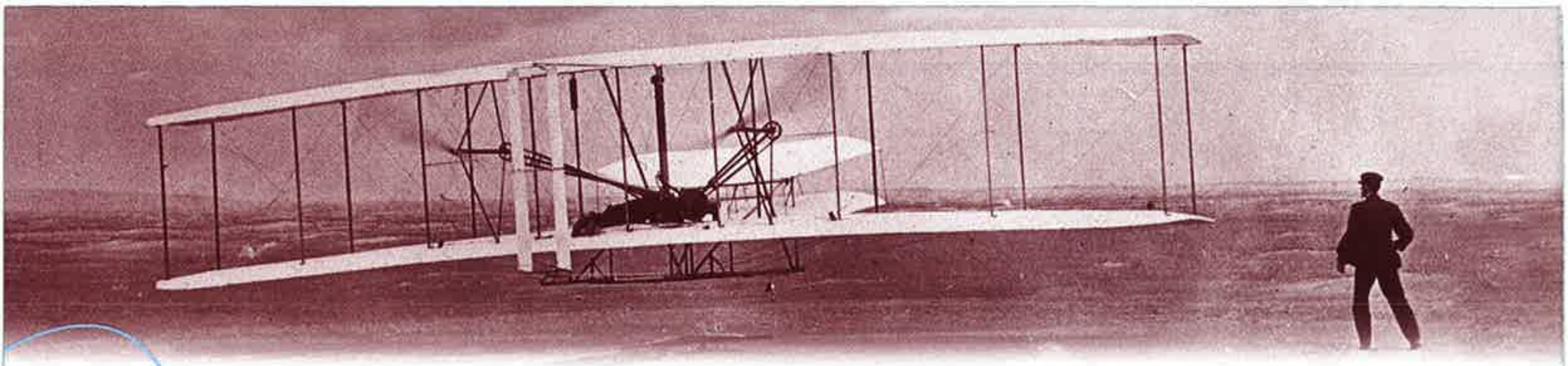
Global Positioning System



The History of Air Navigation

In 1903, the historic first flight of the Wright brothers and the subsequent development and growth of the air transport industry meant that navigation techniques appropriate for air transport were needed. In the 1930s, land-based radio beacons were used to provide bearings for aircraft from airfield to airfield. During World War II, several radio navigation systems were developed, the best-known being LORAN or Long Range Aid to Navigation. Positions were determined by the timing of signals received from different LORAN transmitter stations.

In 1957, the Soviet Union launched Sputnik, the first space satellite. One year later, in 1958, the United States launched Explorer I. With the advent of the satellite, scientists came to realize that placing radio transmitters in space could solve problems posed by land-based radio beacons. A transmitter high above the earth, which is sending a high-frequency radio wave with a special coded signal, can cover a large area with great accuracy. Satellite navigation promised that, for the first time, aircraft would be able to determine their positions at any time, anywhere in the world.

In the mid-1960s, the US Navy developed TRANSIT, the first operational satellite positioning system, to provide more accurate positions for ships and submarines. Six satellites gave worldwide coverage every 90 minutes and provided positions that were accurate to within 200 meters.[1] TRANSIT was effective, but it lacked 24-hour availability.

During that time period, the US Navy and Air Force worked on a number of systems to provide navigation capability for a variety of military applications. These systems often were incompatible with one another. Eventually, in 1973, the Department of Defense directed the development of a global satellite system. The basis for the new system was atomic clocks carried on satellites, a concept that was successfully tested in an earlier Navy program called TIMATION. The Air Force planned to operate the new system, which was the Navstar Global Positioning System. It has since come to be known simply as GPS.

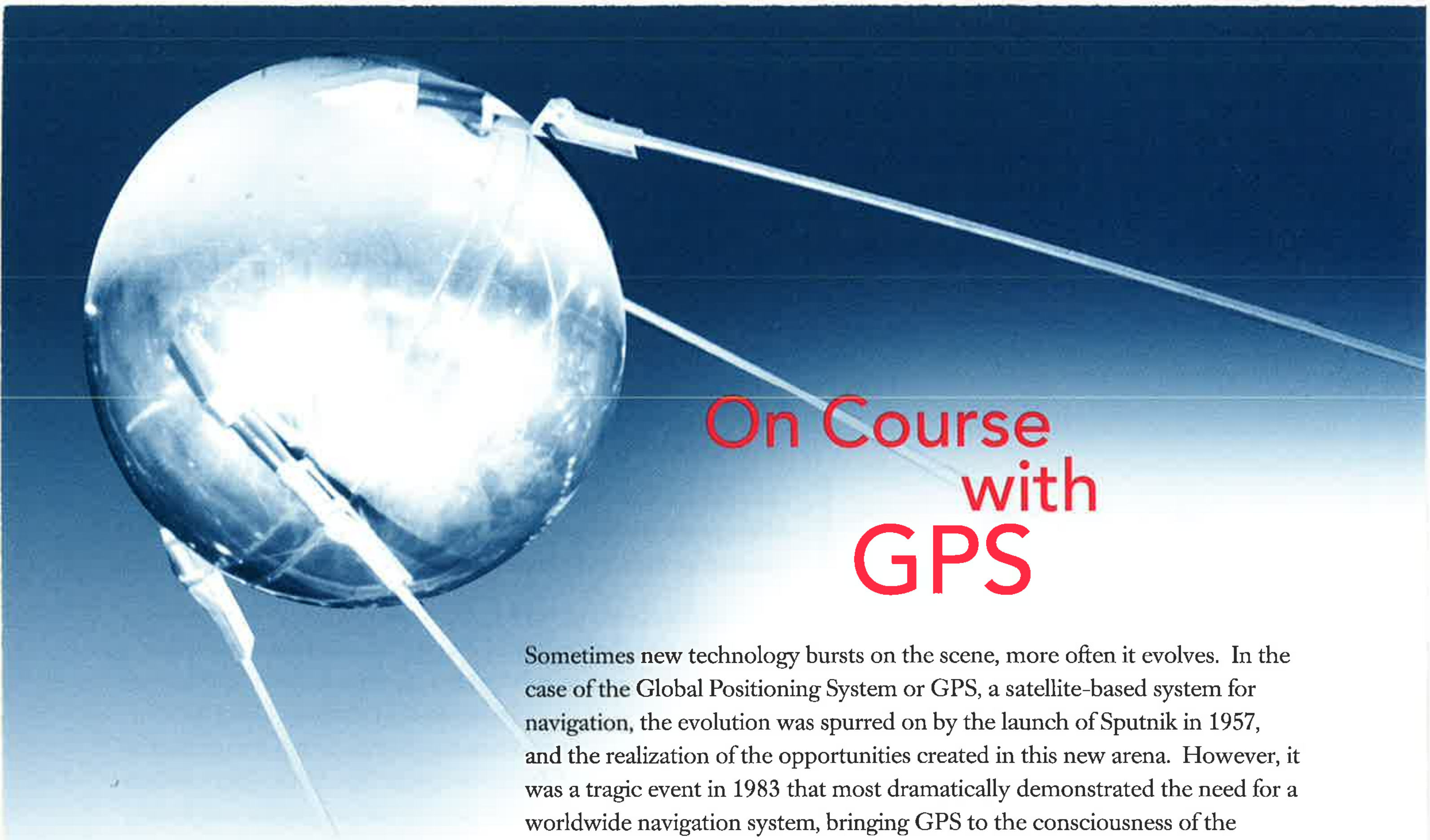
In 1994, the Senate Armed Services Committee, describing the need for a research study funded by the Department of Defense on the future of GPS, said, "It is clear that GPS offers the potential to revolutionize the movement of goods and people the world over. Civil and commercial exploitation of GPS could soon dwarf that of the Department of Defense and lead to large productivity gains and increased safety in all transportation sectors."

