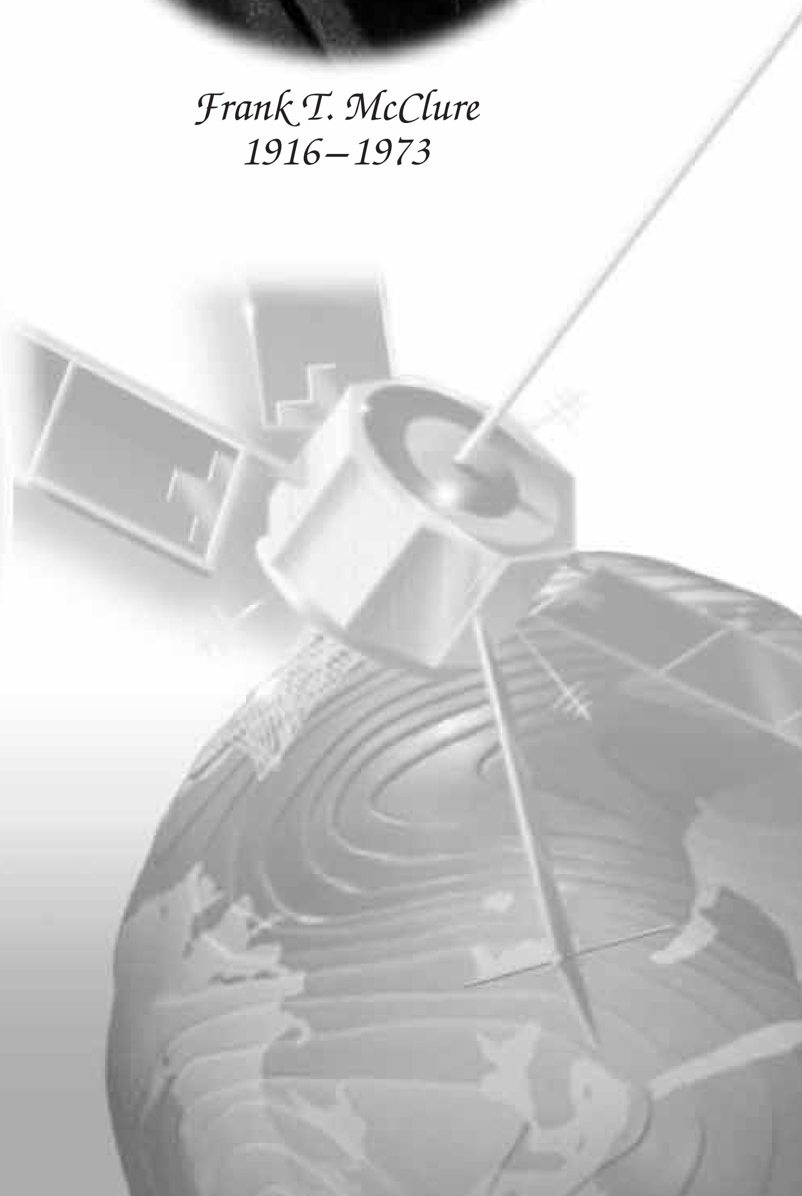
