Guidance From Above in the Gulf War

A satellite system for determining precise locations performed well in its first battlefield tryout—2 years before it was supposed to be fully operational

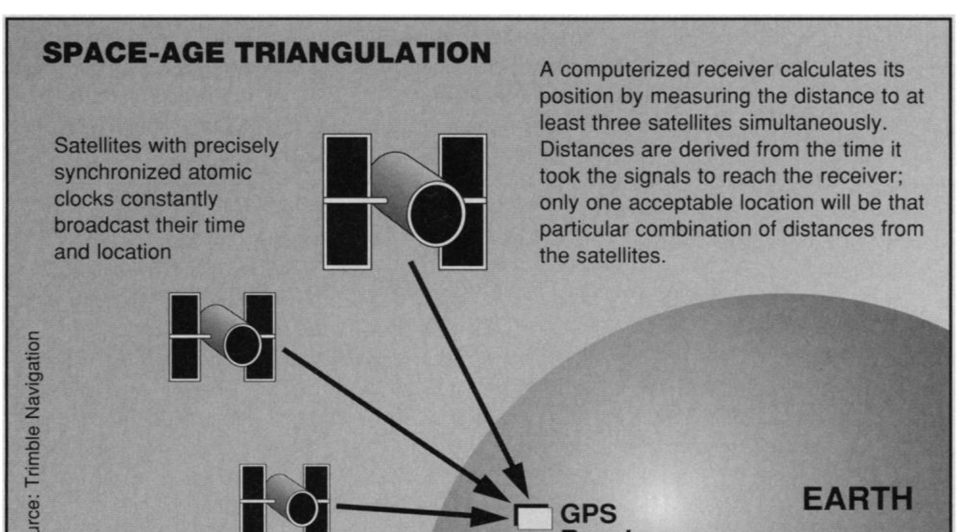
HIGH-TECH WEAPONRY HAS BEEN THE darling of the media in the Persian Gulf war. But one new system has been making a major contribution out of the limelight while attention has been focused on smart bombs and computer-guided missiles. It is a $10-billion space-age method for answering a seemingly simple question: Where am I?

The system, a constellation of satellites called the Navstar Global Positioning System (GPS), has proved invaluable in spite of a few glitches, according to U.S. military commanders. Although defense officials have been tight-lipped about the exact role of GPS in the war, its ability to pinpoint positions of troops and hardware has been used to sharpen the accuracy of B-52 bombers, help guide Navy missiles to their targets, steer ships and soldiers through mine fields, and let soldiers know where they are in the featureless desert.

That's not bad for a system that was not even scheduled to be in full operation until mid-1993. Indeed, the fact that it was available at all for the Gulf war required a hectic scramble to ensure that there would be enough satellites to provide constant coverage in the Middle East, a crash effort to get thousands of GPS receivers in the hands of allied troops, and—ironically—a decision to lift a technical barrier that had previously restricted the most accurate GPS signals to U.S. military users to prevent an enemy from making use of the system (see box).

The Navstar system is a marriage between extremely sophisticated satellite technology and simple geometry. Each Navstar satellite, orbiting Earth once every 12 hours at an altitude of 10,900 nautical miles, carries a precise atomic clock. The satellite constantly broadcasts a signal containing information on the time and its location in space, which can be picked up by a special receiver on the ground that is synchronized to the satellites' clocks. The receiver—which can be small enough to fit in a soldier's battle fatigues—calculates the distance to the satellite from the time it took for the signal to reach it. If three Navstar satellites are in "sight" simultaneously, a computer inside the receiver can quickly work out its precise position by triangulation—in essence, only one point on a plane can be that particular combination of distances from the three satellites. Signals from a fourth satellite are needed to pinpoint a receiver's position in three dimensions: its latitude, longitude, and altitude.

It requires a lot of satellites in orbit to ensure that at least four will be in sight at any particular point on the globe 24 hours a day. Ultimately, the Pentagon intends to have 24 in place (including three spares), but when Operation Desert Storm began, there were only 16—just enough for constant two-dimensional coverage of the Persian Gulf but only intermittent three-dimensional coverage. According to official U.S. government documents, the currently deployed system will provide horizontal locations to within 17.8 meters and, when available, altitudes to within 27.7 meters. Some sources say the true accuracies may be far better, however.