Since the mid-1980s, the Volpe Center and it's Center for Navigation has been involved with the use of GPS in all modes of transportation. In the early 1990s, the Center for Navigation made history when a commercial vessel was tracked for the first time in the St. Lawrence Seaway using a GPS-based system that the Center had developed. The system was based around a half-dozen portable units that used GPS to determine their location. The portable units then transmitted that information to a shore-based control center responsible for scheduling ships waiting to pass through the locks.

In 1995, the Center designed and installed a similar, but much more advanced, system in the Panama Canal. This system consists of 150 mobile units that communicate with a control center via a shore-based UHF communications network. The mobile units consist of a GPS receiver and antenna, a laptop computer, and another radio antenna for communications with the control center.

Advanced GPS navigation systems also are planned for installation in Honduras and Nicaragua as part of a Central America Reconstruction Project, sponsored by the US Agency for International Development. The intention is to provide recovery and reconstruction assistance to the region, which is still suffering from the effects of damage caused by Hurricane Mitch in 1998. The new systems will provide accurate vessel tracking and navigation in harbors and waterways in all weather conditions.

In addition to systems for ships, for the past five years, the Center for Navigation also has been working with a number of international clients on the use of GPS for air navigation. This work is described in the accompanying article.



On Course with GPS

A replica of Sputnik, the first space satellite.

Sometimes new technology bursts on the scene, more often it evolves. In the case of the Global Positioning System or GPS, a satellite-based system for navigation, the evolution was spurred on by the launch of Sputnik in 1957, and the realization of the opportunities created in this new arena. However, it was a tragic event in 1983 that most dramatically demonstrated the need for a worldwide navigation system, bringing GPS to the consciousness of the entire aviation community.

In 1983, a Korean Air Lines 747, heading for Seoul from Alaska and carrying 269 air travelers, veered off course into Russian airspace and was shot down by USSR military fighters, killing everyone on board. Although much debate surrounded the exact circumstances of this event, one thing was certain. A better navigational system might have prevented this tragedy.

At the time of the accident, the US Department of Defense was operating GPS, a navigation system that was extremely accurate. The system provided all-weather round-the-clock navigation capabilities using a constellation of satellites orbiting the earth. Unfortunately, it was only available to military ground, sea, and air forces. After the downing of Korean Flight 707, President Ronald Reagan made an historic decision, issuing a directive that guaranteed that this system would be available at no charge to the entire world.

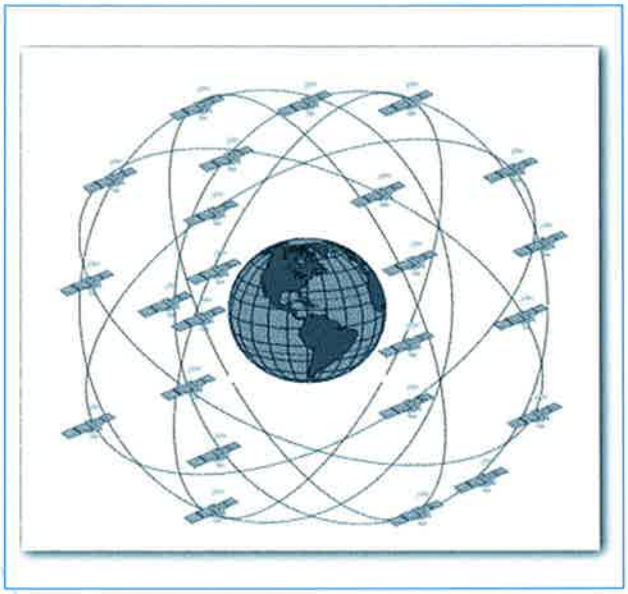
Developed more than 20 years ago, GPS is now an $8 billion industry, which is expected to double to $16 billion in the next few years. It is used in numerous civilian applications around the globe, including vehicle tracking, recreational uses such as hiking and boating, emergency response, and mapping and surveying. One of the biggest beneficiaries, however, has been aviation.

Typically, civilian aircraft navigate from one ground radio beacon, or waypoint, to another.[2] GPS simplifies and improves the method of guiding planes throughout all phases of flight. With a GPS receiver in the cockpit, pilots are provided with accurate position data and can fly a direct route to any destination, anywhere in the world. The result is significant cost savings and increases in overall system efficiency.

