THE AEROSPACE CORPORATION

An Interview with Dr. Brad Parkinson
The Aerospace Corporation
April 1 and June 4, 2003

Dr. Bradford Parkinson, chair of The Aerospace Corporation board of trustees, was named co-recipient of the Charles Stark Draper Prize in February 2003, for his contribution to the development of the Global Positioning System (GPS). Parkinson shared the $500,000 award with Dr. Ivan Getting, the first president of The Aerospace Corporation. The Draper Prize—the engineering profession's equivalent of the Nobel Prize—recognizes engineering achievements that have led to important contributions to everyday life. The citation for the prize awarded to Parkinson and Getting reads, "For pioneering the concept and development of a Global Positioning System that, with incredible precision, tells you where you are and helps you get to where you want to be."

As a young Air Force colonel in the 1960s, Parkinson was the person most responsible for synthesizing elements of the competing navigational systems proposed by the Space Division and supported by Aerospace, the Applied Physics Laboratory, and the Naval Research Station into a single, viable concept. He then tirelessly pushed his vision through the Department of Defense (DOD) until he obtained approval for the program in 1973. After receiving permission to go ahead with GPS, which became the first joint, multiservice, military program office, he shepherded GPS through the developmental phase of concept validation. This phase successfully launched the first GPS satellites, tested the user equipment, and verified the 10-meter accuracy proposed by Parkinson. With the validation complete, he retired from the Air Force in 1978.

Following his retirement, Parkinson continued his involvement with GPS in several ways. In his position as professor of Aeronautics and Astronautics at Stanford University, where he began teaching in 1984, Parkinson has been especially successful in promoting new uses for GPS technology, including the development of a fully blind landing system for aircraft and the use of robotic tractors for farming. Now professor emeritus at Stanford, Parkinson also serves as cochair of the Jet Propulsion Laboratory Advisory Council. Some of his most interesting work concerns his involvement as co-principal investigator of the Gravity Probe B Program, a NASA-funded space probe that attempts to validate Einstein's general theory of relativity.

Steven R. Strom interviewed Parkinson April 1 and June 4, 2003, at Aerospace in El Segundo. Parkinson discussed his involvement in navigating GPS through the military and ultimately gaining DOD approval for the program, which, although now widely used in everyday life, came perilously close to cancellation. A version of this interview appeared in Quest: The History of Spaceflight Quarterly.

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Strom: *Dr. Parkinson, could you begin today by discussing how your educational background prepared you for your eventual role as GPS Program Manager?*

Parkinson: Sure, I'd be glad to address that. I guess you'd have to go back to high school really. I was in a very small all-boys' high school that had an outstanding mathematics teacher, and I happened to have a lot of interest in math. The consequence of that is that as I went through, this natural interest was reinforced, and I achieved a certain amount of skill in math. After I graduated from high school, I went to the Naval Academy and there also excelled in the math and science areas. The thing that I discovered was that I really wanted to get into controls engineering, and it was not delved into in any deep way at the Naval Academy, but I also had a very good electrical engineering professor. This electrical engineering professor happened to be an Air Force officer, an exchange officer at the Naval Academy, and he suggested the educational opportunities in the Air Force were better than those in the Navy.

So I looked into this in quite a bit of depth, and concluded that he was right, that if you went into the Air Force, the chances are you would get sent to further education. I already had in mind that I wanted to get a Ph.D. Furthermore, when you were given that education, the Air Force would then use it and would apply that education to jobs that you would have in the future. So with that in mind I went into the Air Force. I did not elect to go immediately to school, although they offered to send me to MIT initially on my first assignment. I said no, I wanted to find out what the Air Force was all about.

