DR. DONNA L. SHIRLEY
NASA ORAL HISTORY

INTERVIEWED BY CAROL BUTLER
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BUTLER: Today is July 17, 2001. This oral history with Donna Shirley is being conducted for the NASA Oral History Project in her offices at the University of Oklahoma. Carol Butler is the interviewer.

Thank you very much for allowing me to come visit with you today.

SHIRLEY: Okay.

BUTLER: To begin with, I did take a look at your autobiography before coming, and it was very interesting. It did cover a lot about your early life and how you got interested in the space program. So I'd like to just expand on some of the things that were in your book.

To begin with, when you first came to JPL [Jet Propulsion Laboratory, Pasadena, California] early on, were here at JPL, you worked on an early Mars mission—

SHIRLEY: Right.

BUTLER: —by doing some entry studies, I believe.

SHIRLEY: Right.

BUTLER: What were the similarities of that project with what you worked on later that was Mars-related, and then some of the differences?

SHIRLEY: Well, the similarities of the projects were, this project was called *Voyager*. It wasn't the *Voyager* that went on the grand tour, but its name was *Voyager*, and it was going to be a really big project, bigger than anything that had flown and so on. It was going to land on Mars in 1971.

One of the big differences was that in 1966 we didn't have a very good understanding of the thickness of the atmosphere. So when we were trying to design a blunt sphere cone shape, we didn't know how blunt to make it or how round to make the shoulders of it because we didn't know whether the atmosphere was thick or thin. We knew it was thinner than the Earth, but we didn't know how thin it was. So we wanted to make it really, really blunt, and we had all these different models of the atmosphere.

We wanted to make the entry body very blunt so it had as much drag as possible. But we didn't understand the atmosphere very well so we had all these different models of the atmosphere, everything from a really, really thin one up to a little thicker one. Then we would model using very primitive computers that we had in those days as to how the body would come in and how it would wiggle around and be stable or unstable.

If the atmosphere were thick, it turns out that there was time for instabilities to build up and it might start to tumble. You couldn't make it as blunt as if the atmosphere was thinner and you were just going to get right through it. So we spent a lot of time working on the shape of the entry body.

When *Viking* landed on Mars in 1976 they used this blunt sphere cone shape, and by that time we'd had *Mariner 6* and *7* fly by and *Mariner 9* go into orbit so we knew the atmosphere a lot better. The *Viking* blunt sphere cone entry body shapes were a 70 degree half angle, which was blunter than we were really—you know, that was at the blunt end of what we looking at. They proved that these shapes worked just fine. So when it came to *Pathfinder*, we didn't have to reinvent that. We could use the same shape.

Similarly, parachutes, the same thing with parachutes. You didn't know what the atmosphere was going to be like. You didn't know how to design a parachute for such a thin atmosphere going so fast. We had things like, you know, do you fire out a small parachute to slow down and then a bigger parachute? How many of those do you stage? Those were all burning issues. Well, after *Viking*, those questions were pretty much answered.

The entry part of the *Pathfinder* mission was different because, instead of worrying about the thing about "Well, what is the basic shape of it and will the parachute work?" They were able to work on refinements of the parachute from what they'd learned from *Viking*, and they were able to work on the specific stability of the specific configuration of *Pathfinder*.

The other thing that was different between *Pathfinder* and *Viking* was that *Viking* carried the two landers into orbit. So they could pick the landing site better and things based on the pictures from orbit. Then when they got ready to put the landers down, they were going at Mars orbital velocity instead of interplanetary velocity. The *Pathfinder* was going a lot faster so they had to redesign the heat shield to recognize that it was coming in a lot faster. So there were some fairly relatively subtle differences, but they still required a great deal of engineering design to make that work.

Now, the lander in 1971 (that was supposed to be in 1971, that I was working on in 1966 and '67), wasn't supposed to have a rover on it. It was just supposed to land, like *Viking*. We didn't even think about rovers. Now, later I got into doing studies of rovers, and, of course, those rovers were much larger than *Sojourner* turned out to be. So there was a big difference in the size of the rovers and in the technology that was the basis for the rover's brains and going around.

Mars Global Surveyor was different because it did this aerobraking. What we were planning [for the 1971 mission] was just to burn an engine and take the whole thing into orbit, which was the way that *Viking* worked, carried everything into orbit using an engine to slow down. *Mars Observer*, which was launched in 1992 and was lost in '93, was also just going to burn an engine and slow down and get into the proper orbit. But when *Mars Global Surveyor* was being worked on, in order to save money they used a smaller launch vehicle, which meant you couldn't carry enough fuel to slow down at the other end, to take out all that velocity that the launch vehicle put in. They went into a big looping orbit and then dragged through the upper atmosphere of Mars to slow down. Well, that had never been done before except on *Magellan*, which was a Venus project.

At the very end of that mission, they [*Magellan*] used aerobraking in the atmosphere to get it into a lower circular orbit so they could do some more gravity measurements and so on on Venus. This was *Mars Global Surveyor*. The aerobraking was very different than on any previous mission.

Let's see. What else was there? Well, you asked a question about why are these missions completed but the early one canceled, and the answer is politics. There's a book called *Beyond the Moon* [*A Golden Age of Planetary Exploration 1971-1978*] by Bob

[Robert S.] Kraemer that just came out, and he has a nice description of the political situation that led up to the *Voyager* project, which was then canceled. One of the considerations was that there were other projects competing at the time, and one was the Space Shuttle. The Shuttle was taking, you know, a lot of money so they said, "Well, we don't want to spend all this money on this big Mars mission."

Then the other thing was that JPL, being a contractor, there was a certain amount of insecurity about letting JPL manage such a big project. When *Viking* was created a few years after the cancellation of *Voyager*, Langley [Research Center, Hampton, Virginia] got the responsibility for it. Langley was a civil service center so that was okay.

Then, of course, there was just a lot of politicking and it's a lot of when the money becomes available, who's got the upper hand in the administration at the time, and so on. From down in the trenches where I was, none of that was really very visible.

The thing that isn't talked about in the book, I don't think or remember, is that after the *Voyager* project was canceled there was a group of people led by John Gerpheide and Kane Casani, who were trying to send a small probe to Mars. Jim [James] Burke, who is the former project manager on *Ranger*, worked on it, and I worked on it, and we had just a little money left over basically for advanced studies and stuff.

We were looking at making a very small thing with a balsa wood lander that would just crush when it hit the ground and then would open up and there would be a weather instrument or something. We were looking at some very, very modest stuff. We went in and did a whole system design and everything, and John tried very hard to sell that, but it never sold. We never could any funding for it.

We probably could have put a little lander on Mars in 1971, but then they decided to just go with the orbiter, which was, in retrospect, a very wise decision because, at the time when we were studying these things, we didn't know, really, anything about Mars. The *Mariner 4* flew by in 1965 and went by the south pole of the planet. *Mariners 6* and *7*, which flew in 1969, also flew by that same area of the planet. So everybody thought Mars was like the Moon, you know, it was cratered, and the south pole part of Mars is very high, very cratered, ancient terrain, and we hadn't seen the north side of Mars. When *Mariner 9* went into orbit, we were able to map the whole planet, and that's when we saw all the spectacular features like Nix Olymiea [Mount Olympus], the giant volcanoes, and Tarsus Bulge, and then the Valles Marineris and the signs of ancient running water and so on. We didn't have a clue about any of that until 1971.

If we had launched something to land in 1971, it would really have been silly. I mean, we didn't know much about the atmosphere. We knew some about the atmosphere, but we didn't know anything about the atmosphere over how much it could vary. The Martian atmosphere varies a lot between summer and winter, much more than the Earth's atmosphere because it's thin and it gets puffed up very easily when it gets warmer and then collapses down in the winter. So there was just enough uncertainties that doing an orbiter first was definitely the intelligent thing to do.

Also, the other big difference [between *Pathfinder* and *Voyager*] was the cost, an order of magnitude difference in cost. The *Voyager* was supposed to be a multi-billion-dollar mission, or was supposed to be a billion-dollar mission. *Viking* was a billion-dollar mission. If you take the 1976 dollars for *Viking* and inflate them to 1992 dollars, it was $3.6 billion.

Pathfinder and *Mars Global Surveyor* together were a little over 10 percent of that so that was another huge difference.

Another difference was that we had landed with *Viking* so we knew generally what to expect, not really *well* what to expect, but there was enough information so that Matt Golombek, the project scientist, [and] other scientists—he had the whole science community involved—were able to predict reasonably well what the *Pathfinder* landing site would look like. When they got down, it looked very much like what they had predicted that it would look like. They never could have done that just from even *Mariner 9* imagery, much less *Mariner 6* and *7* imagery.

With just the *Viking* imagery and measurements that were made from space and from the ground and the detailed photographs, we were able to design a small rover with some assurance that it would be able to move around and that it wouldn't necessarily sink out of sight and so on. Just the vast amount more of information we had about Mars was one of the things that contributed to being able to do *Pathfinder* and *Sojourner* so cheaply.

BUTLER: It shows the importance of building on those lessons learned in the past.

SHIRLEY: Right. Right. And, in fact, that says a lot for the advantage of a program. The Mars Exploration Program was set up to do exactly that. You learn something, and then you design the next mission based on what you learned.

The problem is that, since they [are] doing them every twenty-six months, there's no time to learn from one mission to affect the next one. The best you can do is affect the one after that. Now, after the failures, they've redesigned the program so that it does have an orbiter in one opportunity and a lander in the next opportunity. When you have an orbiter you can learn something that will apply in the opportunity after that one. It's a much more sensible approach. In fact, it's the way to do exploration.

Now, unfortunately, what happens with most missions now is that somebody decides, "Oh, this is very cool. We're going to do this," so, for instance, Dan [Daniel S.] Goldin's insistence on early sample return. It's way premature for a sample return. You know, we don't know enough about where to go on the planet and things like that. But he thought it would be spectacular and that it would help the budget and so on and would help find life. So he was pounding on sample returns. So everybody was projecting that we were going to do a sample return, completely unrealistic within the available budget, but nobody wanted to say the emperor had no clothes. That's part of the problem.

The current program, where you have something going steadily, is much better than the previous program, where you had one giant orgy of exploration every twenty years. There's too much time between things. You can't take advantage of the technology base because the technology's completely different and so on. But, in the case of the heat shield, for instance, and the parachute, that technology hadn't changed any so they were able to take advantage of it.

BUTLER: And it does seem to be a theme, too, that you have encountered throughout your career in the space program, is the political situation, the environment.

SHIRLEY: Oh, yes. That's space biz. [Laughter] That's the aerospace biz. Anything that's mainly funded by the government is going to be very up and down. I mean, look at the superconducting super collider. It was great, everybody wanted it until Texas got it, and then all of a sudden there was nothing for anybody but Texas. The impetus to spend all that much money on one project in one state was just not that high.

BUTLER: Unfortunately, that is the way it works sometimes.

SHIRLEY: Yes, all the time. All the time. [Laughter]

BUTLER: When that project, when the *Voyager* project that you were working on did go away, you actually left JPL for a brief period and had some interesting experiences.

SHIRLEY: For six months, right. Right.

BUTLER: But coming back, you got involved in trajectory analysis.

SHIRLEY: Right.

BUTLER: Actually, that wasn't working out so well for you, and you switched with an officemate to working on an automated drug identification system.

SHIRLEY: Right.

BUTLER: That seems a unique thing for JPL to be involved in.

SHIRLEY: Well, in the late sixties was when JPL started to do stuff called civil systems, and that was partly an outgrowth of the Vietnam War, the idea that, hey, every brain we've got should be working on something relevant to some social problem. Originally it was things like helicopters and, you know, surveillance from helicopters, and stuff like that. And then they got into, "Well, as a national lab, we owe it to the country to do things that will help the country." So there was quite a bit of activity in all sorts of things. Health care, police work, you name it, we were trying to do it.

So there was this project. There was a guy named Charlie Campen, who somehow got this project. Oh, I know how he got it. He had a personal friendship with the fellow who ran the Santa Clara County Forensics Laboratory, whose name I've forgotten at the moment. This guy said, "You know, Charlie, we're getting overwhelmed," because the drug problem had just started. I mean, drugs came in in the sixties. There weren't any drugs to speak of in any great quantities until the middle sixties. By the time—this was the late sixties—the crime labs, hospital labs, and so on are being just overwhelmed with drug samples to analyze. This fellow said to Charlie, "Hey, you guys are so high tech. Help us with this drug analysis problem." So Charlie managed to get some money from NASA. I can't even remember what part of NASA it came from.