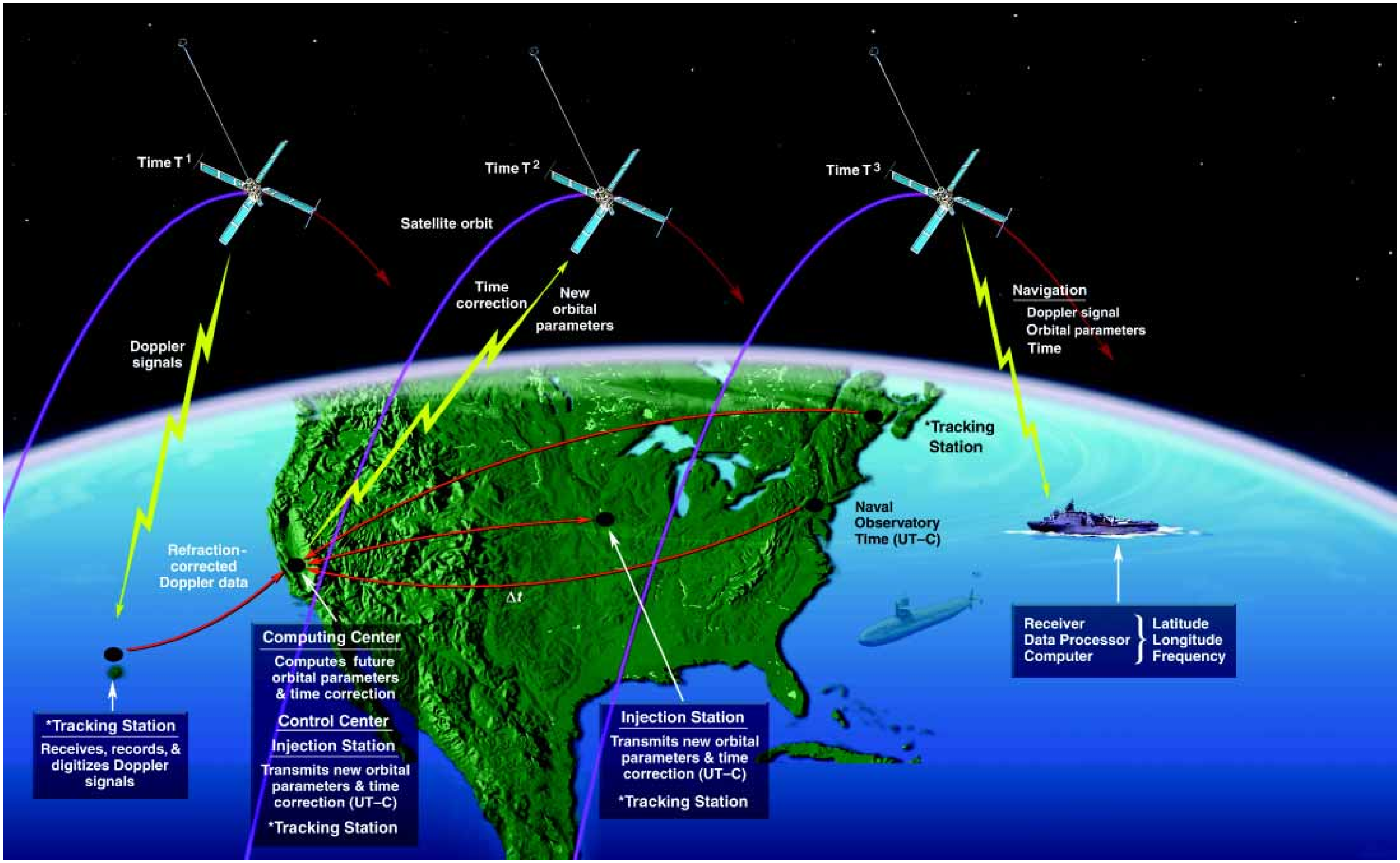
The Legacy of Transit:

A Dedication

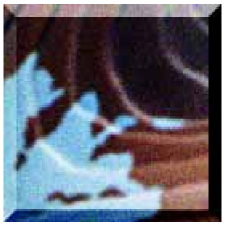
Frank T. McClure
1916–1973

Richard B. Kershner
1913–1982





This illustration shows the major elements of the operational Navy Navigation Satellite System known as Transit. Four tracking stations in the continental United States and Hawaii collected Doppler data as the satellites passed overhead. These stations immediately transmitted the data via land lines to the computing center in California where the orbital ephemeris (position and velocity as a function of time) of each satellite was determined and predicted into the future. The injection stations transmitted the appropriate predicted orbital ephemeris to each satellite where it was stored for continuous rebroadcast to navigators. The navigators measured the time history of the Doppler data and recorded the orbital ephemeris as the satellite passed overhead, which provided the necessary information to determine their positions. (Illustration by Jacob Elbaz.)



The Legacy of Transit: Guest Editor's Introduction

Vincent L. Pisacane

I first encountered the Transit Navigation System, later known as the Navy Navigation Satellite System, when I completed my graduate studies in 1962 and was considering several job offers: two junior faculty positions at known universities with loose NASA affiliations, several engineering positions at large aerospace companies, and a position at The Johns Hopkins University Applied Physics Laboratory. I had played football against Hopkins, but had never heard of APL.

I had become interested in aeronautics at an early age and was later captivated by the space era spawned by *Sputnik I*. During my graduate student days, I had often reclined on the campus lawn before dawn or after dusk to watch the gigantic inflated Echo satellites travel overhead, reflecting the Sun's rays. My long-term goal was clearly academia; however, I believed that to be a good teacher and researcher, one had to first experience the real engineering world.

My interview at Hopkins was intriguing: the focus was clear, the group was small, the goals were ambitious, the people were motivated and dedicated, and the position provided the opportunity to teach in the part-time graduate program. Thus began my professional pursuit of space through the Transit program at APL. My goal was to stay for 3 to 5 years. Admittedly, I can't tell time accurately. Although this particular story is unique to me, many of my Transit colleagues have comparable tales of how they became involved in this once-in-a-lifetime experience.

This issue of the *Technical Digest* is dedicated to the many men and women at APL, the Navy, and supporting organizations who gave so much to bring a bold idea to life. In particular, this issue is dedicated to Frank T. McClure, who conceived the concept of Doppler navigation from the pioneering work of William H. Guier and George C. Weiffenbach, and to Richard B. Kershner, who turned McClure's invention into a real operational system. (See the tributes to McClure and Kershner in this article.)

A TRIBUTE TO FRANK T. McCLURE

Frank T. McClure, the inventor of the Transit Navigation System, was a singular example to his colleagues and collaborators of that too often used descriptor, a "Renaissance man." A Renaissance man is defined as one who has wide interests and is an expert in several areas. McClure is universally acknowledged for his astonishing scientific brilliance characterized by immense depth and breadth, an exceptional clarity of thought, an unusual ability to distinguish the essential from the superfluous, and his notable intolerance of scientific carelessness and imprecision despite his sensitivity to human needs and feelings.

McClure was born on 21 August 1916 in Edmonton, Alberta, a provincial town that obviously ingrained in him the pioneering spirit of the era. He received a bachelor's degree with first class honors in organic chemistry from the University of Alberta at the age of 21, and later obtained a doctorate in physical chemistry from the University of Wisconsin. He was then appointed to the faculty of the University of Rochester, which he left in 1943 to come to Washington to join the Allegheny Ballistics Laboratory to contribute to the national war effort. For his outstanding scientific accomplishments in World War II, he received the Naval Ordnance Development Award in 1945 and the Presidential Certificate of Merit in 1948.

McClure joined APL in 1946 and devoted his early research years to studying the combustion of rocket propellants for guided missiles to protect naval ships from menacing aircraft. This led to his organizing the Panel on Combustion and Instability of Solid Rocket Propellants for Levering Smith, then Commander of the U.S. Navy. Between 1957 and 1964, the scientific output of this panel totaled 100 papers, of which McClure authored or coauthored 26. The impact of this pioneering effort is best described by Smith, Admiral and former Director of the Navy's Strategic Systems Projects Office, who said, ". . . as a result, incalculable savings have been realized in the Polaris, Poseidon, and Minuteman programs, and at the same time a very high reliability of rocket motors has been achieved." In 1960, McClure received the Hildebrand Prize from the Chemical Society of Washington in recognition of his powerful theoretical analyses in the borderline areas of physical chemistry, fluid dynamics, and acoustics.