The Federal Aviation Administration recently has embarked on an aggressive program to make GPS available for use throughout the US National Airspace System and beyond, creating a seamless, worldwide system.

However, despite the promises that GPS brings to aviation, the system needs augmentations to meet the performance criteria for the more stringent phases of flight. In addition, GPS must be monitored to ensure that all parts of the system are working properly at all times. For the past two decades, the Volpe Center and its Center for Navigation have been instrumental in helping to achieve these goals.

Because GPS is a worldwide navigation system, the Center for Navigation also is working to share its expertise with the world aviation community, including recent projects in Australia, Germany, and most recently, Chile. The involvement of the Volpe Center offers the opportunity for other nations to capitalize on advances in GPS, increasing international safety for air carriers and air travelers around the world.



GPS consists of a minimum of 24 satellites, providing 24-hour worldwide coverage.

How Does GPS Work?

The GPS satellite constellation consists of a minimum of 24 satellites orbiting approximately 11,000 miles above the earth. The satellites, operated by the US Air Force, provide 24-hour worldwide coverage.

Each satellite continuously transmits radio signals to GPS receivers.[3] The signals give the location of the satellite and the precise time at which the signal was sent. When the signals arrive at a GPS receiver, the relative arrival times of the signals are measured. Using these measurements, the receiver computes or triangulates the position of the user.[4] A GPS receiver requires signals from at least four satellites to accurately determine its three-dimensional geographic coordinates.

The GPS system currently offers two levels of service: the Precise Positioning Service, which is available only to the Department of Defense and other authorized users, and the Standard Positioning Service, which is available free of charge to civilians worldwide.

GPS and Air Navigation

To meet the performance criteria for critical safety-of-life applications such as aviation, GPS must be able to ensure integrity, accuracy, availability, and continuity.[5] In other words, the system must be able to provide accurate readings and must be able to let a user know when it is unable to do so.

Until recently, the Standard Positioning Service provided civilian users with a horizontal position that was 95 percent accurate to within 100 meters and a vertical position that was accurate to within 150 meters. Although GPS was capable of providing much better accuracy than this, it was degraded in the interest of national security by the use of selective availability.

However, in May of this year, President Bill Clinton discontinued selective availability for the public, making the GPS system approximately 10 times more accurate. Currently, the Standard Positioning Service provides civilian users an accuracy of approximately 12 meters horizontal and 20 meters vertical (95 percent accurate).

Despite this increase in accuracy, errors in the satellite signals still can be introduced by nature as the signals travel through the ionosphere. As a result, the US Department of Transportation is implementing GPS augmentations based on a technique know as Differential GPS.

In Differential GPS, a reference station continuously monitors the GPS signals. Because the position of the reference station has been precisely surveyed, any errors in the satellite signals can be calculated and corrections broadcast to users.

Augmentation systems for aviation that use Differential GPS include the Wide Area and Local Area Augmentation Systems (WAAS and LAAS). These systems support the Federal Aviation Administration's "Free Flight" and "Safer Skies" initiatives, which are aimed at improving the safety and efficiency of the US National Airspace System.[6]

Aircraft pilots continuously must be informed about the integrity of GPS signals, that is, when they cannot rely on GPS for instrument flight rule navigation. This can happen, for example, when a satellite is "out of tolerance," which could result in an inaccurate navigation solution. Currently, algorithms known as Receiver Autonomous Integrity Monitoring (RAIM) and Fault Detection and Exclusion (FDE) determine integrity. RAIM and FDE depend on the number and geometry of satellites visible to a user at a given location. RAIM requires a minimum of five visible satellites in order to detect a failure. FDE requires a minimum of six visible satellites.[7] RAIM availability is predictable and can be provided to a pilot during pre-flight planning.

Developing a GPS RAIM Outage Prediction System

With a GPS receiver, pilots can fly a direct route to any destination in the world.

In the early1990s, the US Air Force asked the Volpe Center to develop a system for predicting RAIM availability for selected military airfields. The predictions were intended to aid pilots in planning their flights to these airfields because they would know whether they could rely on GPS. The system was based on a computer program that calculates RAIM availability for each specified airfield and predicts the beginning and end time of each outage to within one minute. In fact, this US Air Force system was so well received that the Volpe Center went on to develop a similar program for the Federal Aviation Administration.

The program determines the availability of all operational satellites. If any of the satellites are out of service, the program recalculates the outage locations and duration accordingly. When a satellite malfunctions, or is scheduled for routine maintenance, the Master Control Station in Colorado Springs, Colorado, sends a fax to the Federal Aviation Administration office that issues Notices to Airmen (NOTAMs), a service used by both military and civilian aviation. The personnel, who staff the NOTAM office 24 hours a day, ent[illegible] information into the RAIM computer program so that it can calculate G[illegible] availability.

The Volpe Center program for GPS outage reporting was presented at a 1994 International Civil Aviation Organization (ICAO) meeting. The Australian delegate at the meeting realized that Australia was going to need this type of system and arranged a meeting with the US delegate to discuss it. A year later, in 1995, Karen Van Dyke from the Center for Navigation, traveled to Brisbane, Australia, to present details of the US system at a South Pacific Air Traffic Working Group meeting.

Volpe Develops GPS RAIM Outage Reporting System for Australia

The Australian decision to implement a GPS RAIM outage reporting system was prompted largely by the 1994 partial shutdown of the Australian domestic Distance Measuring Equipment network, (DME A), which was their primary air navigation system.[8] After this shutdown, the Australian Civil Aviation Authority approved the use of GPS as a supplemental Instrument Flight Rule en route navigation aid for Australian operations. The following year, Australia approved the use of GPS as a primary means en route navigation aid. The Australian plan was to develop non-precision instrument approaches for GPS, initially as overlays of the existing approaches and eventually as stand-alone GPS approaches.

The Australian system provides pilots with GPS outage information during pre-flight planning.