My officemate was working on, "Okay, how do we design this system? How many drugs a day should it be able to do? How many samples should it be able to do? How many different kinds of drugs should it be able to analyze? Should it be able to analyze just the drugs themselves, or should it be able to analyze blood and urine samples, for example, and so on? What are the requirements for the analysis?"

So he just thought that was stultifying, finally dull. I thought doing esoteric trajectories for future missions way out there, I thought that was very dull. So we traded jobs. We went to our supervisor, and we said, "We want to trade jobs."

He says, "Can you do that?" [Laughter]

We said, "Yes, why not?"

"Well, I'll have to think about that." Then he went away and thought about it. He says, "Okay."

This guy, my officemate's name was Don Green, and Don, as far as I know, is still happily doing trajectory analysis all these years later. What I did was to go around—I can't even remember—I went and talked to Charlie, and Charlie said, "Fine. Well, nobody knows how to do this job anyway so you're not any worse than anybody else."

It basically first involved going to crime labs and watching how they worked. I went up first to the Santa Clara County Laboratory of Criminalistics, is what it was called, the Laboratory of Criminalistics and just watched these analysts do their thing. They would bring the sample in, they would prepare it in various ways, they would analyze it, and then they would write up the results.

Now, each of their steps had to be just exactly to protocol, the reason being that they had to go and testify that they really knew what this stuff was. If you remember the O.J. Simpson trial, for instance—"Were the samples kept completely pure? Could something else have contaminated them? Is this analysis reliable? Has it been done a zillion times and it's always come out the same?" So to get something through in court you have to be able to say, "Yes, I went through this exact procedure that has been determined by previous court cases to be what you need to do to prove that this is indeed drugs."

It's a very laborious process, and there were like six or eight or ten steps they had to go through. They bring in the, say, urine sample, and then they have to split it into various fractions and various parts because some detectors can detect some kinds of drugs and other detectors can detect other kinds of drugs. They have to break up the sample and treat it chemically in different ways depending on what instrument they're going to have look at it at the end. So it involves things like a gas chromatograph, mass spectrometer. It involves things like thin film chromotography, where you'd put it on some gel, and different drugs would go at different speeds through the gel.

At the end of the day you measure and you say, "Ha, this is such and such," or you think it's such and such, or at least you've classified it so now you can take it to the next step. And they used infrared spectrometry and, you know, this whole variety of things. I had to go through and understand all of these steps and how they worked because whatever machine we made had to pretty much duplicate this process or it wouldn't be accepted in court.

Then, the other thing was, I went to some other crime labs, and I found out that each one has a different kind of caseload. The Santa Clara County, for instance, had a very wide variety of samples, blood and urine and all kinds of different drugs and just all kinds of differences, whereas there was a lab in New York City that was a heroine addict test lab that tested for methadone, you know. These people would come in, and they'd have to give a urine sample every day or every week. They were running thousands of these samples through, and they were only looking for one thing.

Here you have the Santa Clara lab that's doing maybe forty samples a day, looking for a hundred things, and then the New York lab doing a thousand samples a day looking for one or two things. Now, how do you build one machine that satisfies all these needs?

We did a survey. I'm remembering. Lowell was the first name of the guy from the Santa Clara County lab. I'll probably think of his last name in a minute. Anyway, he was very respected in the field. He helped us put together a survey and we sent it out to all these crime labs and got it back. Then I said, "Okay, what's the average number of samples, what's the average number of different kinds of drugs they're looking for, and so on and so forth." Then we could start to kind of cluster things. And we asked them, you know, "How much can you pay for it, how much per sample does it have to cost, and so on."

We ended up putting all this stuff together and coming up with we needed something that would do about a hundred different drugs, that could do, I think, forty samples a day, it had to cost less than $50,000, and each sample had to cost less than something or other.

Then at the same time all this was going on we had a team working on, "Well, how can you actually build such a system?" The team that was building it and, you know, I had the requirements, the needs of the forensics labs, and these guys had what could be done. So that was really my first experience of trying to beat together, you know, needs versus capabilities, that process of finding out, you know, what the community wants, what your customer wants, versus what you can do and seeing if you can pull them together in some way so that you can actually build something that will be useful. Because often, what people want is not buildable, and what the engineers want to build isn't useful to anybody.

It finally turned out, after a couple of years, that we just couldn't make it work. The technology of the time was simply not adequate to be built cheaply enough, even in a mass-produced way, to be able to do what it was we wanted to do. We also [looked at] hospital labs and things, trying to see how big the market would be so we could interest, say, Beckman Instruments or one of the big instrument companies in manufacturing this, but it turns out that we didn't think that gas chromatography/ mass spectrometry was going to be cheap enough so we were going with infrared spectrometry. It turned out that GCMS got cheap and was much more reliable and accurate than IR. So some companies actually manufactured some systems not long after we kind of gave up that worked with GCMS.

The other interesting thing about that was that that was one of the technologies that *Viking* took to Mars to look for life, was GCMS. So JPL had some skills at that because we were trying to package this GCMS into such a very, very small and lightweight package. There were actually some people that knew how to do it. But the particular team that we had [on the drug identification project], the guy was an expert in IR, in infrared. That's another reason they wanted to use infrared.

So that actually never worked, but I learned a lot about systems analysis and mission analysis. The next thing that happened was that I was dating a fellow whose roommate was group supervisor for people doing mission analysis, trajectory analysis, and so on, and he needed a mission analyst for the *Mariner Venus Mercury* mission, which was just starting up in 1970.

It had just been sold as being able to be done for $98 million, which was far less than anybody thought it could be done for. But Dr. [William H.] Pickering just sort of thought that was the number that was going to sell, it had to be less than $100 million, so he picked $98 million.

And again, Bob Kramer, in *Beyond the Moon*, has a good story about how that all happened. Pickering called in [Walker E.] "Gene" Giberson and said, "Well, you've got to do this for $98 million," and Gene said, "Wow, really?" Then he went off and he did it. So they were able to successfully do it.

Anyway, Charlie Kohlhase was the fellow who was the group supervisor. He said, "Hey, you're smart. You can figure out how to do this stuff."

I said, "Okay," because I was pretty much out of a job at that point because the AUDRI thing wasn't working. The Automated Drug Identification was AUDRI. It was also the name of an old girlfriend of Charlie Campen, so he liked that name.

On the [*Mariner Venus Mercury*] project I was going to be working for a guy named Vic Clarke, who was the mission design manager… So I walked in the front the first day and I said, "What does a mission analyst do?"

He said, "It's customary to define your own job."

I said, "Well, what needs doing?"

He says, "Well, go talk to the scientists and see what they want so that you can figure out to get the spacecraft and trajectories and everything to do that."

So that was one of my jobs. I was also the PT&G representative, Performance, Trajectory, and Guidance Working Group representative, and that's the group that works with the launch vehicle to say, okay, how accurately do we have to launch, what days can we launch on, what are the launch hold constraints, and so on. So there's all of this work that has to be done in trajectory analysis called—what's the name of the document? Oh, targeting specification, targeting spec. The targeting spec has to be written so that it defines exactly, "If you launch at this given time, we want you to go in this direction so you'll get to the planet." All that has to be worked out, and there were people working on that.

Then I was the one that had to go work with the launch vehicle people to make sure they could really do it. So again, it was a go-between kind of a job. I didn't do the calculations myself but I took and translated the calculations to the people who were building the launch vehicle and who were planning to shoot it off and all that sort of stuff.

On that note, there was a guy named Joe Nieberding, who was from Lewis Research Center [Cleveland, Ohio]. Lewis Research Center procured the launch vehicles, the Atlas Centaur launch vehicle, and was the go-between with the people down at Cape Canaveral that shot them off. And I had to work with Joe and his people a lot so I ended up going down to the Cape, and we had some adventurous times on *Mariner 10* before the launch. That was one of the jobs.

Then another job was working with the scientists and saying, "What is it that you want to do when you go to Mercury and Venus?" Well, this was the first planetary swing-by. This was the first time we'd ever used the gravity of one planet to whip us around and help us get to another planet. That had never been done before. But what it meant was that the place we flew by Venus had to be exactly right to get us to Mercury so there wasn't much flexibility in what we did at Venus. It turns out there was a lot of flexibility about where you pointed the instruments, not flexibility but importance, of where you pointed the instruments, depending on where you flew by the planet.

Then the decisions you could make were mostly at Mercury, which side do you fly on, because Mercury's going to be half lit. The sun shines on half of it and not on the other half. So if you fly by the dark side, it turned out to be better for the particles and fields instruments, the ones that measure magnetic fields and the charged particles and so on. That's more interesting in the wake on the side away from the sun, the solar wake of the planet. But, of course, the camera and the infrared spectrometer and the ultraviolet spectrometer wanted to fly by on the bright side of the planet.

Well, even before I got involved the scientists had kind of fought that out and made that decision, that they were going to fly on the bright side of the planet. Then it came down to, "Well, exactly where do you fly? Do you fly high over the pole, do you fly down under the south pole, do you fly right across the equator, and so on?" Then there were some additional complexities because, I forget the exact time, but Joe Beerer…was the trajectory analyst, and there was a fellow named Giuseppe ["Beppe"] Colombo, who was part of—I think he was part of the imaging team. Anyway, he was an Italian scientist.

They were at a meeting or a conference, I forget which, and Joe was talking about the trajectories, and Giuseppe Colombo stood up and said, "But it will come back." Nobody knew what he meant, and what he meant was that you fly by Venus and you get the gravity assist to Mercury. Well, if you fly by Mercury just right, you get a gravity assist so that it synchronizes you with the orbit of Mercury, and when you come back around again, you pass by Mercury again if you time this just right and fly by just the right place. Poor Joe was very upset because when he went back and looked at his trajectory runs, his computer runs, he found that yes, that was true, and he could have noticed that himself and then he would have gotten credit for it, but he didn't.

So there was a constraint, that you had to go past a certain place at a certain time in order to get this free return to Mercury. There were constraints about how high—you know, if you went too close to the planet, everything was very sharp until you got a lot of blur on the way [past] because you were too close. If you went too far away, then you had good pictures but you didn't have very good pictures coming in and going out. The distance from the planet was important. There were three instruments that were interested in flying on the light side to look at the distance, that worried about the distance. That was the ultraviolet spectrometer, the infrared radiometer, and the camera (the imaging system). And there was a scan platform that was supposed to have the camera, just the cameras, on it, and they were going to have a wide angle lens and a narrow angle lens.

But it turns out that was too heavy and expensive so one of the—I think it was Ed Danielson then, who was one of the engineers on the camera, said, "Well, why don't we just put a filter position?" They were going to have different filters so they could get different colors effectively as they flew by with the camera. He said, "Well, let's just put kind of a magnifying glass in one filter position so that we get a wide angle view of the planet as we go by." You'd get either a wide angle or narrow angle view so you had to juggle all that around.

Then, the other two instruments, the infrared radiometer and the ultraviolet spectrometer, were not on the scan platform. Well, I did some analysis that showed that if you optimized [the ultraviolet spectrometer] for Venus, you'd be pointing in the wrong direction for Mercury and if you optimized for Mercury, vice versa. We did some analysis that showed the best place to put the infrared radiometer and the best direction to point was [to] compromise between Mercury and Venus, but you just couldn't do anything with the ultraviolet spectrometer.

Finally, Bruce Murray, who was the principal investigator on the camera, said, "Well, let's put the ultraviolet spectrometer on the scan platform, and then that way they can scan around." Well, he didn't realize he'd created a monster, because Lyle Broadfoot, who's a very mild-mannered guy, was the ultraviolet principal investigator, but once he got onto the scan platform then he wanted to point the scan platform at things that *he* wanted to look at. And, of course, Bruce's team wanted to point it at things *they* wanted to look at. So now there was this big adjudication that had to go on.

I think there were seven experiments, if I can remember them. There was the infrared radiometer, the UV spectrometer, the imaging system, the charged particle experiment, the magnetic field experiments (the magnetometer), and the radio science experiment. I thought there was one more [Herb Bridge's plasma science experiment]. Well, radio science was radio science and celestial mechanics so it was really kind of two in one.