As the first director of APL's Research Center, serving from 1949 to 1972, McClure established and nurtured an organization that achieved international recognition in numerous research areas in physics and chemistry. The 1000 papers published during his tenure as director are a tribute to his extraordinary scientific leadership. Although a researcher, he possessed an uncanny ability to see beyond the abstract fundamentals to the practical applications. This was evident when William H. Guier and George C. Weiffenbach determined the orbit of *Sputnik I* from a single pass of Doppler data. McClure, recognizing the significance of their accomplishment, conceived and proposed the concept of satellite navigation to solve an important Navy problem. (See the boxed inserts on the opposite page.) This bold thinking resulted in an entirely new dimension to APL, leading to the establishment of the Space Department and APL's extensive involvement in space research and technology for the Department of Defense and NASA. In 1961, McClure received NASA's first Invention Award, honoring his invention of the Transit Navigation System.

The way that McClure's mind worked was aptly illustrated by a story that Richard B. Kershner once told.[1] It was shortly after the end of World War II, and Kershner and McClure were assigned to investigate the possibility of nuclear rockets. Although they were rocket experts, neither was a nuclear physicist. So a professional nuclear physicist was assigned to calculate the amount of fissionable material required for a specific reactor. The physicist's result was 2 tons of fissionable material, and he asked Kershner and McClure to check his 30 pages of calculations. McClure said, "We don't need to check that; it's clearly wrong. Go back and try again." A week later the physicist returned, claiming that he had found the mistake and that the correct answer was a milligram. With some exasperation, McClure said to him, "Look, we know the correct amount is between 1 and 5 lb. Keep trying until you get an answer in that range, and then we'll check you." The answer ended up being about 3 lb.

McClure's other scientific interests included molecular biology and microbiology. His ability to integrate researchers from different specialties is demonstrated by the establishment in 1965 of a collaborative biomedical program with Richard J. Johns of the Johns Hopkins School of Medicine. Both men recognized that the research and technological capabilities of APL could be brought to bear on important medical problems confronted by both research and clinical physicians. This program continues today and led to the establishment in 1995 of the Institute for Advanced Science and Technology in Medicine at APL. Through the years, the program that McClure helped to initiate has produced many significant medical accomplishments, including the development of the argon laser to treat diabetic retinopathy, the programmable implantable insulin infusion pump to treat diabetes, and long-term basic research programs in ophthalmology and neurosciences, to name but a few.

McClure died suddenly on 18 October 1973 at the age of 56 while still employed at APL. His untimely death robbed us of many significant accomplishments that were yet to flow from the mind of this genuine Renaissance man. The eclectic personality of Frank McClure has left an indelible mark on the institution that he served and led so imaginatively and boldly.

REFERENCE

[1] Compilation of remarks presented at the memorial convocation in honor of Frank Trelford McClure, Deputy Director, Applied Physics Laboratory, held at the Merriweather Post Pavilion, Columbia, Maryland, on 26 October 1973. Published by JHU/APL, Laurel, MD (1973).

MEMORANDA FROM FRANK T. McCLURE TO APL DIRECTOR RALPH E. GIBSON

On 18 March 1958, Frank T. McClure wrote two memoranda to APL Director Ralph E. Gibson. The first one started by saying,

> Yesterday I spent an hour with Dr. Guier and Dr. Weiffenbach discussing the work they and their colleagues have been doing on Doppler tracking of satellites. The principal problem facing them was the determination of the direction which this work should take in the future. During this discussion it occurred to me that their work provided a basis for a relatively simple and perhaps quite accurate navigation system.

McClure's second memorandum provided the vision that led to the development of the Transit Navigation System and to APL becoming a major space facility:

> As I see it, this concept may offer the Laboratory an ideal opportunity: first, it definitely puts the Laboratory into the space game; second, it offers a problem that has real military significance; third, it is definitely a Navy problem and therefore fits in well with the Laboratory's long-time Navy relationship; and fourth, it is of direct significance to SP, which is the only activity in the Navy presently with which we have close contact which has funding sufficient to support such a project.