After a couple of years in the Air Force I was sent to MIT, and I got into a program they called "Course Sixteen," which is aeronautics and astronautics. This program was linked directly to what was then known as the Instrumentation Laboratory and later became the Draper Lab. These were the experts on inertial guidance and navigation. They had developed the concept; the first flight of an inertial navigator was done under Dr. [Charles Stark] Draper, who I came to know during my two years there. I actually did my master's thesis in the Draper Lab, and I also picked up a larger number of electrical engineering courses in controls engineering. So my education wasn't just inertial navigation guidance instruments. It was also a fair amount of electrical engineering.

I then went off into my next assignment, which, although it was a working assignment, was also educational and that was at the Central Inertial Guidance Test Facility at Holloman [Air Force Base], where I spent three years as a guidance analyst. I was very fortunate because my assignments included the detailed analysis of individual instruments, it included the analysis of inertial guidance for ICBM's, and it also included the system analysis of inertial navigation systems in airplanes for location. At the end of three years there, I was reassigned to Stanford in the Ph.D. program. Again, I pursued controls engineering on the academic side, and my dissertation was on a version of a gyroscope, which is also, of course, a navigation instrument. So the point is, I think that at the end of that period of my life I had an in-depth understanding of inertial guidance navigation controls and electrical engineering, as well as astrodynamics and quite a bit

of work on satellites. And I believe that all of those were important. The education and experience was a strong contributor to the knowledge that I brought to bear when I was eventually assigned to 621B, which became GPS.

I think another important part of my background education, in the broader sense, was that somewhere along the line I became the head of the Department of Astronautics and Computer Science at the Air Force Academy. I had a very peculiar assignment there, because for one year of it I was involved in the introduction of the AC-130 gunships into combat over Laos. They were using these gunships as interdiction platforms, and they had on board a very sophisticated sensing system, a sophisticated digital control system, and then they used all that information to control either a 40-mm cannon or a 105-mm field howitzer fired sideways. The point is that I gained both a keen appreciation for what it was like to get shot at and also a good appreciation for the need for precision weapon delivery. The AC-130 was without doubt the most precise weapon delivery system that we had in that era. It relied on direct sensing and it was not of a GPS variety, but it was sensitive to the parameters that drive a warrior and that make a warrior more effective. These were all important parts of my education. So, I think when I finally ended up in charge of 621B that all those pieces kind of fell into place, at least in my thinking it did. I suspect that my superior, Lt. Gen. Ken Schultz, probably felt the same way, because when he assigned me to the job he had probably already been told or read exactly what my background was.

Strom: *Once you were in the Air Force, do you remember how long it was before you became aware of Program 621B?*

Parkinson: Yes, I think I have a pretty clear understanding of that. I had been assigned out of the Air Force Academy to the Naval War College, and assumed I would end up going to the Pentagon after that. But instead there was a certain Col. [William R.] Manlove in the Pentagon who put my personnel file in his desk after he saw it being circulated and didn't let it go any farther. He knew he was being reassigned out here to SAMSO (Space and Missile Systems Organization) at the time. He called me up, and he said if I didn't mind would I come down and talk to him? Well I already knew who Col. Manlove was, because he was a part of what was known in the Air Force as the "Guidance Mafia," as was I. The Guidance Mafia was a group of guidance and control officers, mostly educated at the MIT Instrumentation Lab, with master's degrees, or in some cases Ph.D.'s. And this group kind of looked out for each other in a sub-rosa way. So, what Col. Manlove asked me was whether I wanted to simply study things or build things? And my instant reaction was, well I want to build things. And that probably goes back to my youth.

Then he said, well, he was being assigned to a program called ABRES (Advanced Ballistic Re-Entry Systems), which was a major Aerospace/Air Force program here in El Segundo. It was spending about $120 million per year. The program was a cold war pawn really. That money was going to flow in no matter what we spent it on, simply

because it represented a symbolic need to continue advanced ballistic missile technology. And so, the first one hundred days of my assignment here in SAMSO, I was the chief engineer, and fortunately I worked for a Gen. [Herbert A.] Lyon, who gave me virtually complete authority over how the $100 million was spent. Naturally I started spending some money on maneuvering reentry vehicles, which were controlled by inertial guidance systems and had little fins on them. All in all, it was a very, very wonderful experience.