After learning of the Volpe work at the ICAO meeting, Captain Ian Mallett, the Satellite Program Operations Manager for Airservices Australia, visited the Volpe Center to discuss Australian navigation requirements and plans in light of the DME shutdown. An agreement with the Volpe Center for Navigation to develop a satellite outage reporting system for Australia was signed soon thereafter in 1996.

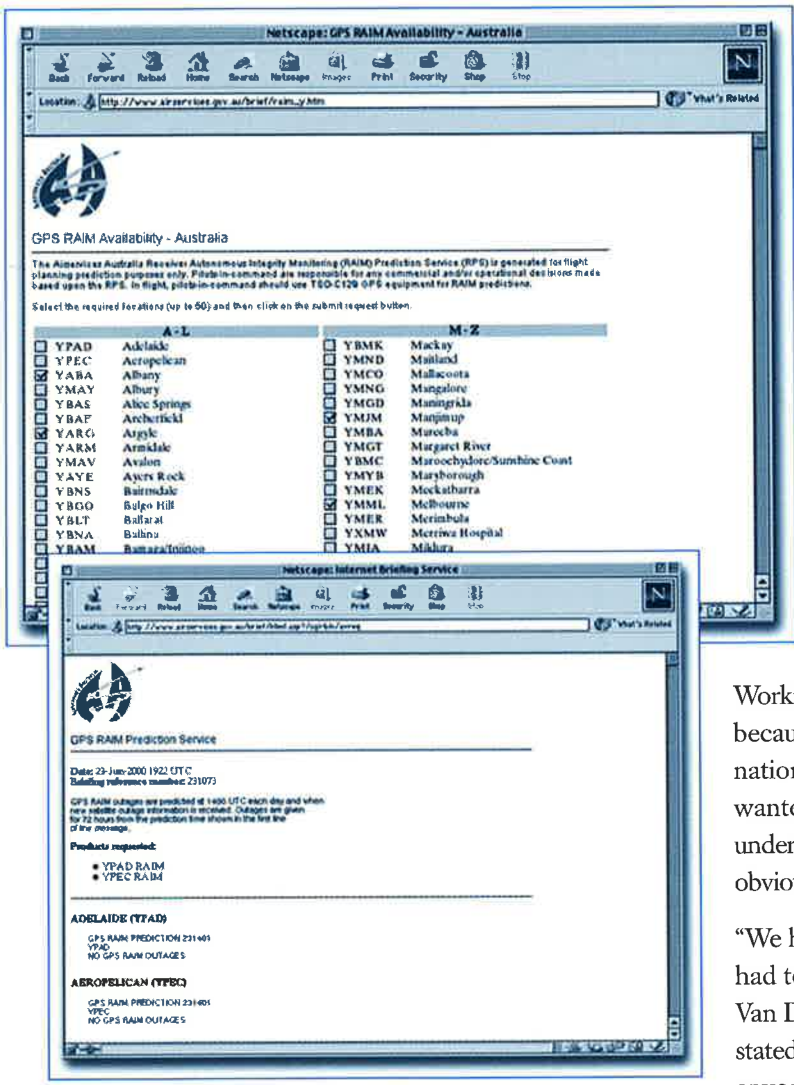
In preparation for deploying the Australian system, Karen Van Dyke met with representatives from Airservices Australia and the Australian Civil Aviation Safety Authority at a meeting in Canberra, Australia. During this meeting, Van Dyke visited with all interested parties in Australia and also flew trial GPS non-precision approach flights to several Australian airfields. In 1998, Van Dyke and Jon Parmet, also of the Center for Navigation, traveled to Australia for the installation of a RAIM prediction and outage reporting system at the Australian International Notice to Airmen (NOTAM) Office in Brisbane, Australia.

The three most important inputs to the prediction system are the GPS almanac, satellite outages, and airfield locations. The almanac data provide the precise positions of all orbiting GPS satellites at a particular time. This information is downloaded once a day from a GPS receiver and, should that receiver fail, the US Coast Guard Internet Web site is used as a backup.

GPS satellite outage information (data on satellites that are malfunctioning or down for routine maintenance) is received via the Aeronautical Fixed Telecommunications Network as NOTAMs from the United States.

The Australian system, which runs on an IBM RISC 6000 workstation, provides pilots with GPS outage information during pre flight planning and predicts satellite availability for non-precision approaches. Prediction information is available for access by pilots and by Airservices Australia staff via the National Aeronautical Information Processing System and also is dispatched to the Airservices Australia Internet Web server.

The Australian system now serves a total of 178 airports within Australia. In addition, Australia currently is providing RAIM predictions to New Zealand and Tonga as part of a joint South Pacific RAIM prediction system. Canada recently has joined the group on a trial basis.



Volpe Introduces GPS RAIM Outage Reporting System to Europe

When other countries learned of the Volpe Center program in Australia, they began to inquire about assistance in setting up their own GPS outage reporting systems. Germany was the first European nation to step up to the plate. In October 1998, the Volpe Center completed installation of a RAIM prediction system at the airport in Frankfurt, Germany. Testing and training also was provided. This work was performed for DFS Deutsche Flugsicherung, the organization responsible for air traffic control in Germany.

Working with Germany was a new challenge for the Volpe Center because they no longer were dealing with an English-speaking nation. For example, German aviation officials understandably wanted the agreement written in German; the Volpe Center understandably wanted the agreement written in English. The obvious solution was to develop one agreement in both languages.

“We had both parties agree to the English version, and then we had to translate it word for word into German,” explains Karen Van Dyke. “After that, we had to develop another paper that stated that both agreements essentially said the same thing before anyone would sign them.” And that was only a small portion of the paperwork involved. “Sometimes,” she says, “It seemed like the agreement never would be signed.” In the end, however, it was well worth the effort.

The Volpe program in Germany initially enabled the DFS to commission stand-alone GPS, non-precision approaches at Munich, Augsberg, and Braunschweig airfields. Now, the system provides service to 42 airfields, including two in the Netherlands. Other European countries such as Switzerland, Austria, Sweden, Norway, Finland, and the Netherlands have expressed interest in working with Germany to expand this capability to their countries.