Well, the radio science experiment just used the radio signals. Everybody thought, well, you know, they just take whatever they get. Well, of course…there was a certain amount of data that had to be sent back, and we didn't have very much data storage on board, and we didn't have very much storage to—we only had 512 words of memory in the computer so you had to store all of the things you wanted the spacecraft to do in only 512 words of memory. You know, your pocket calculator has far more than that in it. But in those days that was the best we had. So there was a lot of squabbling over resources, you know, who gets to program in their instruments getting to do something.

The scan platform, for instance, they wanted it to move a lot so they could get very closely spaced overlapping pictures and make sure they saw everything. But the radio science people actually wanted to move the high-gain antenna, which turned out to be movable, and they wanted to move it so that when the radio signal passed through the atmosphere of Venus, for example, it would be pointed in the right direction so that it would stay as long as possible. The radio signal gets bent. If you just point it in the same direction all the time, it'll just point at the planet. But if you can slew it so that it moves out a little bit as it's going behind the planet, then it curves around the planet and you can get much deeper track through the atmosphere. So they wanted to do that.

It turned out that the slew pattern that the radio scientists wanted to use, if you plotted it in a certain space, it came out shaped like a teardrop. Well, in order to do that, you had to put in a lot steps for the high-gain antenna. So now, do you step the scan platform, or do you step the high-gain antenna? Now there's this big battle between the scan platform people and—[construction noise in background] Oh, dear. I don't know how long they're going to do that.

BUTLER: Well, we'll just keep going.

SHIRLEY: Do you think it'll work?

BUTLER: It'll come through on the tape, but hopefully maybe we can measure it out and maybe they aren't going to do it anymore.

SHIRLEY: No, they do this all the time. They're grinding something in the basement, doing some sort of fixing.

BUTLER: Okay.

SHIRLEY: Anyway, let's see. There was lots of contention. One of my jobs was to try to adjudicate between these scientists about, okay, "Well, how are you going to get the best science here? Can you compromise here, and can you compromise there?" So we wrote a computer program that showed, you know, when you have to slew the high-gain antenna.

Then the imaging people had their own computer program that showed the best way to lay their pictures down. Well, in fact, they liked their computer program so much that they wanted to just do all the planning themselves. We said, "Okay, that's fine for general planning," but then you have to do what's called a double precision trajectory so that you know exactly where things are going to be pointed." Well, they thought that was just a devious ploy by the trajectory people to get control, and they wanted to control everything themselves and plan their own commands and all that sort of stuff.

It took quite a while to demonstrate to them that if they used their system they were going to lose a lot of pictures so they needed to make it work with our system because ours was so much more accurate we could be a lot more efficient in getting pictures. That took a lot of time.

There was all this stuff between the scientists, and then you had the particles and fields people versus the imaging—not just imaging but imaging UV and IR. The particles and fields people were led by Norm Ness, who was a very prickly character. He had the magnetometer. The magnetometer…was very cleverly done. It was on a very long boom, and it had a magnetometer in the middle of the boom and then another one out on the end.

The spacecraft has a magnetic field, but if you have two magnetometers, you can tell, "Okay, this is the component that represents the spacecraft and it's less at the one out on the end than it is at the one in the middle so you can subtract it out." That was a big deal, the first time it had ever flown. Well, that meant it had to be deployed, this big long boom, and it was wobbling, it wobbled around, so the attitude control system had to be designed to accommodate it.

It also meant they wanted to roll the spacecraft periodically so they could calibrate [the magnetometer] as they did a 360-degree roll, so they could calibrate the whole magnetic environment of the sky, which meant you had to do these complicated maneuvers all the time. You know, there were all these complexities, trying to fly these six or seven experiments on this one little spacecraft.

The other thing was, of course, that the spacecraft itself had to be done very, very cheaply. Boeing Corporation won the contract to build the spacecraft, and they were going to use a lot of spare parts from the *Mariner 6* and *7*. John Casani had been, I think, the spacecraft manager on *Mariner 6* and *7*. Gene Giberson got him to be the spacecraft manager on *Mariner 10* because he knew what all of the stuff was on the spacecraft.

Then Boeing had to take all that stuff and integrate it and make it into a new spacecraft that would go not out toward Mars, where it's cold, but in toward Venus and Mercury, where it's hot. In fact, it was going to be hotter than any other spacecraft had ever gotten. So they had to do things like make the solar panels tilt. The solar panels needed to be flat out at Venus so they'd have enough power, but as you got closer to Mercury, they needed to tilt so there wouldn't be all the heat right on the solar panels. They had two choices of how to tilt them. One is they could tilt them like a badminton shuttlecock, they could tilt them in, or they could roll them so they'd be sticking out straight but they would twist around the long axis. They decided to roll them, which turned out to save the mission later on because they were able to do solar sailing.

Anyway, in order to try to reconcile all these things, and not only did we not have very much storage for the command part, we didn't have much storage for the data that was coming back down. Vic Clarke put on a huge campaign to make not only the biggest high-gain antenna we could have to get all this data back but also to upgrade the big ground antennas at Goldstone [in southern California]. It was a super-cooled hydrogen mazer, which meant it could get more bits back, it could hear better. While you're flying by Mercury, I mean, you're gone. They were going really fast. So there's a limited amount of time to take these pictures. There wasn't enough room on the spacecraft [data] storage [system] to store them all so you needed to send them back in real time, as well as store as many as you could. The more you could collect in real time through the Goldstone antenna, the better. Well, that meant we had to arrive over Goldstone because it was the only one of the three big antennas spaced around the planet that had this improvement on it.

So there were all these constraints. One of my jobs was to find out what the scientists wanted. They wanted to do things like calibrate their instruments on the Earth and the Moon as we took off and as we went past Earth and Moon on the way out. Each one had all these desires.

I went around to each guy, and Charlie Kohlhase had told me about something called value functions, which a fellow across the hall named Joaquin Boris had worked on for *Mariner 9*. As a matter of fact, Joaquin Boris was the officemate of Dennis Tito. [Laughter] Just [to bring things full circle].

BUTLER: That's interesting full circle.

SHIRLEY: And Joaquin and Dennis were in an office across the hall from me and three other people. We were working with Dennis in those days. That was before he went off and decided to get rich [Laughter].

But this value function thing, the idea was that you just try to figure out the best you can what's the most valuable and then you give it a number. You assign a more or less arbitrary number to it so that a one is better than a point five or a ten is better than a five. You just do that, and then you fit some sort of curve to it so that you could tell—okay, for instance, if you plot it, we ended up plotting launch date versus "goodness" for each one of these things. Because of the need to swing by Venus at exactly the right time to get to Mercury…the launch date would change depending on exactly where you wanted to fly by Mercury and so on because when you launch differently, Mercury's in a different place when you get to it. So that means the trajectory goes by in a different place. It also had to go in the right place to be able to come back around. So all these constraints.

I plotted them all out. First I had to get everybody's idea of what was good. You know, "Is it more important to be far away from the planet or closer to the planet, and how close." I went around to every single principal investigator and talked to them at great length over a space of about two years and finally was able to plot everybody's desires versus launch date.

It turned out, when you laid them all on top of each other, there was one launch date, November 3rd (and 4th), that were much better than any of the other launch dates. But the launch period opened in October, about October 17th or something like that. In order to launch on the optimal day, you'd have to throw away the first two weeks of the launch period, which meant that if you missed those two or three or four optimal days, now you were driven into a time which was very non-optimal. It was worse than the first part.

Now, do you gamble that you can get off on time and go for the very best science, or do you launch early in case the weather's bad or in case something goes wrong with the launch vehicle? So Gene Giberson was confronted with really tough decisions, but he finally decided to launch on November 3rd. One of the things I have framed around here somewhere is—I guess I don't have it framed anymore. Anyway, it's the letter that says, "We've decided to launch on November 3rd." For a long time I could point to that and say, "I did this." That was my one accomplishment that I could really point to.

So we did; we ended up launching on November 3rd. It was a perfect launch, very successful, and of course, there was all sorts of things, like they sent up balloons to check whether the winds are blowing too hard or not. Everybody's chewing their fingernails. We launched at night, and I was sitting at a console because Gene said that, you know, if anything went wrong, he wanted me to advise him on, you know, "How long can we wait, what's the consequences of not launching the next night, and so on." So I had a console right there and I was watching.

When the rocket started to go off everybody else ran outside, but I had this firm conviction that if I took my eyes off it, it would fail. So I sat there and watched it on the monitor. Fortunately, I had seen another Atlas-Centaur launch not too long before that so at least I'd seen what it looked like at night. [Laughter] [Because] I [had gone] down with the Lewis people, the Lewis Research Center people, and they introduced me to the range safety officer. Another one of my jobs was to tell the range safety officer exactly what to expect because you don't want them pushing that button.

BUTLER: Absolutely not. [Laughter]

SHIRLEY: You tell the range safety officer it's going to do this and then "It's going to do that and then it's going to do this, and it can be off by this much and it'll still be just fine, don't worry about it," you know, and prepare him so that he didn't blow up the rocket casually.

Everything went fine except it turns out there was some sort of problem and it was the first time ever. There's probabilities of going in the direction you want to go. A "one sigma" is about an 80-something percent probability, and a "two sigma" is a 90-something, and a "three sigma" is about a 99 percent probability. "Four sigma" is 99.99 and "five sigma" is 99.999, and we had a five sigma ejection, which meant it went off in a pretty unexpected direction, which meant that we had to expend, then, spacecraft fuel to get it back on the right trajectory. At first we thought that was really going to be a problem, but it turned out to be the least of our problems.

We took off. Everybody flew back to California and started in mission operations. By that time I'd been promoted to be the project engineer for the [Mission Design] section, which meant all the navigation, trajectory analysis, and mission analysis stuff I was supposed to be coordinating. There were a certain number of difficulties about that because, you know, I didn't know how to do trajectory analysis very well. I wasn't an expert in any of these things. I just really had to depend on everybody else. Well, nobody had ever done gravity-assist trajectories before so there were a lot of people that were very skeptical.

We had a review, and our section manager gave us a really hard time because he didn't think that we had done a good job because he couldn't understand it. Now, I couldn't understand it either, but I knew that I just had to trust the navigation people, that they knew what they were doing, because there's no way I'm going to understand what they're doing well enough to second guess them. This guy just couldn't stand it. He just was so upset, and I was going to kill him. I was going to have to just shoot him. Finally, we got together, and he agreed that, you know, there wasn't any way he was going to understand it. I said, "You can either just scrub the mission because you don't understand it or just accept that these guys know what they're doing and they're checking each other." He agreed to do that so we ended up launching.

I remember the night before the launch—no, the night before the first maneuver to correct the trajectory—I had this firm, fixed idea somehow that we had a sign error. There had been cases in the past where sign errors had made us miss the Moon and go the wrong direction and stuff. And everything had to be done by hand, you know, because the computers would spit it out for you but you had to go in and check everything. So I was in there, really, like two o'clock in the morning checking this stuff. Along comes this radio guy from one of the local radio stations. He says, "What are you doing here?"

I said, "Oh, I'm checking to make sure nothing's wrong."

"You mean there's something wrong?"

"No, no, no, no, no. I'm just double checking."

I mean, he was just slavering for, you know, "Things are really wrong and everything's going to be horrible," and I was, "No, no, no, no. I'm just here making sure, double checking." [Laughter] That almost created a big incident there.

Anyway, we flew by, calibrated the cameras. Oh, but the first thing that happened was that the heaters for the camera optics didn't come on. There was a lot of concern that if the heaters didn't come on, that the glass would just get too cold and crack. There was much gnashing of teeth and everything about that, but they just couldn't get the heaters to come on so they finally just went ahead and took pictures with them. They worked fine and the glass never cracked so we were lucky.

But as we went, things started to fall apart on the spacecraft, and they just fell apart and fell apart and fell apart. I can't even remember all of the details of what went when, but at one point the high-gain antenna stopped transmitting as well as it should. Well, this meant that if we went by Mercury with the high-gain antenna not working properly, then they'd lose a lot of the pictures that Vic Clarke had been working so hard to get the Deep Space Network [DSN] to retrofit Goldstone station and all that sort of stuff. That would all be for naught. That went on for quite a while.