I would say about 60 days into that hundred-day experience, a certain Gen. [William W.] Dunn came to see me and announced that he had this program called 621B. It was a technology demonstration program then, and the Air Force and The Aerospace Corporation had collaborated on it, but in terms of technology, it was really an Aerospace program. Dr. [Ivan] Getting, the head of Aerospace had expressed a lot of personal interest in this program, and the technology being developed in part was very pertinent to what we eventually did. As a matter of fact, it was essential.

What had happened is that Aerospace had developed a technique for direct ranging to a satellite using pseudo-random noise. And they had demonstrated this at Holloman Air Force Base. It did not work as well as we hoped it could work, but on the other hand it was instantly obvious that the feasibility was there. So, when Gen. Dunn approached me with this idea I started to look into it, because what he wanted me to do was give up my ABRES assignment and come over and work on 621B, which he concluded was going nowhere. I think he was seeking leadership, he was seeking someone who could go and market the ideas in the Pentagon and also shape the program.

Nothing happened for a period of about another two or three weeks, and then I got called into Gen. Schultz's office. The interview consisted of his sitting at his desk and my sitting at a chair opposite him and his asking me had I heard of 621B, and I said yes. And his asking me how I'd like to be assigned to 621B. And at that point I impertinently said, well general if I'm assigned, am I in charge? And he told me that he couldn't promise that, that was a decision made much higher than him. I said, well in that case I'm not a volunteer, which I think surprised him as an answer. I think first of all he was a little bit surprised by the question, but he was very surprised by my reaction. The net result was I must have gotten 10 feet outside of his office, and he called personnel and told them to reassign me. And so I was assigned to 621B without the promise that I would become program manger, but I think I had laid the groundwork, and from then on there was no question that I was to be the program manager. I have to give Gen. Schultz a lot of credit for helping me in that way. I think also, as things developed, because Gen. Schultz had led the Ballistic Missile Program during some very, very difficult times, he knew what it was to be a program manager or program director. As a result, he understood his job was to keep the world off my back and let me do what I had to do. So he was a very strong delegator, he wanted me to report in and from time to time, gave me some very, very good counseling and advice.

Strom: *How many months did you work before you became the program manager?*

Parkinson: I was reassigned in November of 1972, right about Thanksgiving. There was a more senior colonel to me on the program named Jack Price, who was a very, very fine gentleman. Although technically I was not in charge, he in essence just stepped aside. And I think by the following summer he was reassigned. But in the intervening period, as I started to make a series of almost weekly trips to Washington to convince people to not say no to 621B, it was obvious and I think everyone knew who was in charge. But I was not insubordinate in any way. Col. Price also realized that he wasn't the guy, and he told me that frankly. He said look, we need someone else in here and it's not me.

Strom: *What role did Aerospace play in working toward the synthesis that became GPS?*

Parkinson: The Aerospace Corporation was critical to developing the technology and certain of the concepts that became GPS. Their use of pseudo-random noise codes for the ranging signal was essential to what we see today. In layman's terms, what makes this so interesting is all the GPS signals are broadcast on exactly the same frequency. The differentiation between signals is achieved by looking at the modulation. You seek a replica of that modulation using your own receiver, and as a consequence you can dig out all of the signals of the same frequency, the particular segment that you're seeking. The technical description is that these codes are mutually orthogonal, and by that I mean to say if you average over one full code length, and the code is a sequence of about 1,023 bits, you will not see any answer except the answer that you get when you try to line that code up with its complete exact replica, starting at exactly the same time. I don't know if that is easily understood, but the consequence is very profound. The consequence is that when you receive the signal and digitize it, the digitizing contains all the information for all the signals. That implies that the biases in time between the channels, the errors, are all locked down permanently as soon as you have recorded that signal.