Developing a Desktop GPS RAIM/FDE Outage Reporting System for Chile

Within the past year, the Volpe Center worked with the Chilean Aviation Authority, Direccion General de Aeronautica Civil, to establish a GPS outage reporting system for the Chilean Flight Service Centers. This work was initiated by "word of mouth" when a delegation of Chilean air navigation officials, who were invited to the Federal Aviation Administration Air Traffic Command Center in Herndon, Virginia, expressed interest in GPS and outage reporting.

The Chilean system is unique in that it is a Windows-based system. It is the first RAIM system that the Volpe Center has developed for a desktop computer. In addition to satisfying the air navigation needs of Chile, the system also can be used as a marketing tool both by Chile and by the Volpe Center. "When something is developed on a workstation, you only can show slides," says Karen Van Dyke, "but this system can go right on a laptop." A similar desktop system now has been developed for Germany and both the Federal Aviation Administration and Australia also have expressed interest.

Charting the Future: the European Market and System Compatibility

Early this year, the European Union announced that it plans to go ahead with the development of its own $2.4 billion to $3.2 billion satellite navigation system called Galileo. A similar system called GLONASS or the Global Orbiting Navigation Satellite System is operated by Russia. It is similar in composition and function to GPS, but it is not fully operational.

Galileo is designed to be compatible with GPS so that future receivers, and related technology, will be able to use signals from both systems. Deployment of the Galileo constellation, which will include 25 to 36 satellites, will occur between 2005 and 2007. Galileo is scheduled to become fully operational in 2008. Although some people feel that there is competition between GPS and Galileo, Van Dyke points out, "More satellites will provide redundancy and additional availability."

Recent Developments: GPS Modernization

GPS is undergoing a Modernization Program that is a joint effort between the Department of Defense and the Department of Transportation. Working with the Department of Defense, the civilian agencies of the federal government plan to add two more civilian signals to future GPS satellites in the 2010 to 2015 timeframe. The future GPS will have a total of three civilian GPS signals. Two are protected for safety-of-life applications, such as aviation, and the other will be available for non-critical civilian uses.

When all three civilian GPS signals are broadcast from a sufficient number of satellites, the accuracy of GPS will approach the accuracy now only possible using Differential GPS. In addition, the improved service will be worldwide, not only where the Differential GPS service exists. Additional civilian GPS signals will enable receivers to reduce ionospheric errors with signal-processing techniques. With more than one signal, GPS also is less susceptible to unintentional interference.[9]

The benefits that GPS currently provides to aviation users are just the beginning. With air travel continually on the rise, GPS can assist in providing high levels of safety, while reducing delays, and increasing airway capacity. The future of GPS promises to revolutionize navigation.

Endnotes

1 Positions were obtained by measuring the Doppler shift of the satellite signal.

2 These systems include Very High Frequency Omnidirectional Range (VOR), Distance Measuring Equipment (DME), Instrument Landing System (ILS), nondirectional beacon (NDB), Loran-C, and marker beacons.

3 Four unmanned monitor stations around the world precisely track all satellites (Hawaii and Kwajalein in the Pacific Ocean, Diego Garcia in the Indian Ocean, and Ascension Island in the Atlantic Ocean). At the Master Control Station at Schriever Air Force Base in Colorado Springs, Colorado, the information from the monitor stations is processed to determine satellite clock and orbit states and to update the navigation message of each satellite. This updated information is transmitted to the satellites via four ground antennas.

4 Signals from the GPS satellites often arrive at the receiver at slightly different times because some satellites are further away than others. Therefore, to calculate positions precisely, GPS operations depend on a very accurate time reference, which is provided by atomic clocks on each GPS satellite.

5 Integrity is the ability to provide timely warnings when part or all of the system is providing erroneous information and thus should not be used for navigation. Accuracy is the degree of conformance of the measured position at any given time with the actual or true position. Availability is the ability of a system to be used for navigation when and where it is needed. Continuity is the probability that a service will continue to be available for a specified period of time.

6 As GPS is used increasingly on a global scale, issues of systems compatibility and international standardization become increasingly important. At the beginning of 2000, the International Civil Aviation Organization's Global Navigation Satellite Systems (GNSS) Panel met in Canberra, Australia, to continue work on the international Standards and Recommended Practices for the use of GNSS and its augmentations. These include the US WAAS, Canadian WAAS, Japan MTSAT Satellite Augmentation System (MSAS), and European Geostationary Navigation Overlay System (EGNOS), as well as local GPS augmentations such as the US LAAS. Once these standards are finalized, which is expected to occur by the end of 2000, countries can implement GPS with a guarantee of interoperability between nations.

7 RAIM generally is associated with supplemental navigation, while FDE is associated with primary means navigation. The Federal Aviation Administration has decreed that all GPS receivers certified for instrument flight rule navigation incorporate the RAIM capability.

8 DME will continue to provide navigation services for en route through non-precision approach phases of flight throughout the transition to satellite-based navigation.

9 Today, the Federal Aviation Administration (FAA) is actively working with the Department of Defense and other federal agencies to detect and mitigate the effects of intentional jamming and interference to make sure that the basic GPS service and related augmentation systems are available for safe aviation operations. The FAA has conducted numerous interference and risk mitigation studies with the Department of Defense and other government agencies and, in conjunction with the Volpe Center, is evaluating several interference detection systems that will determine the direction and source of the GPS interference. The Volpe Center also is conducting an investigation of GPS interference, jamming, and spoofing for the Office of the Secretary of Transportation. The activities of the Volpe Center consist of a determination of the potential interference sources and GPS receiver interference mechanisms, and an investigation of mitigation options consisting of both anti-jam user equipment and use of back-up systems.

> "I must go down to the sea again, to the lonely sea and the sky,
> And all I ask is a tall ship and a star to steer her by..."
>
> —*Sea Fever by John Masefield*

The Search for Longitude

In 1492, Christopher Columbus sailed westward from Spain across the Atlantic Ocean in an attempt to reach Asia. Several months later, he landed in the Bahamas. His historic voyage marked the beginning of a new era where traveling by sea was one of the few ways to cover vast distances. However, pinpointing the exact location of a vessel on the sea was always a challenge.