LETTER FROM APL DIRECTOR RALPH E. GIBSON TO THE DEPARTMENT OF THE NAVY

On 4 April 1958, APL Director Ralph E. Gibson advised the Chief of the Bureau of Ordnance, Department of the Navy, on the practical applications of artificial satellites to navigational systems and proposed that APL develop such a system for the Navy:

> This [satellite navigation] method is characterized by the following features:
> 1. The expected accuracy is extremely high; circular probable errors of approximately one-half mile are estimated to be within the present state of the art.
> 2. The receiving apparatus is relatively simple—requiring only one antenna and no accurate base line since no angle measurements are involved.
> 3. It is completely passive.
> 4. It can be used anywhere in the world.
> 5. It can be used in all weather.
> 6. It can be jammed only on line-of-sight radiation.
> 7. The system can be made self-contained.
> 8. Relatively small satellites (about 50 lb weight) can be used.

After proposing a Phase I start-up budget of $937,000, Gibson concluded by saying,

> The systems concepts and development programs described here are still relatively new and hence certain details and especially the cost estimates are subject to modification. However, the basic concepts and systems have been carefully studied and are regarded as reasonably firmly established. In view of the important military and civilian applications of this system and its high potential as a public demonstration of the utility of satellites in contributing to the solution of immediate and practical problems, it is suggested that every effort be made to initiate this program as soon as possible.
>
> The Applied Physics Laboratory has talents and capacity to solve the technical problems and apply the results and the enthusiasm of an experienced group of scientists and engineers to carry out the work expeditiously. We stand ready to make any technical presentations that you may deem advisable and to answer fully any questions that may be raised by this letter.

A TRIBUTE TO RICHARD B. KERSHNER

Richard B. Kershner—mathematician, expert in interior ballistics and guided missiles, systems engineer, motivator of people, and manager extraordinaire—took the concept of Doppler navigation proposed by Frank T. McClure and turned it into a reliable operational system. This was just one of many notable accomplishments of his long and distinguished career in mathematics and engineering.

Kershner was born in Crestline, Ohio, on 11 October 1913. His family moved to Baltimore when he was about a year old because his father was appointed headmaster of the Franklin Day School. In his youth, he went to sea twice, first as a deck boy on a freighter at the age of 14, and later as an ordinary seaman after his first year of college. When he was just 16, Kershner entered the engineering program at The Johns Hopkins University. During his second year of study, he was admitted to a new Hopkins graduate program for specially qualified undergraduates and later received his doctorate in mathematics. When he received his Ph.D. from Hopkins at the age of 23, he had already published more than a dozen papers in the prestigious *American Journal of Mathematics*. Although he was a proud mathematician in principle, he was always the consummate engineer in practice.

After graduation, Kershner was appointed an Instructor of Mathematics at the University of Wisconsin, where he met two people who were to significantly influence his life's work: undergraduate Frank T. McClure and colleague Joseph O. Hirschfelder. After three years at the University of Wisconsin, he returned to Hopkins as Assistant Professor of Mathematics. As World War II approached, he established a collaboration with Hirschfelder in the increasingly important area of the internal ballistics of guns and rockets. The results of this work, published as National Defense Research Reports, provided the fundamental understanding necessary to the development of advanced ordnance and rocket systems. After the attack on Pearl Harbor, he joined the Allegheny Ballistic Laboratory, where he continued the practical application of interior ballistics to ordnance for the war effort.

Kershner joined APL in 1946. Although the war was over, his interests had shifted from pure mathematics to the more practical engineering. His first important task at APL was to help solve the launching problems of a supersonic missile called Talos to defend the Navy Fleet against air attacks. He later contributed to the design of an advanced guidance and control system that performed so well that the Navy put it into production, naming it Terrier, as proposed by Kershner. Problems with mass producing Terrier led Kershner and his lifetime friend Alexander Kossiakoff, who later became Director of APL, to propose and develop a new concept of missile construction. This concept involved compartmentalizing the missile into stand-alone subsystems that could be tested individually before integration. This system was followed by the Tartar missile system, which was designed by Kershner and his collaborators and included several innovative concepts.