The Pentagon's appetite for Navstar was whetted long before the Gulf war, when the system proved its worth in several military situations. For example, Navy mine sweepers used Navstar to pinpoint mine fields in the Persian Gulf during the Iran-Iraq war. And Air Force pilots used the system to mark the positions of key bridges in Panama during the U.S. intervention there in 1989; maps of Panama were too inaccurate to provide precise coordinates for bombing runs. The Gulf war has provided the first full-scale battlefield tryout for Navstar, however.

The war has, for example, inaugurated the use of Navstar receivers to help precision-guided missiles wend their way to their targets: The Navy's new Stand-off Land Attack Missile uses a Navstar receiver to update and correct information from the missile's on-board inertial guidance system. Navstar receivers are also being used for more mundane purposes, such as determining the precise location of a howitzer preparing to fire at enemy positions. Knowing the weapon's exact location is essential for accurate targeting. Before Navstar, gunners had to rely on time-consuming surveying to fix their positions, now they can do it in minutes.

The Pentagon had to use a lot of ingenuity to patch together an operational system however. For a start, as soon as the troop buildup began, it was clear that there wouldn't be nearly enough military Navstar receivers to go around. Before the war, military procurement programs had encountered technical problems and testing delays with the receivers, and only 4000 were on hand when the Middle East crisis struck.

Consequently, the military has turned to the civilian sector, snapping up receivers that had been aimed at users such as mariners and scientists. Although these do not meet the military's standards for ruggedness, they did offer one virtue: quick availability.

Since September, the Air Force has purchased more than 10,000 of the lightweight receivers for itself and the other military services, according to General Ronald Yates,

After the War: Who Will Get Accurate Navstar Data?

What would prevent Saddam Hussein's troops from using the Pentagon's Navstar Global Positioning System (GPS) for their own military operations? Virtually nothing. All they would need would be unclassified civilian GPS receivers to pick up the signals, and those devices are relatively easy to come by.

There is no evidence that Iraqi forces have, in fact, used Navstar. But the Pentagon is sufficiently concerned that an enemy could tap into the technology that it has devised a way to ensure that in future only U.S. military forces can get highly accurate information from the system. Other users—including scientists—would have access only to imprecise positioning data. In essence, the scheme, which is known as "selective availability," involves the broadcast by Navstar satellites of two distinct signals. One, which can be picked up only by special classified military receivers, would provide instantaneous information accurate to 17.8 meters. The other, available to anybody with a civilian receiver, would carry a slight distortion that would reduce the accuracy to 100 meters.

The Pentagon actually implemented selective availability last March but, ironically, had to suspend it during the Gulf war because U.S. forces had too few military receivers to go around and were forced to rely on civilian models (see accompanying story). When the crisis is over, however, selective availability will almost certainly be reimposed. And that prospect angers many civilian users. "The military has come up with a system that is useful to mankind. Now they don't want mankind to have full use of it," says Roger Bilham of the University of Colorado, who is using GPS data to predict seismic risks in developing nations.

The GPS system has a vast range of potential users outside the military, such as tracking freight shipments, marine navigation, and oceanographic and geophysical research. Though 100-meter accuracy is fine for some of these applications, it's too imprecise for others: monitoring the location of railroad cars, for example, where tracks are close together, and navigating through rock-infested straits where accuracies of a few meters are needed.

One group of GPS users—geodesists who use GPS for ultraprecise measurements of the movement of Earth's crust—has developed ways around the problem, however. Unlike troops, who need instantaneous fixes on their positions because they are constantly moving around, geodesists monitor the relative positions of specific points on Earth over long periods of time. They use GPS data from many satellites and a technique called differential GPS that employs several receivers to cancel out minor errors.

Before selective availability was introduced into the system, geodesists were able to use these techniques to fix positions to an accuracy of a few millimeters. But there was some concern that the Pentagon's new measures would degrade the data to unacceptable levels. It turns out, however, that careful experimental design and additional processing of data can cancel out the distortions in the signals, according to several researchers. "I think we've learned to live with selective availability," says Bill Melbourne of the Jet Propulsion Laboratory in Pasadena. But the solution is costly: Perhaps an order of magnitude increase in GPS readings is required, which in turn increases the costs of data storage, transmission, and analysis, Melbourne says.