Then the high-gain antenna, because we were getting so close to the sun, there was a sunshade and the camera had to kind of peer over the sunshade to see, and the instruments had to peer over because you had to really protect them from the sun. The high-gain antenna had been painted white so it would also reflect the sun and stay cool, relatively cool. Well, the paint they'd used, unfortunately, flaked off. Now, the thing that kept the spacecraft stable was it had a sun sensor and it had a Canopus tracker. The Canopus tracker would look up at the brightest star in the northern part of the sky, which was Canopus, and, you know, it could tell if Canopus were drifting in the slit that had a finite width. If Canopus got over to one side, the attitude control system would fire the jets and it would straighten back up again.

Well, in this case, when a paint flake came by with the sun shining on it, it was brighter than Canopus. So the attitude of the spacecraft was just follow it and turn and turn and turn, following this paint flake, and then the paint flake would drift off, and then it [the spacecraft] wouldn't know where it was. So it would kind of go catatonic and call for help, which was what it was programmed to do. Well, it kept doing that, and we knew that if it did that at Venus or Mercury, then we'd lose everything because it would be pointed in the wrong direction.

It also had gyroscopes on board so that they were able to fly most of the time on the gyroscopes. And later on, that proved to be a problem, too.

Then what happened? A lot of things, but the worst thing that happened was, all of a sudden, the attitude control system got stuck and started to blow all this attitude control gas. Well, the way an attitude control system works is, you know, it's on its little Canopus tracker and it goes "psst-psst" with a little jet of—I forget what the gas was. Anyway, it's got a gas in there. And then it would go "pst" in the other direction to rocket back to the other side. Well, in this case it went "Sh-s-s-s-s-s", and it was losing gas like crazy. They managed to stop it, I think, just by turning off the tracker, stop it hemorrhaging gas. Then Bill Purdy and a guy named Shumacher, Bob…I think his name is—Larry Shumacher? [Yes,] Larry Shumacher. Anyway, they were trying to figure out what to do about it. They finally came up with the idea of turning off—how did they do it?

There was also a problem with the gyroscopes, that when the gyroscopes came on they would cause the computer to reset. [Laughter] So then it wouldn't know what it was supposed to do.

All of these things were going on at once. I can't even remember—you know, I'd have to go back and read all the details about how they actually did it.

BUTLER: Well, I think you cover a lot of them in your book.

SHIRLEY: Yes. The biggest part was that they just didn't have any more attitude control gas. What they did was to turn the solar panels differentially so that it would kind of slowly rotate due to solar pressure pushing on it like an airplane wing. If they'd made it like a badminton shuttlecock, they wouldn't have been able to do that. The fact that they could rotate these things around the long axis, they were able to do "solar sailing" and make it move very, very slowly so it wouldn't get off too much. As long as you weren't at a planet trying to point the instruments accurately, it didn't matter anyway.

Then there was problems because, of course, the particles and fields people kept wanting to do these calibrations, 360 degree rotations, which of course took gas. There were big arguments about, "Well, I've got to calibrate my instrument or it won't work." It was wild.

We finally got to Venus and had a successful mission by Venus [in February 1974]. But then we had to do—again, I can't remember off the top of my head the order of all these things. Oh, they didn't want to have to depend on the gyroscopes because they would do what was called a power-on reset. That would reset the computer, and it wouldn't know where it was, it wouldn't know where it was in the sequence so it wouldn't know to tell the cameras to take pictures or anything like that.

In order to avoid turning on the gyros, they wanted to do what's called a sun-line-only maneuver. That meant they had to find the right place in the trajectory where they could just burn the engines in the direction they were going fixed on the sun and correct the trajectory to get it on the right path. Jerry Jones, the navigation guy, came up with this idea of the sun-line-maneuver. That saved the day. The solar sailors managed to keep going all the way to Mercury.

Oh, and as the high-gain antenna warmed up, it fixed the high-gain antenna feed. So by the time we got to Mercury, all the 117 kilobits per second capability was back. If it hadn't fixed itself, they would have only had…[about 56] kilobits per second, which would have been half-size pictures instead of these full-size pictures. So that worked. The whole project was a great success.

The biggest surprises were that Mercury had this little magnetic field which nobody expected because it's a very small planet and it doesn't spin very fast, and they expected that the core would have cooled long ago so there's nothing to make a dynamo, which is what makes magnetic fields on Jupiter and Earth and things like that. Venus doesn't have one because it…goes so slowly. So finding a magnetic field on Mercury was this big surprise, and they still don't completely understand it.

An almost-discovery was that the ultraviolet spectrometer thought that they'd found a moon. They were pointed, and they saw this bright object, and it was right before a big press conference. Lyle Broadfoot announced that they'd found this moon, and he had named it "Charlie" after his brother or something like that. Then one of the navigators noticed that there was star right there where they thought this moon was. But before he could get to the project scientist to tell him, "No, no, don't announce this moon," he'd already announced it. So that was a big deal in the papers and kind of overwhelmed all of the real science because they thought they'd found a moon of Mercury named Charlie. So it was pretty exciting.

You've asked about the voice—

BUTLER: Actually, like the story leads into it, working with the media and balancing all these challenges that the spacecraft was experiencing over this time and various discoveries. How was that, working with the media?

SHIRLEY: Well, it was fine. Al Hibbs was the senior voice, and Al is just great, you know, very experienced, very intelligent, and just smooth, I mean, really, and funny. I just was sort of his understudy.

The head of JPL Public Information at the time was named Frank Colella. They were a little skeptical. You know, Al wanted somebody who understood the mission. They auditioned me and I did okay, but one of the early things was, they said, "Well, we've got our first pictures back from—" I guess it was the Earth calibration or something, "And NBC is going to broadcast these things on national television. We want a voiceover."

Al said, "Well, Donna should do it." [Laughter]

I'm like, "Uh-uh-uh."

The first one was actually terrible. It was very, "Uh-blah-blah-blah."

They said, "No, no, no. Cut. You have to make it more scientific."

Then it was too dull.

"Cut." He says, "Okay. One more time, and that's all the chances you get."

So I kind of pulled it together, stumbled through it, and they said it was okay. That was my first national TV exposure, just my voice, and I really blew it.

Then it gets easier the more you do it. What we would do is, we would sit in a place called the blue room, and mostly we would interview people. If we were taking pictures, we'd bring in one of the imaging team and say, "What is this? Explain it to us." Then they would talk about it, and then that would be video taped, and then that video feed would be provided to the news media, who could pick and choose what they wanted from it.

Occasionally, the news media would ask one of us to come out and talk to them. I did a little bit of that. But mostly it was just sitting in the blue room, talking to Al about what's going on and what's happening, and interviewing people. Usually they only interview scientists, but I [talked them] into interviewing engineers, you know, about, how does this mission really work, and things like that. That was the thing I contributed. It was a lot of fun. I really enjoyed it, and it was a good lead-in to being able to do it later. I was the voice of *Voyager* for the Uranus encounter. In fact, I did so well on it that Frank Colella wanted me to be a full-time PIO [Public Information Officer] person.

I said, "No, I don't want to be a full-time PIO person." He appealed to the deputy director of the laboratory, General [Terry] Terhune, and General Terhune said, "Well, you could have a great career here."

I said, "I don't want a great career as a broadcaster. I want to be an engineer." [Laughter]

So he said, "Oh, okay."

You know, you're a young engineer and you're getting that kind of pressure from upper management, it was pretty interesting. So that was a lot of fun.

BUTLER: Obviously there were several challenges for this whole mission. Was there any single biggest challenge for either the team or you?

SHIRLEY: Well, the biggest challenge for the team was building it for $98 million. That was a huge challenge. That was half of what something else had been built for. As a matter of fact, a lot of the lessons learned came in handy on *Pathfinder* and *Mars Global Surveyor* because it was, you know, how you could do these things cheaply when you only had one. For instance, there was only one spacecraft on *Mariner 10*. That's why I was able to talk Gene into launching in the middle of the launch period, because if there's only one shot, you've got to make it good. If there had been two spacecraft, we would have launched one at the beginning and then one in the middle.

That was a huge challenge. Then just flying it with all of the problems, just incessant problems. You know, the mission seems like it was longer than it was. It was launched in November, and we got to Mercury in March so it was only four months, but it just felt like it went on forever. Everybody was just working all the time because you never knew when the next thing would break.

Every time something would change, you had to reprogram the computer. Well, 512 words, okay, that's not so much, but for each one of those you had to write out a complete sequence of events and boil it down into what commands you were going to send. The sequence of events would be feet high when it was printed out in computer print-outs. So everybody would have to get the sequence of events and laboriously, line by line, go over the whole thing. It was just spectacularly difficult because things kept breaking and then you'd have to re-do everything, and then breaking and you'd have to re-do everything again.

Trying to decide things like, okay, do you invest some of your computer program in what happens if you lose contact with the spacecraft? You want it to go ahead and carry out a mission anyway. So you have to put enough in at each stage so that if you lost contact with it, whatever it would be able to do, you would have a mission in it. Now, that's not really much of a problem early in the mission, whereas, if you lost contact, you've lost the whole mission anyway. But now, once you get close to Venus, you know, what do you put in? The management made the decision not to put in any Mercury stuff until we'd flown by Venus because the odds of flying by Venus and losing contact and still having any viable mission at Mercury were just zilch. So it just was a Venus spacecraft until Venus, and then you had to scramble around now that you know where you flew by, and you put in a Mercury mission. But you've still got to do all this particles and fields stuff as you're going along. So you can't fill everything up with Mercury. It was pretty exciting.

BUTLER: Certainly a lot of challenges through the whole thing and many different aspects that you have to take into consideration.

SHIRLEY: Right. Right. It was hairy.

BUTLER: And everything did go very well.

SHIRLEY: Yes, it ended up working. But, of course, it's all done with the people. The engineers and scientists were just willing to put in whatever it took to make it work. I mean, for the scientists, it was their data, the culmination of their career, and you can certainly see why. But the engineers just were absolutely dedicated and devoted and were sleeping on tables, and nobody ever went home. So it was pretty wild. It's one of those things where it's much better to talk about it afterwards than to line through it.

BUTLER: Yes. Absolutely. Absolutely. I think there have been a variety of incidents like that in the space program. Most people have a similar viewpoint.

SHIRLEY: Oh, yes. Well, the Apollo 13. It was kind of Apollo 13 only no people on board.

BUTLER: And a much longer time frame.

SHIRLEY: A much longer time frame. But, you get accustomed—you know, these spacecraft become like people to you. You're not willing to lose them lightly, having invested four, five, six years of your life in them.

BUTLER: A lot of time and effort to make it all. And as you said, for the scientists, it's so much of their career.

SHIRLEY: Right. The chances to fly are so few and far between that they're really determined to get the most out of it.

BUTLER: Yes. Absolutely.

SHIRLEY: Okay. We're not making much progress, are we?

BUTLER: We're doing all right. I think we'll make it.

Now we're kind of actually moving into a transition time for you. There were some other projects, but you also had your daughter about this time.

SHIRLEY: Right, 1977. Well, actually it was later. I got through with *Mariner 10* in 1974, and I was really burned out with flight operations. You know, it's just so intense. I said, "Gee, I'd like to work on something else for a while." I ended up being offered a job in Civil Systems. We talked about that earlier. Rody Stephenson was the section manager, and he said, "Oh, I've got this neat task I want you to lead."

I said, "Okay."

I was offered by Norm Haynes an opportunity to do basically the same job I'd done for *Mariner 10* on *Voyager*, which was going to go to the outer planets. I said, "No. I've already done that. I want to do something different."

I went over to Civil Systems, and when I got there Rody said, "Oh, well, we don't have any tasks, but we've got this group we want you to manage." Well, a group is a line organization. It doesn't have any particular end product. You know, it's just ten or twelve people, or fifteen or twenty or thirty, however many there are, working on various jobs in a certain class of jobs.

I said, "Well, I don't want to be a group supervisor. I don't like line management because there's no product."

He kept saying, "Well, that's the only job we've got."

Well, by this time Norm had filled the *Voyager* job with somebody else so I was kind of stuck. So I said, "Okay."

I had the Civil Systems Group, and the Civil Systems Group was a wild bunch. We had, oh, people who just didn't fit in very well anywhere else. [Laughter] And as we got into this stuff, one of the things, for instance, was, we were working on a lot of energy things so we had solar energy projects and coal projects and geothermal energy projects and so on. In 1974, for example, it was the oil crisis. 1973 was the big oil crisis and where OPEC [Organization of Petroleum Exporting Countries] was actually first starting to flex its muscles and long gas lines and everybody panicking and so on.