For thousands of years, early navigators limited their sea voyages to coastal routes to avoid becoming lost. Dead reckoning was the only navigation method available. In dead reckoning, the navigator finds his position by measuring the course and distance that he has sailed from some known point. But at the end of the 15th Century, as trade between distant ports increased, new methods for determining position were needed. Early navigators turned to the heavens for answers.

Using observations of the sun, stars, and planets to calculate position, celestial navigation or "shooting the stars" remains a basic skill even for the navigators of today. Until the early 18th Century, mariners used Polaris, or the North Star, in the northern hemisphere and the Southern Cross in the southern hemisphere to determine north-south latitude. However, a method for determining east-west longitude remained elusive.

The search for longitude spanned four centuries and was one of the most pressing scientific challenges of the time. Because longitude changes constantly with respect to the heavens as the earth rotates, the key element in determining longitude was a method for precise time keeping. However, in the era of pendulum clocks, precise time keeping at sea was impossible. Early astronomers such as Galileo Galilei and Sir Isaac Newton proposed a number of theories that looked to the natural world to provide a clock to be used by navigators. Galileo's theory, for example, involved calculating the position of the sun and the moon in relation to the position of the moons of Jupiter to determine longitude at sea. These theories, however, failed in practice when the navigators were unable to implement them reliably.

Periodically, the governments of the great maritime nations offered rewards for a workable method. In 1714, the British Parliament offered a reward of £20,000—an enormous sum of money at that time—for a practicable and useful means of determining longitude.

An English clockmaker named John Harrison finally answered the challenge in the mid-1700s. Harrison successfully constructed a mechanical clock that could keep accurate time at sea. With this first marine chronometer, the modern era in navigation had begun.

Along the way, a number of navigation tools were created to aid mariners. Among these, the sextant has come to be widely recognized as the universal nautical symbol. In fact, the sextant, in conjunction with the magnetic compass, has been a basic navigational tool for more than two centuries. A sextant uses adjustable mirrors to measure the exact angle of the stars, moon, and sun above the horizon. In combination with a chronometer, a sextant is a simple, accurate, and low-cost way even today to calculate position.

Glossary

Types of Navigation Systems

Primary means navigation is a system that, for a given operation or phase of flight, must meet the accuracy and integrity requirements, but need not meet full availability and continuity of service requirements. Safety is achieved by either limiting flights to specific time periods, or through appropriate procedural restriction and operational requirements.

Sole means navigation is a system that, for a given phase of flight, must allow the aircraft to meet all four navigation system performance requirements—accuracy, integrity, availability, and continuity of service.

Supplemental means navigation is a system that must be used in conjunction with a sole means navigation system.

Phases of Air Navigation

En route is a phase of navigation covering operations between a point of departure and termination of mission. For airborne missions, the en route phase of navigation has two subcategories—en route oceanic and en route domestic.

Oceanic en route is the phase of flight between the departure and arrival terminal phases, with an extended flight plan over an ocean.

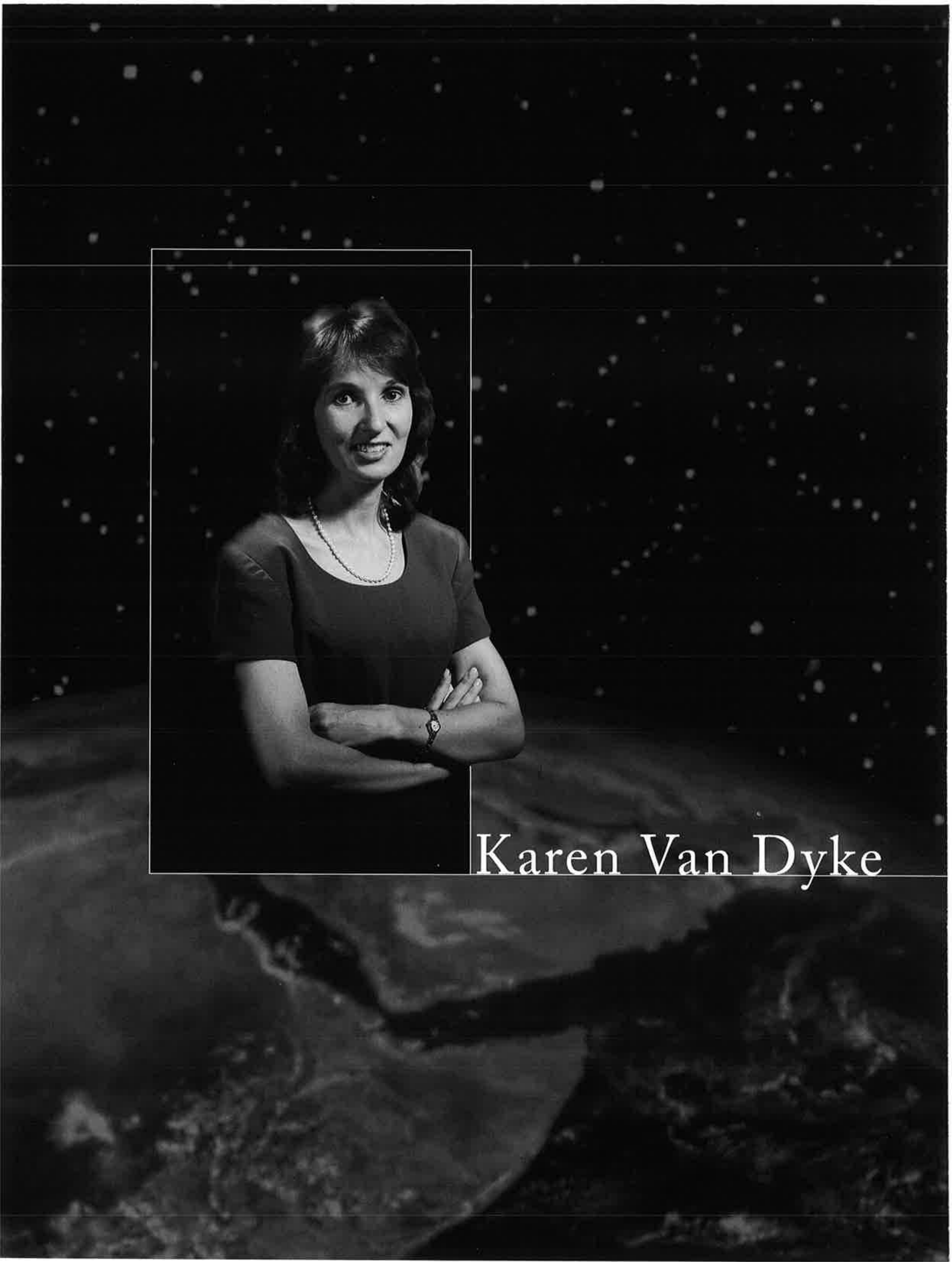
Domestic en route is the phase of flight between the departure and arrival terminal phases, with departure and arrival points within the same country.