The Aerospace Corporation pioneered that concept, and they also pioneered the development of user equipment that could take those codes and make them into a navigation solution. And that demonstration, which was carried out in the late '60s and early '70s at Holloman Air Force Base, I think was an essential persuader to the rest of the world that this could be done. So I think enormous credit goes to Dr. Getting, but also to Dr. Phil Diamond, Mr. Walt Milton, and a whole host of wonderful Aerospace engineers who were involved at that time.

Now when I came on the program, I understood 621B at a rudimentary level, but I didn't understand it in depth. So, I conceived of a very cruel method of finding out what was going on in great depth. My method was to have educational sessions at 7:00 every morning, roughly three mornings a week. They lasted roughly an hour and a half, during

which an Aerospace engineer would get up and talk about one or another very esoteric aspect of the system. I think the record was that one morning, for an hour and a half, a gentleman named Frank Butterfield—I remember him very vividly, a wonderful engineer—he came in with a stack of probably 20 or 30 vugraphs that he'd intended to present us that morning. He never got off the first vugraph. That one question led to another, and this went on for a period of two to three months. At the end of which, not only did I understand everything that had gone before in great depth, all of my people did too. This was a great unifying method of having us all dealing from the same sheet of paper. So as we went forward and eventually synthesized GPS out of the cancelled 621B, as well as Timation and Transit, the other two contributors to GPS, we were standing on very solid technical ground. So Aerospace also contributed to that education.

Strom: *When did 621B gradually evolve into the GPS program?*

Parkinson: As we delved into the politics of 621B, it became obvious that in part, a portion of the reason that it did not gain approval was there were some technical questions. But the other part was that there were two competing programs. One was hard to figure out, because it was in the Navy's SPO (System Program Office) program that also developed Transit, and they were fairly secretive. But it turns out they were contemplating putting a PRN (Pseudo Random Noise) code generator on the low-altitude Transit satellites. Meanwhile, of course, Transit itself had developed a great body of wonderful software to predict orbits. And all of these satellite navigation systems require that the satellite knows where it is. That is part of the evolution in a way.

The other major program was Timation, and that was being done under Dr. Roger Easton at the Naval Research Laboratory. Its purpose ostensibly was a little different, but it was competing. Its purpose was to orbit clocks so that they could perform time transfer, and initially they orbited some quartz clocks. They had some plans to orbit rubidium, but it became obvious that the concepts 621B had advocated, which was a concept generating the signal on the ground, sending it up to the satellite, and then retransmitting it, had some vulnerabilities. It also probably had some inaccuracies, because with all the transfers of signals, maintaining precise time to an accuracy of nanoseconds would probably have been very difficult to do.

After I listened to the stories that were being offered against doing 621B, the stories by Transit and the stories by Timation, it became clear to me that 621B was not necessarily the best answer. It had a lot of good elements, but it was not the whole idea. So, meanwhile, the famous meeting that took place between myself and Dr. Mal [Malcolm R.] Currie came to bear on this. Dr. Currie was the deputy secretary of defense for research and engineering and the number three person in DOD. He had, for some personal reasons, a series of trips he had to take so that he could spend the weekend in Los Angeles. During these trips, he needed a reason for military travel, that is, he had to have a military purpose. And the logical one was to come and visit SAMSO, visit Gen.

Schultz. After he had come out here a few times, Gen. Schultz ran out of things to tell him. At that point Gen. Schultz said, well let's send him down for the whole afternoon and he can talk to Brad Parkinson. Brad talks a lot, that'll keep him occupied. And I don't know if it was quite that simple of a story, but that's how it appeared to me.

So, at this point I, a very lowly and new colonel, spent a whole afternoon with the third most powerful person in DOD, and clearly the most powerful person when it came to program approval. I had a stack of vugraphs that was about four inches high, and we sat in my very small office, just he and I, and spent the whole afternoon together. He had a Ph.D. in nuclear physics and was a very bright guy, a very quick learner. At the end of that—I didn't realize at the time, although I found out later—he found a program that he really loved, and that was 621B. And it turned out that was essential in later phases of what developed, because he protected me from certain forces within the Pentagon and allowed me to continue with what I was trying to do.