In the mid-1950s, the Navy began development of the Polaris system, which was the naval leg of the triad of nuclear deterrence and later proved to be the most valuable. This development involved a specially designed nuclear-powered submarine from which a missile could be launched while it remained submerged. Kershner led the Laboratory's support of the Polaris system for 5 years. He also conceived the rigorous continuous test protocols of the Fleet Ballistic Missile Program that are still adhered to today and for which the Laboratory still plays a major role for the Navy.

A critical requirement of the Polaris system was to be able to determine its position with an accuracy at least commensurate with the accuracy with which it expected to hit its target. The solution was the Doppler navigation concept proposed by McClure, and Kershner was given the responsibility to translate the concept into practice. In 1958, he brought together a uniquely talented group of engineers and scientists who formed the APL Space Department. These people included William H. Guier and George C. Weiffenbach, who had demonstrated that the orbit of *Sputnik I* could be accurately determined by Doppler tracking. The group quickly developed the art of satellite design, fabrication, integration, and testing, so that in just 10 months, the first of many satellites was launched. Many problems had to be overcome before the navigation system, known as Transit, could be considered a success. These included building reliable, low-power, and radiation-resistant electronic systems; understanding the deleterious space particle environment; determining the gravitational field of the Earth to unprecedented accuracy; building oscillator systems with unparalleled stability; and developing operational software during a time when computers and software engineering tools were limited.

In 1964, the Transit Navigation System became operational, and in 1967, it was declared operational for civilian use by Vice President Hubert Humphrey. It continued in operation with a reliability of over 99.77%; the system was never out of service until the end of 1996 when it was retired. Although Kershner's title was Department Head, in reality he was also the Transit program manager. His inspirational leadership, management wisdom, and ability to elicit the best from his staff established a "can-do" culture that is part of his legacy. During and subsequent to the development of the Transit system, APL achieved the many "firsts" identified on the inside back cover of this issue. To date, the Laboratory has built over 55 complete spacecraft and hundreds of space instruments for the Department of Defense and NASA.

Kershner received many awards for his accomplishments. During World War II, he earned the President's Certificate of Merit. On four occasions he received the Distinguished Public Service Award, which is the highest award conferred by the government on a private citizen. The last one was presented by Vice President Humphrey in 1967. He also received two awards from the Institution of Navigation: the Hays Award to recognize his contributions to navigation and the First Award of the Satellite Navigation Division to recognize his inspiration and leadership in the field. In 1981, he was awarded The Johns Hopkins University Eisenhower Medal from the University President Milton S. Eisenhower.

Kershner died on 15 February 1982 after a long illness. He was a remarkable leader, exceptional mathematician, and consummate engineer who sought the classical simple solution to complex problems. For those of us who had the privilege to work with him, he was a uniquely talented individual, a brilliant scientist, a perceptive being, and a natural leader.

The development of the Transit Navigation System, which provided significantly improved accuracy and the ability to navigate in any kind of weather, was unique from many perspectives. As an element of the Fleet Ballistic Missile Program, which helped maintain the security of the United States and hastened the end of the Cold War and the fall of the Soviet Union, it entailed a special relationship with the Department of Defense. In addition, it came at the beginning of the space era, which brought many new technical challenges. For example, the effects of the space environment on materials and electronics had to be determined precisely; components and systems had to be miniaturized and work at extraordinarily low power levels; control systems had to operate in an entirely new environment; the reliability of parts had to be extended immensely; the gravitational field of the Earth had to be determined to unprecedented accuracy; the uncertainty of propagation in the atmosphere and ionosphere had to be mitigated; oscillators that performed with remarkable stability had to be built; and sophisticated software systems that operated reliably had to be developed. All of these formidable tasks were accomplished by a relatively small group of dedicated people and resulted in a system that operated as envisioned.

