

written "621B"—the official US Air Force designation at that time. Perhaps I may be forgiven for this slip; after all, a third of a century has elapsed since the start in 1963 of the Aerospace Corp efforts on what is currently called GPS, and the system studies and demonstrations of the 1960s and GPS now are basically the same.

The Aerospace Corp was established in 1960 as a nonprofit corporation to support the US Air Force in planning and to serve as systems engineer for ballistic missile and space systems. From the beginning, Aerospace initiated a number of studies. One of them, called Navsat, was later designated by the air force as project 621B.

The Navsat study was undertaken in response to the following internally generated specifications:

- ▷ The use of satellites to provide worldwide coverage.
- ▷ The use of appropriate-frequency radio waves to provide all-weather capability and to minimize propagation errors.
- ▷ An unlimited number of inexpensive, nonradiating user receivers.
- ▷ Continuous three-dimensional position fixing responsive to the dynamic characteristics of users, ranging from fixed to fast moving.
- ▷ A position accuracy of approximately 30 feet.

These specifications were met by the ensuing studies and the designs verified by ground-based field tests of the critical elements—radio transmitters and receivers as well as data processors.

Philip Diamond directed and supervised the project from its inception in 1963 until 1974, when it was authorized as a formal Department of Defense program. The Aerospace team introduced the concept of using pseudorange data from four satellites. This scheme permitted the use of inexpensive quartz clocks in the user equipment, and as a by-product it provided for accurate time transfer to each user. A four-satellite synchronous constellation was proposed as the cheapest system with which to demonstrate the concepts, and one that could be later expanded to provide worldwide coverage by adding three or four more such constellations.

Hideyoshi Nakamura and other members of the team fleshed out the pseudorange, four-satellite concept, and in 1965 Aerospace disclosed its first exemplary complete system concept. In that first concept, precise timekeeping was based on the use of ground-based atomic clocks with frequent updates to the satellites. Many

ground stations would be required, and such uplinks would be subject to jamming. NRL's development and flight testing of atomic clocks on the Timation satellites aided in the resolution of this technology deficiency.

Another member of the Aerospace team, James Woodford, introduced the use of a pseudorandom sequence of binary digits modulated onto the carrier frequency using code-division multiplexing. This permitted the use of the same frequency by all satellites and identification of each satellite.

Since the satellites were to be of medium cost, with available transmission power being limited to a few tens of watts illuminating a large fraction of Earth's surface, the signal level at the surface would be some 30 decibels below ambient noise. However, using a radiated code bandwidth of, say, 10–20 megacycles would provide some 60-dB processing gain (the exact number depending on many factors, including the antijam characteristics of the receiver as well as integration with inertial measurement units on dynamic platforms), with error-free inputs to a navigation computer.

W. J. Cooke performed relativistic corrections for the study in 1966, and C. K. Kretcher and R. H. Huddleston refined those corrections, including general relativistic considerations, for the specific orbits in 1973. Arthur Shapiro also made initial contributions to the relativity question and proposed the details of a special relativity experiment using the satellites, which was later carried out by Aerospace personnel.

The above-mentioned contributions are all examples of technical work and studies done at Aerospace that were critical to GPS as finally implemented.

True to the charter of the air force to make use of the best available current technology, the use by the navy's TRANSIT of two frequencies for obtaining ionospheric propagation corrections was also incorporated.

As for the question of orbits, Aerospace proposed the least expensive demonstration program—a constellation of four satellites, three with 24-hour inclined orbits and a central stationary satellite. Easton at NRL proposed a system with 8-hour circular orbits. The need for concurrence across military departments if the program was to succeed necessitated a compromise; in particular, the navy's potential interest in having worldwide coverage from the start dictated a deployment with circular, inclined orbits. By 1968–69 a 12-hour orbital deployment with about 20 satellites had been settled on.

The history of GPS is complex, in-

volving a great many people and organizations. It cannot be adequately documented in a few letters to PHYSICS TODAY. I hope that some professional historian or historians, with no vested interest, will see fit to do a thorough study of this history while many of the participants are still alive—perhaps as a project akin to the Laser History Project cosponsored by the American Institute of Physics in the 1980s.

I thank Philip Diamond for contributing to this letter by providing me with his recollections.

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Superfluid Rollin Film Gets Exposed

In his discussion of the discovery of superfluidity, (July, page 30), Russell Donnelly says that the fundamental understanding and actual discovery of superfluidity, via flow through capillaries, was made by P. A. Kapitsa and separately by J. F. Allen and A. D. Misener, as evidenced by their letters published in *Nature* in January 1938.¹

He leaves out all mention of the Rollin film—that remarkable film that leads to bulk transfer and can creep vertically against gravity over the sides of containers. B. V. Rollin postulated the existence of this basic process of superfluid film flow in 1936 to explain the anomalous heat flow. Its nature was elucidated by the significant work of many investigators, particularly J. G. Daunt and K. Mendelssohn (1938, 1939) and also Rollin and F. Simon (1936, 1939) and N. Kurti (1936) at the University of Oxford, as well as others in the Soviet Union.¹

This work and these workers were crucial to achieving a full understanding of superfluidity. Capillaries were not enough.

References

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