I think at the same time Dr. Currie had confidence in me, but he was also hearing these other [competing] stories. So, he conceived of this as a joint program that would involve all services, and to my knowledge we were then designated as the first joint program office.

Strom: *There was a major crisis that occurred in August 1973. Can you tell me something about what the crisis involved?*

Parkinson: In August of 1973, we were scheduled to hold a DSARC, which stands for Defense Systems Acquisition Review Council. This is a very large meeting, and it was instituted by David Packard as a means of getting a very crisp decision on a program. In the run-up to that DSARC, I had presented 621B to many, many people, and as I went into the meeting, of course, there were high hopes that 621B would be approved. And the outcome of this meeting was a yes or a no. It was a thumbs up or thumbs down. I put on my presentation, which I thought was okay. At the end of that meeting, they went around the table and the answer was thumbs down. So at that point we had a cancelled program. However, Dr. Currie looked up at me and said, Brad I want to see you in my office right after this meeting. I thought, because I knew it was one of his favorite programs, that I was going to run into some kind of a chastisement for the fact that we had not passed the DSARC. So I went into his office, but found just the opposite. He said, listen you did a very, very nice job, but you and I know that this not truly a joint program. We cancelled 621B, but what I want you to do is go back, reconstitute it as a joint program, and bring it to me as quickly as you possibly can, and I am very, very certain that we are going to approve it.

And that led to my assembling over Labor Day weekend in the Pentagon, a group of about a dozen people, largely my Air Force officers with Ph.D.s and master's from MIT and elsewhere. There were one or two Aerospace people there. But the point was, I had to shed all preconceived notions about what the program was going to be. And I wanted

to select among the competing concepts the very, very best as a joint program. I knew that if I did that, the opposition from Timation and Transit would disappear, since I had already taken their best ideas and put them into one program. There was no way they could oppose it. So we spent that long Labor Day weekend in the Pentagon. I think that the loneliest place in the world is the Pentagon on a Labor Day weekend. They don't even hardly have the lights on in the halls. No one is walking around. Normally if you go into the Pentagon it's a bustle of traffic. Nobody was around, nobody was there to bother us, and the outcome was at the end of that weekend we had the decision coordinating paper of seven pages that described GPS as you know it today.

Strom: *After you arrived at the basic concept of GPS, as we currently know it, how did you ultimately gain DSARC approval for the program?*

Parkinson: In September of 1973, at the end of that Labor Day weekend, we had a fairly detailed concept of what GPS would be. We then flushed that out in the form of both a presentation and a bunch of descriptive material, and over the next three months I hit the road. I went to every significant office in the Pentagon. I went around to the operating commands, explained to them what this concept would do for them. And in general, the idea was to try to ensure that nobody would say no. In the Pentagon it's hard to get people to say yes, but if you have a few that say yes, and nobody else says no, generally you've carried the day. At the time I was working for Gen. Ken Schultz, and I think he was astounded at the effort that was required to get people to simply accept what we were trying to do. Because it was a joint program, it was also important that we go around and speak to the other services. So when I went to the Pentagon I was speaking to all services, the DOD hierarchy as well. At the end of November, we had already scheduled for mid-December the meeting called the DSARC. And by the end of November, it became clear that there was no significant resistance. The pockets of resistance that had existed before in the Navy did not have any technical basis anymore, because in essence we had accommodated their needs and frankly, tried to adapt the technologies they had that were superior to 621B.