The articles in this issue are only a sample of the many scientific and technological accomplishments of the Transit era. To put the importance of navigation into perspective and set a wonderful context for describing the development of Transit, the issue begins with a brief history of early navigation by Dava Sobel. Ms. Sobel is the prize-winning author of *Longitude*,[1] which chronicles the development of the chronometer, a mechanical watch that kept sufficiently accurate time aboard ship to be of use in determining the longitude.

The next article is by William H. Guier and George C. Weiffenbach,[2] who carried out the pioneering work that led to the concept of Doppler navigation and were key in making the concept a reality. Their article describes the events leading to the determination of the orbit of *Sputnik I* from a single pass of Doppler data and discusses the very beginning of the development of the Transit system.

Robert J. Danchik, a Transit program manager, chronicles the overall development of the Transit system to provide all-weather, reliable, and accurate navigation to submarines without revealing their positions. He describes the system's characteristics and its initial funding by the Navy and the Advanced Research Projects Agency.

Gary C. Kennedy and Michael J. Crawford of the Naval Satellite Operations Center (NAVSOC) describe the day-to-day operations that resulted in a 100% system availability and a 99.77% individual satellite availability. Appropriately, their article is dedicated to the men and women at NAVSOC who sustained this exceptional level of reliability for 32 years. They also discuss the breakthroughs in satellite management resulting from the Transit system.

As mentioned previously, Transit's success depended on the ability to precisely determine the gravitational field of the Earth. With this information, scientists could accurately predict the orbits of the Transit satellites, from which navigators could determine their exact positions. Steve M. Yionoulis describes the techniques used to surmount this formidable computational challenge during the infancy of the computer age.

The trapped-particle radiation environment of the Earth, known as the Van Allen radiation belts, is named for James Van Allen of the University of Iowa, who led APL's high-altitude research program using captured V2 rockets from World War II.[3] This trapped radiation posed a potentially serious problem for the Transit materials and electronics that would be required to operate in space for extended periods. The techniques used and the experiments performed to better understand the space environment are described by Carl O. Bostrom and Donald J. Williams.

Transit navigation receivers had to accurately and reliably recover the Doppler signal, satellite ephemerides, and timing information from the satellites. The receivers processed this information to make an ionospheric correction and then solved for the latitude and longitude of the observer. Different receivers were required for different purposes. In some cases, accuracy was the major requirement; however, if the units were to be carried by backpack, then reduced weight and size were of utmost importance. Low cost was a driving factor for civilian use. Lauren J. Rueger directed much of the receiver work and describes it in his article.

Technologies developed specifically for Transit were later transferred to other applications. Robert E. Fischell discusses several implantable medical devices that use Transit-derived telemetry and command systems for programming and data retrieval. This technology has contributed to the ongoing collaborative biomedical program that was established between the Johns Hopkins School of Medicine and APL in 1965.

The concluding article is by Arnold J. Tucker, who recently retired as Associate Director for Research at the Applied Research Laboratory at the University of Texas. He discusses the long-term use of Transit for ionospheric studies and describes a new Transit-based ionospheric study that began on 1 January 1997.

The primary mission of Transit is complete, yet the system, born of research and scientific curiosity, is still being used to study the Earth's ionosphere. But even when that work concludes, the Transit satellites will continue to orbit the Earth in silent tribute to the countless people who contributed to this remarkable achievement.

In place of Transit, the NAVSTAR Global Positioning System, or GPS as it is more frequently called, has assumed the responsibility for providing all-weather navigation and surveying. GPS is a second-generation navigation satellite system that provides continuous location by using measurements of the pseudo-range from four or more satellites that are simultaneously in view. GPS became fully operational in 1994 and will provide precise navigation for the foreseeable future.

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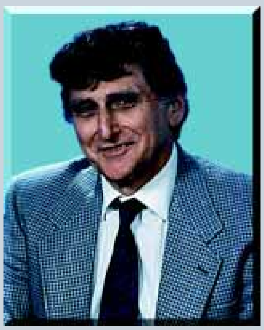

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