Some scientists therefore remain critical of selective availability. "None of DOD's rationales makes sense," says Michael Bevis, a geophysicist at North Carolina State University who uses GPS in his studies of the tectonic properties of the southwestern Pacific Ocean. For example, Bevis notes that the Soviet Union is deploying its own set of navigational satellites and he argues that the Soviets thus are unlikely to try to use GPS.

Further, says Bevis, there is no justification for using selective availability during peacetime. During a crisis or war, the Pentagon could activate selective availability if needed, he argues. But Air Force Lieutenant Colonel Jules McNeff, an aide to the assistant secretary of defense for command, control, communications, and intelligence, says such an arrangement would be unacceptable. The military's GPS operating procedures are different with selective availability off and on, he claims, so troops that drill with GPS during peacetime might not be able to use the system effectively during war. Further, switching selective availability on and off in response to global tensions also would mean that civilian users would face inconsistent levels of accuracy from GPS, McNeff says. Once selective availability is put into place permanently, civilian users will be better served by a consistent, though degraded, level of accuracy, he says.

The proven military effectiveness of the Navstar system in the Gulf war will almost certainly reinforce the Pentagon's desire to keep accurate GPS data to itself. Says McNeff: "Selective availability shouldn't be a surprise to anyone." No surprise, perhaps, but for geodesists it will be a costly nuisance and for a few users it could be crippling. ■ V.K.

commander of the Air Force Systems Command, the R&D agency that spearheads the Navstar project. "Navstar receivers are one of the hottest commodities on the Arabian peninsula today," Yates told an industry group last week. "They're being used in ships, tanks, and helicopters, and our ground troops can't get them fast enough," he says.

Their use in the Army's new M1 Abrams tank indicates one novel way Navstar is being incorporated into battlefield tactics—and some of the problems involved in getting the system fully operational in time for the war. Navstar is supposed to help prevent U.S. tanks from accidentally firing on one another during the confusion of a ground battle. The strategy is simple: Tanks broadcast their Navstar-determined positions to one another through secure radio links. But an M1 tank is sealed in battle to protect the soldiers inside from artillery and biological and chemical weapons and, just as an automobile radio stops working inside a deep tunnel, the hand-held Navstar receivers would not work inside the tanks. Thus the Army quickly had to retrofit the tanks with special antennas mounted atop the vehicles and linked to the Navstar receivers by a cable. "That way, you won't have to open up the tank" to determine your position, says one Army official.

Problems with the system haven't been only on the ground: The satellites themselves also have posed some challenges. When the crisis broke in August, only 14 satellites were available, including 6 aging experimental ones, some of which date back to the late 1970s, when the Pentagon first began space tests of the system. As a result, the Middle East did not have continuous Navstar coverage. In the following months, as U.S. forces massed in the Middle East, Air Force workers launched two more Navstar satellites into orbits designed to improve coverage over the Middle East, and ground controllers at Falcon Air Force Base, Colorado, managed to deploy the satellites in record time.

Unfortunately, just as allied forces were about to launch the air offensive, a component used to stabilize one of the older experimental Navstar satellites failed. The loss of that satellite—which had lasted 6 years beyond its 4-year design life—resulted in a reduction in coverage in the Middle East and elsewhere. To keep the satellite from tumbling, ground controllers ordered it to spin at a high speed. That prevented it from pointing its antennas toward Earth, however. Then, just hours before the United States launched its assault on Iraq on 17 January, ground controllers figured out a way to make the antennas point at Earth briefly once a day, when the satellite is over the Middle East.

Another problem reared its head on 12 December, when a control circuit for one of the solar panels aboard a newly launched Navstar satellite failed. The satellite continued to broadcast a useful navigation signal, and a second control circuit was available to replace the failed unit, but Air Force officials have delayed any further Navstar launches until they can determine whether the flaw is present in other satellites awaiting launch.

Nonetheless, Pentagon officials remain effusive about the program. Vice Admiral Jerry Tuttle, the U.S. Navy's director of space, command and control, echoes a common prediction when he says that the system "will revolutionize tactics in every warfare area." Adds Tuttle: "I would love to be back in the fleet to develop tactics around GPS."