So in December, we went through that [DSARC] meeting, and there was no problem. We received permission to move ahead, and we got the formal letter in early January. We then put out the RFPs (Request for Proposals) for the various components of the system. At this point, we made a very, very significant decision, which was that the integration of the program would be done by the program office. There was no integrating contractor, and frankly, I was almost fired by my boss, my three-star general, because he initially did not accept that I could do that. He did not think that we had the technical bandwidth to do it. So I went through a presentation with him and explained to him how we were going to control the interfaces, control the contractors, and although this was not called that at the time, what we were really doing was synthesizing an integrated product team.

This team consisted of the blue suiters [Air Force officers], of whom we had a substantial number. Virtually all of them had master's degrees from universities such as MIT, Purdue, Michigan, or Ph.D.'s. I had a small cadre at that point of Aerospace people, as I remember it numbered about 25. The idea was that were going to manage this team internally. It turned out that was a very wise decision. I had hired some very, very bright Air Force officers, who had previous experience in integrated systems at Holloman. When we got to the point of actually building this system, they could drive down to the smallest details on the interface documents. As a consequence, once we got around to actually assembling things it went very, very smoothly. And the reason is that the system of systems engineering, assembling all these pieces together and understanding their interactions, had been carefully thought out. So I'm very proud of those people. I think that in all the flurry of distributing credit, in many cases they don't receive enough credit. And I'm including, of course, the Aerospace technical people. They had some excellent people on RF (radio frequency), excellent people on the control segment, orbit prediction, etc.

Strom: *How did you arrive at your concept of systems engineering for GPS?*

Parkinson: Well, at the outset although the interfaces were relatively clean, that is to say that the interface between the satellite and the user equipment, for example, was an RF signal that had some modulation on it. So conceptionally that's easy. The truth is the devil was in the details. And I felt that unless we had total cognizance of how those details were going to be adjusted and worked out, that something was going to come off the track. But just because we had the need wasn't enough. You also had to have the capability to deal with the problem.

In this case we had a gentleman named Major Mel Birnbaum. He had hired some help from Jim Spilker and his company, Stanford Telecom, on defining the exact signal structure. So in working out each of those interfaces, and here we're talking all aspects, from how you actually gather data to how you can calculate orbits at the meter level in real time. We're talking about how you modulate a signal with enough significant bits so that the user, when he strips them off, is not losing accuracy. We're talking about how you integrate an inertial system with a GPS system and ensure that synergy is a real help, and that the GPS calibrates the inertial system, and the inertial system helps the GPS system resist jamming. All those things were part of what we had to design and integrate.

So the concept I had is that system engineering would only work if there were this broad cognizance over the whole system. At the same time, I had great sensitivity to the fact that everything we were doing really related to the warrior. What we were doing is trying to put together a system that would enhance and revolutionize warfare. The model that we had—"drop five bombs in the same hole"—meant don't forget the end product of what we're trying to deal with here. And one of the primary tests that we had designed in from the beginning was a demonstration of how well you could actually drop blind

bombs. And I'm pleased to say that when we did it, the conventional wisdom—I don't think I could tell you what the accuracies actually were—was that a perfect bomb could not be dropped to an accuracy of better than 50 feet. And frankly we put the lie to that, because we did better. I think that was because of attention to a lot of details, and here again I'm including Aerospace as well as the blue suiters, or we would not have arrived at that result.

Strom: *Can you tell me about some of the early developmental work that went on with GPS up to the time of your retirement from the Air Force in 1978?*

Parkinson: We had with broad brush created the system design, but much of the details had been left for later. In other words, the DSARC did not, for example, totally define the signal structure. It did not define exactly what the antenna pattern had to be. It did not define exactly how we would process the data and do our uploads to the satellites. So a whole series of technical studies and trade offs were being performed. Aerospace was very much in the midst of this. In particular, my friend and colleague Ed Lassiter, who was the head of the Aerospace GPS Program Office, was invaluable. He also had a charming ability, if he thought I was going slightly off track, to come into my office and close the door and explain how it was slightly screwed up and needed a little straightening out. I was always willing to listen to him, because I set great store by the knowledge and wisdom that he also offered.