Congress passed a bunch of laws, the National Solar Heating and Cooling Act, the SHAC Act. They formed an outfit called ERDA, the Energy Research and Development Administration, which later became the Department of Energy. They passed a National Geothermal Energy Act, which said that the nation was going to produce 20 percent of its energy [from] geothermal by the year 2000. This [looked] pretty impossible so they wrote in that NASA was going to develop this plan, because, I mean, NASA, "They can send a man to the Moon, they can do anything, right?" So NASA got it.

They said, "Aah, JPL, you do it." They handed it off to JPL. Well, JPL, you know, plunged in, formed a team, started working, and discovered fairly soon that most of the problems were not technical problems. Yes, there were tough technical problems, to take a low energy thing like geothermal and be able to make it profitable, and you can only use it there, where the heat is, so then you have to pipe the energy out somewhere. There's lots of technical problems. But the things that were really in the way were the non-technical problems, like zoning regulations and the way utilities get their money back on capital investment and all sorts of things.

We said, "Boy, we need an economist." My boos said, "Donna, you're the head of the Civil Systems Group. Go hire an economist."

Well, I had no idea what an economist did, not the slightest clue. I kind of floundered around, and we found one guy who was from UCLA, who we hired. He came up, and his eyes immediately swelled shut because he was allergic to something in the area. He turned around and went back to UCLA and we never saw him again.

I was advertising. Caltech [California Institute of Technology, Pasadena, California] said they would help us out because they had an economics department. I brought in this one guy who seemed kind of plausible, and he had done his master's thesis on fin fish. Fin fish are not shellfish. Fin fish are like tuna fish or anything with fins. It swims, as opposed to shrimp or clams or shellfish. He started doing this talk in front of all these Caltech professors, and it became obvious, even to me, within about ten minutes that he had no idea what he was talking about. Pretty soon these professors started to ask him really hard questions, and he ended up just sort of admitting he didn't know what he was talking about.

Afterward, I ran up to the head of the department and said, "Please forgive me. I'm so sorry I've wasted your time. Oh, my gosh, I feel terrible."

And then Roger Nall came charging up and said, "That was a complete waste of our time."

Charlie Plott said, "She's already apologized."

I said, "I really need help."

They said, "Okay. It obvious we're going to have to help you so we'll go out and we'll find you some candidates and screen them for you." They did, and we got our first economist. Our first economist was a guy named Jim Doane. They brought him in, interviewed him. He came in from Maine, I think. He was living in Maine. We hired him, and then we got another one named Rich O'Toole, hired him in. Both of these guys were six feet tall and had beautiful blonde wives. We said, "Well, now we know how to find economists. Six feet tall, beautiful blonde wife." Well, the next one was Katchin Terasawa, who was a little Asian guy with a short, dark wife. So that didn't work.

Anyway, we managed that once you get one, then you can get some more. So we hired four or five economists. Then we hired a woman named Ora Citron, who was a policy expert in environmental policy. If you want to put a geothermal plant in an environmentally sensitive place, you have to file an environmental impact statement. You know, you had to take all that into account in the cost of these things.

Then we hired a lawyer, who helped us out with all the legal aspects.

So we ended up writing a big section of this report, this national geothermal plan that was on all the—"What are the barriers to getting it done?" One of the things I ended up doing was going around to utility companies and asking them, you know, "Why would you invest or why wouldn't you invest in geothermal?"

Well, it turns out that the way utilities are regulated, they can't recover the capital cost. They have to go and build a plant, and then they're allowed to put the recovery of the cost into their rate base, and that's how they recover things. So in order to make something pay, they have to invest in something that's got a fairly fast payback to it because there's a limit to how much in advance they can fund one of these plants. Well, geothermal plants would take a long time to pay back so they were very unattractive.

Then we got into, okay, "Well, what kind of incentives would the government have to offer in order to get power plants and other people to use this kind of stuff?" It ended up to be a huge report. Then the technical part of the report was done and the whole thing was delivered to NASA.

NASA had it all printed up in hundreds of copies and shipped it over to—I think DOE was in place by then. No, it was ERDA, it [was] still there. ERDA wouldn't take it. ERDA said, "This has in here government funding over the next twenty years, that if you want to make this happen, you have to spend this much money on these things in this year, and here's a budget, and here's the process by which you're going to have to develop the technology, and here's the laws you're going to have to change." We had this whole plan laid out.

They said, "Well, we can't be committed to a long-term budget plan. We have to be able to do it year by year politically and all this sort of stuff." So it just sat there on their front steps, these boxes of reports, for a long time. We know they actually must have taken some in because later on we would see things crop up in Department of Energy procurements or legislative suggestions and things that would be from our report. So we know it was used, but it was never used directly.

We had another project that was the Low-Cost Solar Photovoltaic Project, which was trying to bring the cost of solar electric energy down to a dollar a watt. It involved getting industry to install the kinds of infrastructure to be able to manufacture solar cells cheaply, but it also involved developing the new technology so solar cells would be more efficient.

So they had to march along together, and there was all sorts of economics involved in that. Then, when—let's see, who was elected? [President James E.] Jimmy Carter, and then [Ronald W.] Reagan was elected, and as soon as Reagan was elected, the energy crisis was declared over. He tore out the solar hot water system on the roof of the White House that

Carter had had installed, and all that energy stuff just went away and people started driving big cars again. Now we're up to where we are now.

That was interesting, and then it was kind of in the middle of that period, well, toward the end of that period, that I took off and had my daughter. By that time the group had gotten big enough that I could split it twice. Then the second time I gave both halves of the group away and went on to Division staff. A division is about 500 or 600 people. I was in a staff position, sort of trying to coordinate all the energy work that was going on within the division.

After I had my daughter I realized that, gee, I hadn't done anything in space in a long time, and, you know, my passion is really space stuff so how could I get back into space? I went to John Beckman, who was the head of Advanced Studies for the space side of the house, and said, "John, I want a space job."

He said, "Well, I don't have any big projects."

I said, "That's okay. I'll start small. I'll put myself inside a group and just do whatever it is you want me to do."

He says, "Well, I've got this one study called Saturn Orbiter Dual Probes that's going to be the next big lab mission." He says, "But right now there's hardly any money in it, but it's going to be big."

I ran that for a year, and it [cost] $250,000 or something, and that turned into *Cassini* later on. The idea was to orbit Saturn and drop a probe into the atmosphere of Saturn and atmosphere of Titan. This was in about 1978 or so. We worked on that for a year or two, and then a guy named Dave Smith became the section manager. The first thing he did was yank me out of the group and put me on section staff and give me all the jobs that he didn't want to do. [Laughter]

I was running around doing all this line management stuff, and I just couldn't stand it. But Dave only stayed about fifteen months and went off to be on the *Magellan* project, what later became *Magellan*—Venus Orbiting Imaging Radar, VOIR initially, and then it turned into *Magellan*. He recommended me for section manager. Norm Haynes, who was the division manager by that time, said okay and hired me to be the section manager.

It was just dreadful. I mean, line management is the pits. You spend all your time on parking and office space and fighting over salaries, you know, inadequate amount of money so you're trying to give your people more money than the other people's people because your people are better, right? People that have family problems and alcohol problems. It's just awful.

There's a thing called the—what is it called? [The Autonomous Satellite Project (ASP).] It was an automated systems study for the Air Force run by a guy named Dave Evans. The idea was to look at Air Force projects and missions and say, can we automate these so that they can be more easily operated, because the Air Force, all of its stuff had to have twenty-four hours a day observation by somebody on the ground. They had this big thing called the Blue Cube in Sunnyvale [California], and if the Blue Cube were ever to be wiped out, which one missile would do, then all the space assets would be worthless. They wanted to make them [the spacecraft] more autonomous, like planetary spacecraft.

They came to JPL and said, "Hey, how can we do this?" I ran part of a study that was looking at, okay, "How do we make this system more autonomous?" We came up with a big report and really looked into how to make a spacecraft take care of itself. We found out that there were some things that we could have done fairly cheaply to make this more autonomous than it was, some things were more expensive, and so on. We finally got down to it, and the Air Force said, "Well, if we have any more mass or money, we put it into payload." They put it into a bigger spy satellite or bigger eye or bigger ear or whatever, and they wouldn't spend any money on protecting their assets and reducing risk.

In the meantime, it was pretty clear that we had a pretty good autonomous spacecraft capability. Along in 1980 started up the space station. Well, Al Hibbs, who had been my voice partner [on Mariner 10], was running the advanced study stuff, at least that part of the of the advanced study stuff. I said, "Gee, Al, I'd like to help you out on space station. That sounds like a lot of fun. Get me out of this line management stuff." Within a few months I was running the JPL Space Station team, such as it was.

Now, between 1980 and '84, before Space Station *Freedom* was actually sold to President Reagan, this guy named John [D.] Hodge was running the Space Station team. John's strategy, by necessity, was that he didn't spend any money on anything because he didn't have any money, but everybody wanted to play so that when the Space Station, which was going to be the next big NASA billions of dollars project—every contractor in the country wanted to be in line for a piece of it and every center wanted to be in line for a piece of it.

Well, all the other centers are civil service. They had people they could just assign to the station because their salaries are paid out of the R&PM [research and project management] budget. But JPL is a contractor, so our salaries had to come out of the R&D [research and development] budget. Well, the R&PM budget is regarded as, "Well, that's just there and we don't cost anything, but if you're spending R&D money, that's money we could be spending on our own contractors so we don't like you, JPL, spending it." So there was a lot of hostility to JPL being involved.

John Hodge wanted us to be involved very much because he had been involved [with JPL before]. In some of the early days of the space program JPL had come in and bailed out NASA a couple of times and provided people and done work and stuff like that that John really valued. He just thought JPL was a great organization so he wanted us involved. He kind of shoved us down their throats.

Well, lots of hostility, and not only that, here's this pushy broad from California. [Laughter] And the culture is completely different, was completely different, in NASA. Nobody ever said anything [negative] in an open meeting; all the deals were worked behind the scenes. At JPL you got up and just slugged it out in open meetings, you know, and yelled and screamed and carried on, and there was nothing done behind the scenes. So it was this completely foreign culture for us.

Then the other thing, the real culmination of it was that John Hodge, after it got a little bit bigger, a guy named Phil [Philip E.] Culbertson came in and replaced—not replaced John but was put in an associate administrator slot. Culbertson was the one that was handing out pieces of the pie to the various centers. We [JPL] had said, "Look, all we want, we want to do some autonomous stuff. We want to do robotic stuff for space. That's what we know how to do, it fits into our technology well, and we also want to make sure that the science community is protected and well treated," because on the Shuttle—it's very difficult to get a payload on the Shuttle.

They showed pictures of people with stacks of paper much taller than they were that were the required documentation to fly on the Shuttle. We said, "We want to make it easier for people to fly on the station. We think you ought to have an office, a customer integration office, and that office ought to be at Goddard [Space Flight Center, Greenbelt, Maryland]," because Goddard is the other science center, JPL and Goddard. We knew that Goddard would take good care of the scientists.

Noel Hinners, who was the head of Goddard, said, "I don't want anything to do with this. This is a complete waste of time." So they said, "We won't do it."

So I went to Lew Allen, who was the director of JPL at that time, and I said, "Look, somebody's got to represent the customers so we'd better step up and volunteer." Lew wrote a letter to Phil Culbertson saying, "Since Goddard has chosen not to take this role, we would like to have this role," and there you are. Two weeks later, Goddard had the role of customer integration plus they had the two polar platforms that were supposed to be part of the Space Station to buy off the science community.

The science community said, "Well, the station doesn't do most of us any good because you've got people stomping around, you can't point instruments accurately, it's not good for microgravity, and so on. Really, we want platforms that are just tended by people. So let's put some platforms up flying alongside, and then we want a polar platform, because if you're going to observe the Earth, you want to observe it from polar orbit. We want a human tended platform formation flying with the station, and we want two polar platforms, one in an a.m. orbit and one in a p.m. orbit, that are going to fly these big instruments and look at the Earth and everything like that."

Noel said, "I'll take the job if you'll give us the platforms."