■ VINCENT KIERNAN

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Caltech Deals With Fraud Allegations

"We have become aware that certain of the original data referred to in the article by Urban et al. (Cell ***52**, 257-271, 1989) are unavailable, and thus we are unable to verify that all of the conclusions in that paper are correct. Therefore, we would like to retract that paper. We are now repeating those experiments. No one regrets this episode more than we."*

Those few words in the 25 January issue of *Cell* made painfully public what many immunologists have known for months: there has been trouble in the lab of Caltech biologist Leroy Hood. Two postdoctoral fellows, working in a particularly hot area of immune system research, are under investigation for two apparently unrelated instances of possible research fraud. Hood himself is in no way implicated, though he was a coauthor on both papers. The *Cell* paper is the second to be retracted by the Hood group in recent months—the first was retracted last September from the *Journal of Experimental Medicine*. At this stage, it is unclear whether there will be more retractions.

To protect the interests of the two postdocs, neither Hood nor Caltech officials will divulge any details of the investigations. But scientists outside the lab who have followed events since last summer say both Hood and the university have handled the matter in an exemplary way. Indeed, if the National Institutes of Health upholds the findings of Caltech's two investigations, the Hood experience could well become a model for other laboratories grappling with allegations of fraud.

The problem first came to light last summer, when a researcher in Hood's group was unable to repeat an experiment performed by one of the postdocs. When he examined the data more closely, he found what looked like evidence of a doctored Southern blot. He took his suspicions to Hood, who notified the chairman of the biology division the next day.

According to Paul Jennings, Caltech's vice president and provost, the university immediately conducted an inquiry to see whether an investigation was warranted. Once they determined it was, they notified the Office of Scientific Integrity (OSI) at NIH, the other sponsoring agencies, as well as the journals that published the work, and the coauthors. Caltech then launched a formal investigation, which was just completed and sent for review to Caltech's president, Thomas Everhart, along with recommended actions.

Very early in the investigation Hood realized, and Jennings agreed, that the paper containing the questionable Southern blots, originally published in the December 1989 issue of the *Journal of Experimental Medicine*, would have to be retracted. Hood also withdrew one or more manuscripts that had been submitted for publication more recently. At about that time, in late summer, he personally wrote to many of his colleagues in the immunology community, alerting them to the possible problem, the ongoing investigation, and the pending retraction.

In the course of the first investigation, Caltech uncovered evidence suggesting there might be trouble with the work of another postdoc. The problem includes, it seems, the missing data referred to in the *Cell* retraction. The two postdocs were working on related aspects of the same project, but sources inside the lab say there is no evidence of collusion. Again, Caltech quickly conducted a preliminary inquiry and then launched a formal investigation, which is now half finished. Under NIH guidelines it must be completed by 15 April.

But Hood did not wait for the results of the investigation to retract the *Cell* paper, which deals with a potential method of blocking autoimmune reactions, such as those involved in multiple sclerosis. Hood is not certain that the conclusions of that important paper are wrong but feels uncomfortable about it, given the questions about the postdoc's performance. His group is now repeating those experiments.

Concerning the first investigation, Caltech president Everhart is expected to announce the committee's findings and recommend disciplinary actions or sanctions, if any, within a couple of weeks. The report of the investigating committee was also sent to the OSI at NIH. OSI usually accepts the findings of the home institution, although it has the option of launching its own investigation. If misconduct is found, OSI adds its own recommendations for sanctions and then forwards the report and recommendations to the Public Health Service for additional review.

These are the first fraud investigations to be conducted at Caltech, and Jennings describes them as "tremendously difficult" for all concerned, as "people's reputations are at stake." Outside observers say, however, that they don't expect the fallout for Hood or his group to be severe because both he and the university moved so decisively.

Says James Allison, an immunologist at the University of California at Berkeley: "Lee moved in exactly the right way for science and for his reputation. It certainly doesn't help [his reputation]. But because he acted very promptly and decisively, he minimized the damage."

Adds Berkeley colleague Gerald Rubin, head of the genetics division: "I think a lot of people have learned from the pain and suffering David Baltimore went through. Baltimore was faulted because he was too eager to defend his co-workers. That got him into trouble."

■ LESLIE ROBERTS