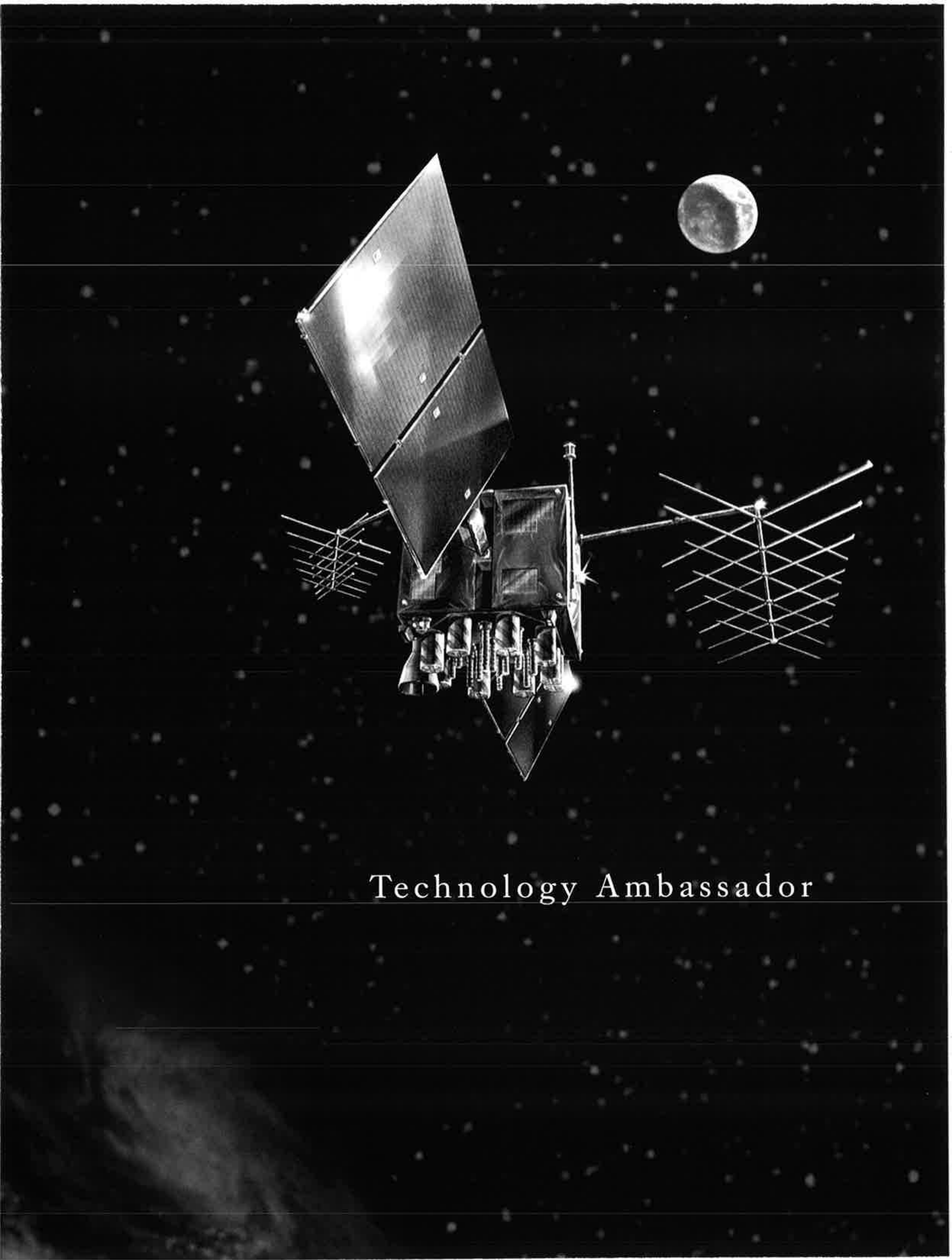
Terminal is a phase of navigation covering operations required to initiate or terminate a planned mission or function at appropriate facilities. For airborne missions, the terminal phase is used to describe airspace in which approach control service or airport traffic control service is provided.

Types of Approaches

Non-precision approaches are standard instrument approach procedures in which the aircraft is provided with only horizontal guidance and position information.

Precision approaches are standard instrument approach procedures where the aircraft is provided with vertical and horizontal guidance and position information.


Karen Van Dyke



Technology Ambassador

Karen Van Dyke: the Volpe Center's GPS expert brings satellite outage reporting to the world

When Karen Van Dyke received her bachelor's degree in electrical engineering from the University of Lowell in 1988, she, like many of her classmates, considered pursuing a position at one of the local high-tech computer firms. Instead, she decided to spend the summer working with one of her professors, who was conducting research for the Volpe Center on the Global Positioning System (GPS), a navigation system based on an array of satellites that provides signals which allow users to accurately determine their positions. That summer project opened the door to a distinguished career. Twelve years later, Karen is a Senior Project Leader in the Center for Navigation, and one of the most respected GPS experts in the country.