Phil said, "Fine. You have the platforms."

Well, we knew those platforms were not going to last as soon as the budget started getting cut, and of course, they didn't. They went away real soon. In the meantime, the science community had been coopted, and they had formed a science team, and we kept trying to tell them, "Hey, you know, you guys are being bait-and-switched," but it got enough of the science community behind that helped them sell the station. Then, as soon as that happened, the first things to get cut out, of course, were the polar platforms and then the accommodations for the science instruments and so on. It was pretty cynical.

Phil never did write Lew back, never sent a response to his letter. I ran into Phil later, and I said, "Phil, that was pretty shabby."

He said, "Yes." He says, "I really am embarrassed about that." He says, "I should have written him back." He says, "I just panicked, you know, the idea of this contractor taking over some major role on the space station," because everybody was fighting over the station.

The big elephants were Johnson [Space Center, Houston, Texas] and Marshall [Space Flight Center, Huntsville, Alabama], of course, fighting, but Lewis was in trying to get a piece of the action to do the power. They had the power system for a while. Then Goddard had muscled in with these platforms. So now, Phil's seeing, "Oh, my gosh. Now we've got one more player in here, and it's this weird contractor that everybody hates. We've got to do something about that." So for a while the station stumbled along as this four-headed monster.

In the meantime, they were letting contracts. Now there was enough money, and President Reagan said, "Okay, we're going to have Space Station *Freedom*." He announced that in, I believe, in '84 so it would be in the '86 budget. Everybody's off, you know, visions of sugarplums dancing in their heads, spending money.

At one point—I forget when this occurred, but at one point Johnson [Space Center] was going to have the human parts of the station, which makes sense. You know, they fly the astronauts, they have the spacesuits, and all that sort of stuff. So they had a contract with one of the—Boeing [Company] and Rockwell [International Corporation] were the two big contractors. So they had one of them that was going to build all of the cans. Then Marshall had the other contractor, and they were going to build all the structure and all that sort of stuff.

Well, I think it was the Houston delegation, congressional delegation, had decided that Marshall had more than Texas so that was not good. They went in and lobbied, and they ended up swapping. Now Marshall is trying to do the cans and JSC is trying to do the structure, and neither one of them is comfortable with their contractors, and it was really a mess.

Then they decided not to put in the advanced power technology. It was just like the Shuttle; they underfunded it in the first place. All the things that were going to be done to make it easy to operate and low cost and so on went by the board right away. Lewis ended up getting cut out because they weren't going to do the fancy new technology power system. Then, when the platforms went away, the Goddard role dwindled down to just the customer integration role. I really don't know what this current situation is on the station. I mean, it's gone through so many iterations. But it started out very badly.

Something that the history books should recount is—I don't know this first-hand, but I was on the team that was working on the design of the station, trying to come up with—we were told that $8 billion was the target number so we tried and tried and tried and tried and tried and tried and tried to design something for $8 billion. Now, we could have done it, but it didn't meet the other requirements, which was that it's got to have a big piece of the action for this contractor, a [big] piece for that contractor, and it's got to be JSC's idea and Marshall's idea and so on. With all the constraints that went on, the design we came up with an absolute minimum of $12 billion if it had, you know, nothing in it, and $16 billion meant absolute minimum to have any function.

BUTLER: If I can pause for a moment just to change the tape.

SHIRLEY: Sure. [Tape change]

We designed this station, and, you know, it was a kluge, it was a camel, a greyhound designed by a committee kind of thing, but it was a design. And our team leader, Neil [B.] Hutchinson, went to Jim [James M.] Beggs, who was the administrator at the time, and said, "Mr. Beggs, I know you want us to do it for $8 billion, but we can't, and here's why." He went through the whole thing with him. At the end of it, Beggs got up and said, "We'll go with $8 billion."

So all of this stuff about "Why has the cost grown so much?" The cost didn't grow. I mean, the cost has grown a lot in recent years, but originally it was just like the Shuttle. The Shuttle was sold on the same basis. They picked the 99.999 percentile high flight rate so they could claim that the cost, then, would be low because they were going to fly so many payloads, and they just picked a flight rate number that would justify a cost of the Shuttle that everybody knew was not going to happen. So NASA has made a real policy through more than one administrator of not being truthful about the cost of things.

At any rate, at that point it became clear that it wasn't going to work. So I went off and—let's see, what did I do in '84?

BUTLER: I think you even made a comment in your book at this point in time, saying that pursuing missions for the government is an inherently frustrating task for everyone.

SHIRLEY: Yes, it really is.

BUTLER: Is there a way to do these kinds of missions, talking space. I mean, it has been frustrating for—as you say, you've gone through so many iterations, so many issues. Is there a way to do these sort of missions without those frustrations, or is it the scale of these programs that cause that?

SHIRLEY: I think it's the scale of the programs. There are several things that happen. One is what I call "engineering hubris," which is, "I'm an engineer. I'm smart. I can make this work." So the engineers buy in to their own demise in a large part by taking on jobs that they shouldn't take on because, well, "I'm smart. I can figure out how to make this work."

But the thing that really drives it is usually somebody's ego. You know, "Let's bring a sample back at all costs because that's the right thing to do, I personally think," says the administrator at NASA, and nobody will stand up to him because there's this huge fear factor.

The government's extremely hierarchical. You know, people know that their careers are going to be trashed.

Because the government doesn't pay very well, a lot of the top people won't go into it. So you end up with not the top people.

People who go in and work for the government are there because they're dedicated to the job, to whatever it is that's being produced. And only the government, up until now, has been big enough to do space missions. Now that's changing with things like *Pathfinder* and *Mars Global Surveyor* and *Sojourner*. Radio hams now have been flying small satellites for years, [nanosatellites]. The technology is now advancing where it's going to be possible for people to fulfill their dreams without having to necessarily work for the government.

Now, the government's getting in the way in a lot of ways. A lot of the government policies are actively blocking the ability of small companies and things like that to go into space. But eventually that will get overcome, just like aircraft companies actually got started.

I think kind of the bottom line is that anything that has a lot of money involved that's political, the pork question comes in overwhelmingly. I mean, it's just irresistible. The only way you can sell something—just like I mentioned the supercollider. As long as the supercollider was open competition it had tons of support. When it got down to one state, all of a sudden there was only one congressional delegation that was pushing for it, and the rest of them said, "Hey, I'm not getting any of it. Why do I want it?"

With the station, John Hodge and Phil Culbertson did it the only way they could. Everybody had a share. Did you ever read *Catch 22*?

BUTLER: Yes.

SHIRLEY: Milo Minderbinder, you know, "Everybody's got a share"?

BUTLER: Yes.

SHIRLEY: It's the only way you can sell these vast government projects because it's a system of checks and balances and it's simply that they won't give you the money to do something all in one chunk. Station, as the most horrible example of it, is, okay, you've got zillions of contractors involved, you've got zillions of countries involved, it's become an instrument of foreign policy, it's become an instrument of pork, making sure the money keeps flowing out to whoever's congressional district. It's the first time I ever saw NASA do this, but they actually went around selling the station. They had a map showing the jobs and how widely spread they were across the country because that's what it takes with our particular system of government.

At least it's more or less above board. [Laughter] Other governments work the same way, but it's just much more clandestine, and people get shot and stuff.

So it's very, very difficult to do large projects efficiently. It's just when vast amounts of money are being spent, it's just very hard to do it.

Now, fairly small projects can be done if you can get an initial agreement. Like with the rover, *Mariner 10*, with all of the early *Mariner* missions, even *Viking*, it was, "Here's what needs to be done. Here's how much money it's going to take." And the big missions did tend to overrun, but they overran almost always because there was insufficient planning up front.

There's guy named Werner Gruel, who was a NASA cost analyst, and he had this great curve that showed if you spent less than 5 percent of the project cost before you made a commitment to the cost, that it would overrun. If you spent 10 percent of the cost before, it wouldn't overrun. So it's simply the work you do to really understand the work, and you need to do a lot of work to understand the work involved. Invariably, when somebody says, "I think it's going to this," or, "I think it's going to be that," or you go off what they call design reference mission. It's the tendency to jump in and get a point design, and then you can cost that. Then you become a slave to it. So you do a point design. You haven't done very many tradeoffs or anything because the job is just [to come up with] this point design so you can cost it so you can get it into the budget because the budget cycle is so long. Then, you know, that just means that you're forced to do sloppy work.

When you find out what it's really going to cost, there's only two things to do. One is overrun, or one is descope. People are extremely reluctant to descope because they don't want to admit that they couldn't do it or they're afraid it'll get canceled. So they go ahead and just hope that somehow—this is where the engineering hubris comes in—they hope they're going to be able to pull it off. Then, when they can't pull it off, everybody beats on the engineers. Well, it's not the engineers initially. It was the politicians and the managers and so on and so forth.

It's a real vicious cycle. In the case of something like—well, *Mariner 10*, for instance, $98 million. "Okay, you can do anything you want, but don't exceed $98 million." With *Pathfinder*, $265 million. "You can do anything you want, but just land on Mars, and that's all we care about, and take some pictures." So they were able to fight off all the scientists trying to pile on.

In the case of the rover, we spent two years getting our requirements and our money to match. I mean, it took two years of hard struggle to beat off all the opposition and beat off the attempt to pile more stuff on. Fortunately, we had a wonderful sponsor named [Dr.] Murray [S.] Hirschbein, who was willing to work with us. Murray was not easy. He was very, very tough on us and made us really do our jobs and justify everything. But once he was convinced, he would go in and fight for us.

Now, that's rare. Most [NASA] Headquarters people will not fight for you. You know, they just flow it down, and they won't go in and manipulate the system for you and things like that, or at least a lot of them won't. It's because, you know, they're not very well paid. They're not getting the best. And if they are the best, they just stay there and get enormously frustrated because they know the right thing to do and they don't want to do the wrong thing. So it's an extremely difficult situation, trying to get any of this done. But up to now it's been kind of the only game in town.

However, as I mentioned, and this is more for the end of it, I'm now on a thing called a—I'm a space science advisor to the Oklahoma Space Industry Development Authority. Things like this are springing up all over the country. You know, there's the Florida Space Authority, there's the California Space Authority, the Texas Space Authority, Oklahoma Space Authority. The objective is basically to attract commercial space businesses, and people are starting to respond to commercial space businesses.

The telecommunications industry has been profitable for years. The remote sensing industry is starting to get there. Whether space manufacturing will ever amount to anything, who knows? But now these small private companies are starting to nibble into the launch business that's been a total government contractor monopoly for all these years, and things have to be fixed.

Like the FAA [Federal Aviation Administration] right now is totally restrictive on communications and adding all sorts of burdens to launching small launch vehicles and so forth. So there's all kinds of government barriers to market penetration. The fact that the government continues to subsidize its existing fleet means it's almost impossible for another launch vehicle to be developed and penetrate that market. So there's lots of government barriers being put up. But it's going to happen. I mean, there's enough stubborn people who are probably going to make it happen.

As the states start to, now, see that it's to their benefit to try to get the legislation changed and the regulations changed and so on, there'll start to be a groundswell of that. In probably another ten years people will be able to live out their dreams without having to depend on the government.

Now, the big ones are always going to be government-funded. You're not going to build a station, you're not going to have a Mars human mission and all that sort of stuff without international cooperation and all the things that go along with that. But students are now flying payloads. There's a projection in *Aerospace America*—let's see if I can find it here, "Space Mission Model 2001 to 2010," and lower Earth orbits. There's hundreds of them, geostationary, and there's tiny ones, you know. Here's twenty-three 6160's that weigh between 0.1 and 100 kilograms. So there's just going to be lots of opportunity. Then it's going to be up to people—it's really going to be up to the engineers to say, "Okay, what can I do for the money?" And to stick to it and not over-bid, not over-commit.

That's kind of in a nutshell the—it's a long nutshell, but that's kind of the biggest problem that faces any big government enterprise, and it's the same whether it's the interstate highway system or medicine, you know, the big medical establishment and heavily government-subsidized medical stuff. Any time there's lots of money being spent, there's lots of stuff in the way of doing it right.

BUTLER: I guess this doesn't relate directly to your work at NASA, but in reflecting on Space Station, *Pathfinder*—of setting these goals, having a reasonable goal, and in looking at government projects, look at what they did do in the early days of the space program with going to the Moon.