We also continued a stream of conversations with the operating commands during this period of time. Roughly three or four times a year, I would make a tour and go around to each of the major operating commands—at that time it was TAC (Tactical Air Command), SAC (Strategic Air Command), and MAC (Military Airlift Command), the communications people—and inform them exactly what we were doing and try to describe how we thought it would benefit them. At the same time, I would listen to them and find out their concerns, in terms of building equipment and gaining capability.

So I think that keeping an eye on your market, so to speak, the users that you're going to deal with was a very prime part of the way we evolved at this time. Turning a little back to the Aerospace role, we also would use the laboratory structure of Aerospace at times, particularly when it came to some of the details of the user equipment, piece parts for satellites, and how you tested and verified certain things in terms of the qualification of testing program. We found that the labs were invaluable in helping us carry forward the objectives. It was great to be able to draw on that large group of very knowledgeable people who had seen a lot of problems. They had the scar tissue that said they knew where the problems were.

Strom: *What were your personal feelings regarding the status of GPS at the time of your retirement?*

Parkinson: Well, it's interesting because it was clear that by the time that I retired we had satellites up, we had user equipment working, and we had test results. In essence, we had done the full proof of concept that we were asked to do back in l973. By 1979, it was clear that we had done all the right things. On the other hand, it was also clear that the Air Force had a very peculiar attitude regarding GPS. In spite of all those trips to the operating commands, it was not clear the Air Force really understood what the potential impact was. And in part the bombing tests that we had run were put in place to demonstrate what we were talking about. But in terms, for example, of accuracy and bombing that payoff is so enormous that I don't think that the operators of TAC, and certainly SAC, who never had at that time even accepted the system or understood the impact.

As a result, when I left I still had a queasy feeling that although GPS was a good program, the Air Force still had not totally endorsed it. And that was born out by later developments, because there were a series of decisions, perhaps major ones, made every three or four years in which the Air Force offered up GPS for total cancellation, in spite of all the promise it had shown. And in each case it usually was someone in the civilian chain of command, usually at DOD, who stepped in and reversed the decision. But GPS came very, very close to termination on a number of occasions.

Strom: *After you retired from the Air Force, did your keep up with GPS developments during the phase two and phase three periods?*

Parkinson: I followed what the JPO (Joint Program Office) was doing, but frankly for a period of 20 years I never went back except I think for one occasion, which was strictly a social visit. I had decided that it would be uncomfortable for me to involve myself with any military program. As a result when I got to Stanford in 1974, I started a strong research program on civilian applications, and that is ongoing to today and has introduced a couple of interesting new developments for the FAA (Federal Aviation Administration). We pioneered the system that they are now deploying operationally called Wide Area Augmentation. We did the first studies of that and actually put together a prototype system whose central control was on the Stanford campus. We demonstrated the ability to do blind landings and did 110 straight blind landings using a 737 United airplane that had been provided by FAA. We received a lot of good FAA sponsorship. I also got good sponsorship from John Deere on the robotic farm tractors. We were given two large farm tractors, and we showed the ability of GPS to control those at the level of one or two inches on a rough field, and go back year after year to exactly the same place within one or two inches, and it turns out that is now a successful commercial business. And there are a number of manufacturers producing that equipment, but we did the first existence proofs of that.

So, in many cases keeping up with developments is not exactly the right word. I think my students were on the forefront of GPS developments during that period, and they continue to this day. My colleague Per Enge, who has given seminars at Aerospace, is

now gradually taking the reins of power. He now runs over half of the GPS program at Stanford, and I expect in the next few years he will take over the whole thing. He has a number of very bright colleagues that he's assembled around him, and I expect there will be further developments in GPS in years to come.