Karen's career has spanned a period when GPS applications matured into critical components of the national transportation system. When she started, says Karen, "GPS was an evolving system and its applications for all modes of transportation were fairly new. I understood that it was going to be an expanding technology with wide-ranging impacts. That was exciting!" Little did she know how far it would take her. Today, she is helping to develop GPS systems for air safety, and sharing these new technologies with organizations around the globe.

Karen also is quick to describe how her preconceived ideas about working for the government were radically changed. As a recent graduate, she wondered whether work at the Volpe Center would give her the professional experience she was seeking. "You always think about government bureaucracy and paperwork, but what really sold me was when I came to visit Volpe and I met top-notch engineers and saw the work they were performing. It was so intriguing."

One challenging aspect of GPS technology is the determination of where and when reliable navigation signals will be unavailable due to the configuration of satellites. Because it has serious implications for air safety, this issue is a major concern of the Federal Aviation Administration (FAA). Hence, in 1990, the FAA asked the Volpe Center to develop algorithms that would predict the availability of GPS integrity for oceanic through non-precision approach phases of flight.[1]

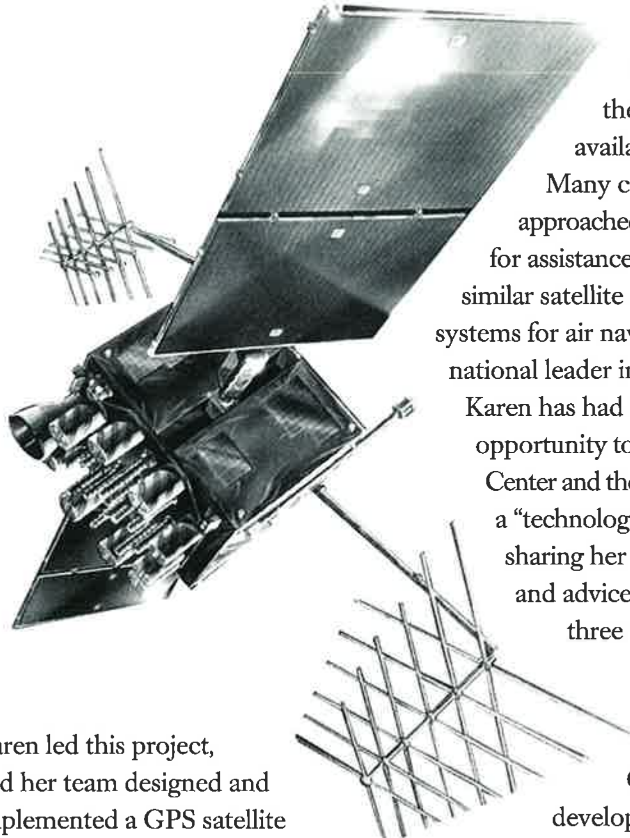
"GPS was an evolving system and its applications for all modes of transportation were fairly new. I understood that it was going to be an expanding technology with wide-ranging impacts. That was exciting!"

In response to the Federal Aviation Administration request, Karen and the Volpe Center project team, in conjunction with RTCA, Inc., developed Receiver Autonomous Integrity Monitoring and Fault Detection and Exclusion algorithms. The Volpe Center then applied those algorithms in order to predict when GPS signals would not be available for the different phases of flight.

Once the availability algorithms were developed, the Federal Aviation Administration and the US Air Force charged the Volpe Center with developing a method for disseminating satellite non-availability information to pilots during the pre-flight planning process.

[1] For more information on the phases of flight, see the accompanying article on GPS.

"You always think about government bureaucracy and paperwork, but what really sold me was when I came to visit Volpe and I met top-notch engineers and saw the work they were performing. It was so intriguing."



Karen led this project, and her team designed and implemented a GPS satellite outage reporting system that was integrated into the Federal Aviation Administration aeronautical information system and the Notice to Airmen system of the Department of Defense.

As an extension of this work, Karen is conducting availability and integrity studies for aviation applications of GPS and accompanying Wide Area and Local Area Augmentation Systems for all phases of flight, including precision approaches. The Federal Aviation Administration also has requested a methodology for incorporating these predictions into the Notice to Airmen system.

True to its name, GPS is a global system, and countries around the world have begun to address the issues of satellite availability for aviation. Many countries have approached the Volpe Center for assistance with developing similar satellite outage reporting systems for air navigation. As a national leader in this technology, Karen has had a wonderful opportunity to represent the Center and the United States as a "technology ambassador," sharing her technical expertise and advice with peers on three continents. Her project group has assisted Australia, Germany, and Chile with the development of systems similar to those designed for the Federal Aviation Administration. Other countries also have expressed an interest in using the services of the Volpe Center.

These international efforts have provided the Center for Navigation with valuable business experience and a fresh perspective on GPS technology. "The thing that struck me the most was that they have a completely different way of addressing the benefits that this technology can provide to them," says Karen about her Australian colleagues. "They spend a lot of time researching cost-effective methods and looking for innovative, low-cost solutions. From a technology standpoint, it is refreshing to see that ingenuity." Karen is confident that there is a great deal to learn from researchers around the world, and she views each international assignment as an opportunity to both share information and gain new ideas.

In addition to her role at the Volpe Center, Karen is dedicated to the advancement of GPS technology nationwide. She currently serves as the President of the Institute of Navigation, a nonprofit professional society dedicated to the advancement of the art and science of navigation.

She has been on their council since 1992 as the Air Navigation Technical Representative and also has served as the Eastern Region Representative. The Institute of Navigation serves a diverse international community of technical experts and others interested in navigation and position determination for air, space, marine, and land applications.

Karen has published more than a dozen papers on GPS and is a co-author of the book, *Understanding GPS: Principles and Applications,* a 1996 reference text on GPS that includes information on markets and applications of products and services based on satellite navigation. She now holds a master's degree in electrical engineering from the University of Massachusetts at Lowell. For more information on the work that Karen has been doing, and her accomplishments, see the GPS story in this issue of the *Volpe Journal.*