SHIRLEY: Right. Well, Webb took the budget and quadrupled it or something like that over what he thought he would need. At that point, when you don't know what you're doing, that's about what you have to do. Then, there was so much work to go around, and the contractors at the time were not entrenched, and they hadn't built the buildings and hired all the people and everything. But once Apollo was over, then here's this big infrastructure in place. Now you've created it, you've got to feed it. So NASA has been feeding its infrastructure ever since. It's just a piece of the military-industrial complex, which [President Dwight D.] Eisenhower feared so much and which is with us.

BUTLER: Well, it should be interesting to see what does come of it, as you said, in these next ten years and these individual groups and the space authorities begin to grow up.

SHIRLEY: Yes. It's really fun to be in on at the beginning.

BUTLER: It must be.

SHIRLEY: Yes. It's fun to track this stuff. I mean, you get to talk to some interesting people. I've got one I talked to called J.P. Aerospace that launches things. They launch balloons. They've been around for twenty years now. They launch balloons, and then they dangle rockets from the balloons, and the rockets then fire and go up into orbit from being taken up by a balloon.

BUTLER: Oh, how interesting. Wow. That's neat. I hadn't heard of that before.

SHIRLEY: Yes. In fact, they were called "rockoons" for a while, a cross between a rocket and a balloon. Evidently, Jim [James A.] Van Allen, way back in the early, early days of space, early fifties, mid-fifties, was doing this kind of thing to launch his instruments.

BUTLER: Really? I guess it's a technology, then, that works pretty well.

SHIRLEY: That's right. Yes.

BUTLER: That's great. Well, it's just the innovation that people can get into.

SHIRLEY: Yes. Okay. Wow.

BUTLER: We've moved out of Space Station, and after that point was when you began to get into rovers, which then kind of dominated your career for a good rest of the time at JPL. In your book you talked about a lot of the different concepts for the rovers. As you've said, there were some very large ones down to *Sojourner*.

SHIRLEY: Right.

BUTLER: Looking at all those different rovers, or different capabilities, what do you see as their future? We've just been talking here about the future of the space program in general, but rovers, both for the space program and even their applicability on Earth, you talked about some of that in your book as well.

SHIRLEY: Well, what we did was, in '84 I was working for a guy named Don [Donald] Rea, who was head of something called TSPD, Technology and Space Program Development. Don said, based on our Space Station work and everything we've been doing, he wanted to have an automation robotics program but he couldn't find anybody to manage it. I mean, we had the people who were doing the technical work, but none of them wanted to go sell the program and put it together and interact with [NASA] Headquarters and so on. I said, "Well, I don't know anything about automation and robotics, but sure, I'll try it."

It took me about a year. I had to go take some classes and go around and talk to all these people, and we actually got to be pretty successful and increased our budget every year and so on doing this technology work. It was a problem because, of course, the technologists didn't want to have to have any particular targets in mind. They just wanted to do fun research. On the other hand, people were starting to do studies on Mars rovers. They'd been looking at Mars rovers for years and years, lunar rovers and Mars rovers, since the sixties. But not much had ever happened.

In 1987, '86 and '87, people were doing studies of these rovers, and then we started to say, "Well, what kind of technology would it really take to make these rovers work?" So we started to really hook in the technology with the rovers.

Then [NASA] Headquarters got interested. Lee [B.] Holcomb, I think, was the program manager at Headquarters who was very interested in this stuff. So he started to fund it. And other places besides JPL were getting into rovers, and by 1992, The Planetary Society was able to have a rover expo in Washington [D.C.], where they had everything from *Ambler*, which was like twenty feet high and it was a walker. It had six legs, and each leg would kind of swing independently: "Chonk, r-r-r-r-r, chonk, r-r-r-r-r, chonk." [Laughter] And a guy came into the exhibit and said, "Wow, what a great gate for [the exhibit]," because *Ambler* is just sitting there. That was Carnegie-Mellon [University, Pittsburgh, Pennsylvania].

Then they had another one, which was an eight-legged purple walker called *Dante*, which was going to go down into a volcano in the Antarctic, and later tried to do it and failed and then ended up going down in the Mount Spur in wherever it is, somewhere up north, and sort of worked.

At any rate, there were these big walkers. Then *Robby* was this big JPL roller, which was so big so it could carry its own brain because in the late eighties and early nineties the computers were such that you just didn't have small computers. I was carrying around a computer at that point called an Otrona, which was known as a portable, but it weighed nineteen pounds. I used to lug it across the country…

BUTLER: Oh my.

SHIRLEY: I thought it was great. You know, there was a computer you could carry. It was pretty remarkable. JPL used Otronas for years. Everybody had these things, because it was quite a while before computers really got to be laptops and so on and real portable.

At any rate, because it had to use this big computer so it could use its high-tech artificial intelligence technique, then it had to have a lot of power and it had to have big wheels. So it was a very large rover.

Then there were people like Dave [David P.] Miller, who were making very small rovers. Dave had a little tiny walker that a kid from MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts] had put together called *Genghis*. Then there was a company called I.S. Robotics that had a little walker called *Attilla*. Then Dave had one that had treads on it called *Treader*. Then we had *Rocky*. So there was just this wide variety. MIT had one called MITy, which was a little rover. Then the Russians even had a little version of their Marsokhod, which was a fairly good-sized rover.

So there were just all of these rovers in 1992. Back in 1986, there had essentially been none. So there was a time when the computer technology—the idea that, "Well, we've landed on Mars, we've landed on the Moon, now we need to do the next thing." So all that was starting to come together.

Plus, they needed autonomy for the Space Station. So Space Station autonomy was putting quite a bit of money into it, and JPL was trying to get a piece of that action. We were basically the NASA center who was farthest along in terms of technology in automation and robotics. One of the things I was trying to do was to sell stuff for the station again. Here I am.

But Goddard, in the meantime, had gotten their piece of the Space Station. So Noel Hinners decided that he wanted Goddard to be an automation and robotics lead center. We said, "Well, we already are," and he said, "Well, hey, but I've got the money to put into the station." Because they needed robotics for payload servicing and everything like that, he made the argument that Goddard ought to have that piece.

So what they wanted was—I've forgotten the acronym on it [Flight Telerobotic Servicer (FTS)], but anyway, it was a human-scale robot, two arms that could go around and support astronauts and put things together. Then they were going to have the big canted arm like the arm on the Shuttle for carrying the big pieces around. Goddard said, "We want to manage the contract for this human-scale robot."

We went in and said, "Okay, you guys have got the contract. Why don't you let us do the breadboard system for you and then what's called a brassboard system, which would be an actual working model, and then we'll give this technology to your contractor."

"No," says Noel, "We're going to do it ourselves."

In the meantime, the cost for the thing had been estimated at $300 million, and we knew it couldn't be done for $300 million. You know, it was much more like a billion-dollar development because it was incredibly difficult and complicated with the technology of the time, and they still haven't done it. Still nobody's really done it.

So we said, "Hey, this is way underbid," but Noel said, "Ah, we can do it." Anyway, they took it on, and it turned out to be a total disaster. Martin Marietta [Corporation] won the contract for it and couldn't make it work. One of the big problems was just jamming everything into something, like the tendons of the arm into something the scale of a human arm. Then there were all the problems of the astronauts didn't want the thing around because it was—you know, John Henry and the steam drill: they were afraid it was going to put them out of a job. So there was just flap, flap, flap. Anyway, we didn't get to do that. You know, we were still doing technology development, but we didn't get to do that piece.

There was another big push for another Mars mission. Now we're going to have a Mars Rover Sample Return [MRSR]. So there was a big project started to study that. Johnson Space Center said, "Wait a minute. We want a piece of the action on this because now it's a precursor to human missions so we want to get involved in it. We want to run the Mars Rover Sample Return."

They put a guy named John—I'll think of it in a minute, anyway, one of their big guns, a guy who reported directly to their Director, was put in charge of their piece of Mars Rover Sample Return.

I was supposed to be running our piece of Mars Rover Sample Return. But at the time, I was finally getting this autonomy and robotics program together, and Lee Holcomb had me come—no. But that time Ray Colladay was running it at Headquarters. Ray said, "Come in and give a presentation to the NASA Advisory Council." I did, and they loved it. They thought it was great. They said, "We're going to make a recommendation to [James C.] Fletcher, the [NASA] Administrator that this go ahead full blast," and so on.

Colladay just thought I was the greatest thing since sliced bread. Don says, "Well, we can't make you the head of the Mars Rover Sample Return thing because we'd have to pull you out of this autonomy and robotics program. So why don't you do the rover part, which is autonomy and robotics, that for a while, and then we'll precess you into running the study."

In the meantime, John [W.] Aaron, that was the guy from JSC, a very good guy, but, you know, a big hummer. Don calls me up and says, "Wait a minute. They've put this big hummer up, somebody who reports directly to the Director. What should we do?"

I said, "Well, why don't you run the study because you report directly to the Director of JPL, and that'll be parity, and then the rest of us will really do the work for you."

He decided to do that. He did that. Well, that left me with just the rover. That was fine and we chunked along for a while, but it was always this big conflict with Johnson. We'd work with them fine technically, but then there was always this power struggle going on.

We worked and worked and worked, and we came up with a cost estimate for the total mission, because when JSC wanted to do it, they wanted to get ready for a human mission. What we wanted to have was orbiters, and everything had to be redundant, so it was going to be orbiters that could see things the size of a meter, which meter scale is what we thought, well, then we can design a rover just to run anywhere because we'll know where everything is.

Well, that's enormously difficult and expensive. The orbiters themselves were a couple of billion dollars, the two rovers were going to be a couple of billion dollars, and then the sample return was going to be another couple of billion dollars. It worked out to about a $6 billion total overall mission package.

This was supposed to be a precursor, then, to this big human exploration program, which in the early nineties was getting cranked up. JSC was out pushing as hard as they could to sell this huge human exploration program. There were various studies done, lots and lots of studies. Sally [K.] Ride did one and Tom [Thomas O.] Paine did one. [General Thomas P.] Tom Stafford, then, was asked to lead something called a Synthesis Group. The Synthesis Group was these graybeards who were going to come up with this grand strategy for human exploration of the solar system. Then there were a bunch of worker bees.

I volunteered to be the worker bee for rovers because we were afraid that rovers would get knocked out completely because JSC really wanted to send astronauts. Anyway, I spent six months commuting back and forth to Washington, and we put together this Synthesis Group study. When we did the cost, they decided not to put in any cost numbers. So this thing was just vast, and it was just full. You know, it was Milo Minderbinder.

The military came in. The nukes from Los Alamos [National Laboratory, New Mexico] and Lawrence Livermore [National Laboratory, California], who, because of the end of the Cold War, were losing their—you know, the Cold War ended in '89, '90, '91. So now all the nuke guys are frantically looking for a reason to exist. They're jumping on, "Oh, we've got to have nuclear power for this Mars mission." For instance, there were two options. One is you build this huge nuclear power plant so you can go fast and so you don't lose all the calcium in your bones and everything like that. Another one is that you fly there with chemical rockets, going really fast, and then you capture, use the atmosphere of Mars to slow down. Then you still get there fast, but now you can use chemical rockets.

Well, of course, the nukes didn't like that. They quickly got that scenario downgraded. "Oh, it's too dangerous. It won't work, etc, etc, but this big nuclear fusion engine will work great." There was a whole bunch of chicanery and all that kind of stuff in that.

When the cost started to leak out, and JSC had done something called the ninety-day study before that, which estimated $400 billion or $500 billion [for the human Mars mission]. That number was suppressed and really never allowed to come out officially, but it leaked out. Congress said the same thing they said back when they found out the cost of the original *Voyager* mission, back in the 1960s. They said, "We're not going to spend that kind of money. Forget it." They canceled the human exploration stuff.

In the process, they cut off all the funding for all Mars missions, including the robotic ones. So now we were completely out of money. At that point, and that was '91, we couldn't have anybody working on Mars because we couldn't pay any salaries. On top of that, you know, I wasn't the Mars Rover Sample Return person. I was just the Mars rover person. Anyway, it ended up that I basically had to go find another job.

My friend Charlie Kohlhase—remember back on *Mariner 10*? Well, Charlie Kohlhase, once again to the rescue, said, "Well, I'm advertising for a project engineer [on the Cassini mission to Saturn]." He says, "Why don't you review the job description."