Strom: *Can you describe to me your own feelings when GPS was successfully used during the Persian Gulf War and then later when the system was declared fully operational in 1995?*

Parkinson: Well, first of all I wasn't surprised. I guess in a certain sense I was disappointed that it had taken that long to become fully operational. The satellites that we put up in the late '70s and early '80s had most of the characteristics of today's satellites, and in terms of signal structure they are virtually identical. So had the Air Force had the will to do so, that operational day could have been 10 years earlier. Nonetheless, we are all victims of our own history, and in this case the history was a slow acceptance period for the Air Force. And the Persian Gulf War of 1991, the incidents in Kosovo, and the Gulf War of today have all, each one, shown a successively more sophisticated use of GPS. Those successive improvements in GPS to me were not surprising at all. My background at MIT was in guidance and control inertial navigation and I understood, I think, as well as most anyone what the payoff was of precision weapon delivery.

And when I'm talking precision, I'm talking down to the meter level. And I think there is still a ways to go here. I think with the new small diameter bomb problem, there is going to be an even greater imperative to use the accuracy that GPS inherently has. If we can land airplanes, if I can position an airplane in three dimensions to roughly two inches on each of those three axes, there's no reason in my opinion that we can't devise systems and operational procedures to drop bombs within a meter or two of a target. Completely blind, and by that I mean through the clouds, through the weather. It implies that we put as much energy into locating the target in our common grid as we do in dropping the bomb.

But the point is, if the underlying GPS system has the accuracy that we're talking about, you can go to 250-pound bombs, you can take out military targets, and go even further to avoiding collateral damage. I've called GPS the humanitarian weapon. It is humanitarian in the sense that the military hits what the military has to hit, and does not hit things that should not have been hit. I am very, very proud of our military in the recent war in Iraq, because I think they went to great lengths to use the GPS capability to ensure that it was the humanitarian weapon of war, as contradictory as that might sound. My feeling was one of pride that I had some part in this. I also, every time I look backwards in time, am amazed at how many people made contributions to this system. Many of whom we've forgotten, and in some cases they are now dead. And when several of us will get together, usually our thoughts turn back to some of those heroes in the early years who sacrificed a lot, they certainly sacrificed family life and in some

cases I even think their health, by putting in the kind of hours and the effort that was necessary to ensure that we didn't trip and fall. Because I think in part, the Air Force allowed us to go ahead the first time in 1973 and 1974, because it was not clear to them that we wouldn't simply stumble and not ever get there. I think they thought that the 10-meter accuracy requirement was preposterous on a worldwide basis, and I don't think that they thought we could bring it in for the cost that we said we were. And we came very, very close to doing that, and on the schedule that we said we were going to bring it in on. We launched the first satellite 44 months after the go-ahead. That's an absolutely astounding result. Today it's not uncommon to have 10 years from the time that you get an RFP to the time that you actually get the satellite. But we did that in 44 months. And I say "we," I think the emphasis here is on a whole bunch of people: Aerospace, the contractors, and certainly the blue suiters helped to make that happen. So, a lot of pride.

Strom: *Earlier this year, you received the Draper Prize for your contributions to GPS. Can you tell me your reaction when you learned of this news?*

Parkinson: Well, it wasn't a total surprise. It seemed to me that the contribution GPS was making to the world, and in particular to this country, was noteworthy and certainly a top contender for something like a Draper Prize. But on the other hand I was also kind of humbled, because every time something like this happens and the award goes to the guy in charge, you recognize—Isaac Newton talked about standing on the shoulders of giants—it was many, many, giants that I stood on the shoulders of, many, many. And so when I go back, I frankly can get pretty emotional when I think about all of them. I felt the prize itself was recognition in honoring the contributions that so many people had made. And it goes all the way from the people who approved the system, the people who developed the technological predecessors, the people who helped develop it, and the users of today who are demonstrating through a lot of creativity many ways that we did not foresee GPS could be used. So I felt good about it, because it was a recognition, and I think the glory gets distributed around to a lot of people.

Strom: *All right, thank you very much for your time, Dr. Parkinson.*

Parkinson: You bet.