I said, "I don't like that job description." So I wrote another one. I said, "Now, this is really what a project engineer should do."

He said, "Well, that's a good job description."

I said, "In fact, I think I'll apply for it."

So I did. So I was the project engineer, and John Casani was the [Cassini] project manager. I worked for Charlie, and my job was basically to, once again, try to get the scientists and the engineers to communicate with each other and try to get all this complexity to work and so on. I did that for about a year, and then, all of a sudden, some money cropped up for Mars stuff again. [Dr.] Charles Elachi, who's now the Director of JPL, had scraped together some money to do a demonstration of the rover that we'd actually built when we were working on the Mars Rover Sample Return rovers. I [had] kluged up some money to let Dave Miller build this *Rocky 3*. Dave Miller and Don Bickler put together *Rocky 3*, and it worked well enough they were able to do a little demonstration. Then Charles was able to scrape up enough money to do a better version of it. So Lonne Lane, then, took over and produced *Rocky 4* and did a demonstration in June, and that was the basis for now a micro rover project.

I applied for the micro rover project manager job and got that. The idea was to sell a micro rover to the technology people at NASA that would actually fly. Unfortunately, we didn't have a way to fly. Then we had to figure out how to piggyback on something. So that's how *Pathfinder* came into the act.

BUTLER: As you were getting into this and through working on the rover programs, you talk in your book about the artificial intelligence capability with the rovers.

SHIRLEY: Yes, right.

BUTLER: And here you've gone from talking about the big rover that's carrying his own [brain]—and then now down to the micro rovers.

SHIRLEY: Right.

BUTLER: Obviously, throughout the program there was a lot of growth in the computer technology abilities and in artificial intelligence capabilities themselves, the software end of things as well. About that growth that you've seen, and do you think that those levels of growth are going to continue into the future?

SHIRLEY: Okay. Well, back when I first started working on autonomy in robotics, you know, the artificial intelligence people were pretty confident that they were going to be making progress and so on much faster than it turned out that they eventually did.

The Robby, the big rover that had to be big enough to carry its own brain, was using a sophisticated artificial intelligence technique to scan a scene with multiple cameras, then to analyze the elevations in the scene, pick the smoothest, least hazard[ous] place, and then actually plan its own path to go from where it was to some goal. There were things running around that could do that fairly fast on roads, like Martin Marietta had one. Carnegie-Mellon had a slow one that would go around and follow roads and things like that. They would look at the edges of roads, for instance, to detect things. So there were a lot of people working on this kind of hazard-detection and avoidance and following technology. Unfortunately, it all took huge computational resources with the technology of the time.

A guy named Rod Brooks at MIT had a different idea. He said, "Well, hey, what if, instead of making this thing think like a person, we make it think like a bug?" An insect just goes along, walking along, let's say, and it comes to an obstacle. It then bumps into the obstacle, and bumps into it, and then keeps trying to go around it. Finally it goes around it, and it goes on walking again. So insects have these various behaviors. So it's just a walking behavior, then an obstacle avoidance behavior, then a walking behavior again. If you layer these behaviors so that you have walking and then you layer obstacle avoidance on top of that, now you have what's being called a subsumption architecture. Each behavior subsumes the one underneath it and encompasses it.

Dave Miller and his group at JPL were working on that sort of architecture for little indoor robots. One was named *FANG* [Fully Autonomous Navigational Gizmo]. Then there was another one called *Tooth*. Tooth was, oh, eight or ten inches long, and it would run around and pick up cups and follow the wall and drop them. So it had these very simple kinds of behaviors.

At the same time, Don Bickler was working in his garage on this rocker bogie, which was a six-wheel drive system with the wheels hooked together with a system of levers that would let them rock and go over obstacles. So it could handle much larger obstacles than a four-wheel drive. Don and Dave were both working on this Mars Rover Sample Return study back in the late eighties, [that I was managing] and so I said, "Why don't you take *Tooth's* brain and put it on *Rocky's* body, and then we'll see if we can make a little rover that'll go outside."

Because Martin Marietta and FMC Corporation were working on studies with us and looking at—there's a vast range of different kinds of rovers that could do Mars Rover Sample Return. We had everything from flying rovers and hopping rovers and rolling rovers and great big heavy rovers and Godzilla rovers to graceful little tiny rovers. We were trying to build models of everything just to see what would work, walkers and rollers. We ended up with *Rocky* so we'd kind of anchor one end of our trade space, and *Rocky* worked pretty well.

Originally, back in the early eighties, there was something called MESUR. Now, MESUR was the Mars Environmental SURvey. Ames Research Center [Mountain View, California] came up with this idea of MESUR, and they [come up with this] design and said, "Oh, we think we could land sixteen payloads or twenty payloads or something for $200 million on Mars and just do a network or weather stations. By the way, we think we can do some seismology, too." So the community of weather people and seismology people got very excited about all this, and they said, "Oh, JPL, you idiots, why does it cost you so much? We're going to land these small landers all over the planet."

JPL did some analysis and showed that it really wasn't quite as cheap as they thought, it was really bigger than that, and so on. Anyway, JPL ended up, with a certain amount of political banging around, ended up with the MESUR project. Tony Spear was brought in to head the MESUR project.

Well, somebody said, "Well, gosh, you know, before we land twenty of these things, try to build twenty of them, let's try to build one and see if we can really land on Mars cheaply." So that's what happened with MESUR *Pathfinder*. It was supposed to be pretty much built out of whatever we had available, and then it was just going to demonstrate the concept of landing cheaper. Then we were going to make it much smaller for these others.

In the meantime, several things happened. One was that it was discovered that, for instance, seismology—a guy at JPL built this little seismograph the size of a deck of cards, and it was just great, and you could deliver that even with *Rocky 4*, the rover, because that's what Lonnie [Lane] and his team demonstrated, was putting this seismograph in place. Unfortunately, the temperature swings on Mars completely mask any seismic events you might hear because as the little case of it expands and contracts, you know, you're going to get these signals that this thing isn't going to be able to distinguish from a Mars quake. Then you have to protect it thermally. Well, then you've got to put this big box around it, and it's not small anymore.

On top of that, you don't know how often a Mars quake—you don't know *if* they occur and you don't know how often they occur so you have to listen all the time and take data all the time, which means you've got these vast quantities of data. Well, you're not going to store them in a cigarette pack size.

And you have to keep the power on all the time so it has to be able to operate at night because if the seismic event occurs at night. So that means you've got to have batteries. Pretty soon, the support system for this little cigarette-pack-size monitor got really big.

Well, okay, we're not going to be able to do seismometry but let's try to do weather. So when *Pathfinder* launched, it basically had a weather station, a camera, and they had a very limited budget for science instruments.

Then along came the Germans and said, "Well, we'll give you this Alpha Proton spectrometer for free, which if you put it up against a rock will measure the elemental composition of the rock." Then the University of Chicago said, "We'd like to add an X-ray channel to this thing." So now the whole thing is the size of a coffee cup, something like that, and if we put it on a rock, now we can measure the composition of the rock.

The geologists love this because *Viking* only got soil, only got dirt. The secret of the history of Mars, of course, is in the rocks, not in the dirt, which has all been weathered and chemically changed and so on. So they were really interested in having this spectrometer go on a rock. Well, how are they going to get it there? So we said, "Well, we've got this rover," and the lander was paid for by the science part of NASA; the rover is paid for by the technology development part of NASA, so two separate budgets.

The rover, we, after much thrashing around, concluded we couldn't do it for less than $25 million, even though it had been originally bid at $10 million. We said, "Okay, $25 million is what it's going to take to do this," and good old Murray [Hirshbein], once we finally convinced him, he went and got us $25 million.

In the meantime, Tony [Spear], who's got his hands full just landing on Mars, the last thing he wants is this stupid rover, particularly run by me, who he regards as a real amateur, not having flight hardware experience and so on, not to mention the fact that I'm a woman. He didn't want the rover, and the science didn't want the rover because they envisioned *Robby*. They wanted a big rover. They didn't want this stupid little rover that won't carry any instruments and can't do anything, and they don't want any money to be spent flying this rover. They want science instruments, not a rover.

It finally got down to where Matt Golombek and [Henry] Hank Moore, who is another scientist [of the USGS], did an analysis and showed that the odds of being able to get the spectrometer on a rock if you used an arm or springs or anything like that were so low that it wasn't worth doing. Then, after Lonnie had demonstrated doing something with this little rover, we had a better model of it. So after a while, people started to come around.

Because we didn't want any money to change hands between the Code R [Office of Aerospace Technology] and Code S [Office of Space Science] by the time we got down, we said, "Okay, if you guys will pay to fly us to Mars, I mean, you pay the cost of integrating the rover into the lander, we'll pay the cost of integrating the instrument into the rover, which we think will be about the same." So we worked out this barter system. So no money ever changed hands. After a lot of struggle and turmoil and *sturm und drang* [German: storm and stress], it worked.

BUTLER: It did, and everything did go very well with it.

SHIRLEY: It did. Actually, the spectrometer never worked properly because it wasn't calibrated beforehand. The principal investigators are rather free-wheeling. At one point—what was the PI's name? Rudy, Rudy Rieder—Rudy brought the instrument over in his suitcase, and he put it in the back of a taxi and was driving through Chicago, and the taxi was rear-ended. The instrument turned out to be okay, but still, [he] was lugging it around in a suitcase, a piece of flight hardware.

So they were a little cavalier, and they didn't properly calibrate the instrument beforehand, and we didn't have anything to do with the quality of the instruments so "it wasn't our problem." But I think they finally managed to get some calibration. So the data they got they never could interpret quite properly because they hadn't properly calibrated for the amount of carbon dioxide in the atmosphere that was going to be between the emitter of the alpha particles and the receiver of the alpha [particles], protons and x-rays that were bouncing back. The carbon dioxide, you know, gets in there and affects that. I don't know to this day whether they've ever figured it all out exactly, but apparently, for the 2003 mission, I think they've got that problem licked. They'll fly another one on 2003.

Anyway, the point of the mission really was not to get science, to just prove that it could be done. But it turned out that by the time *Pathfinder* landed, the emphasis—what we had done is we said, "Okay, we've worked out a strategy for the Mars exploration program."

We said, "Volatiles and climate will be the first things we want to tackle. Where did all the water go? So let's find out where the volatiles are." So the *Pathfinder* was a scientific—not a waste, but it didn't really add a whole lot of new science.

Mars Global Surveyor was just flying the *Mars Observer* instruments over again, and the next orbiters were supposed to fly the instruments that were too big to fly on *Mars Global Surveyor*. So we said, "Okay, what do we do with the next landers?" Well, volatiles and climate. We try to really understand the water." The payload [for the '98 lander] that was selected to go to the south pole was to specifically look for water, which is certainly the important volatile. That's how that was picked. Then, the orbiter was picked because you've got to fly one of the two leftover *Mars Observer* instruments, and the only one that we could possibly see that would fit weight-wise was the infrared radiometer.

Then they came along and said, "Oh, and by the way, you've got to fly this camera. Not only do you have to fly one camera, you have to fly a camera on the lander to look while you're coming down."

And also this twenty-six-month problem. You know, by the time the Mars '98 missions are being designed, it was like 1995, '96, and at that time *Pathfinder* is still being scoffed at. The airbags, you know, were just seen as absolutely silly and everybody was laughing at them and nobody believed they would work. So Lockheed Martin [Corporation] selected rocket engines [for landing] because that's what they'd done on *Viking*. They built *Viking*. The technology of the airbags was not discovered to be the end-all and be-all until after *Pathfinder* landed in 1997.

Well, that was too late even for the 2001 lander, which the only way the cost could come down would be to make it as identical as possible to the '98 lander. So airbags were pushed even further into the future. Now everybody, of course, thinks just because they worked once they're now the panacea for everything, but actually, it's a highly risky technology, even today.

But the other thing that happened was with the failure of *Mars Observer* and the selection of *Mars Global Surveyor*, *Pathfinder* was already chunking long. It was going to demonstrate some technology. *Mars Global Surveyor* was brought in to refly the *Mars Observer* instruments, as many as you could. They said, "Okay, the budget is $250 million." For *Pathfinder*, $250 million. For MGS [$250 billion] (roughly). Then, for '98, they said, "Okay, you're going to have $150 million a year to do this program." So we came up with our science rationale, and we said, "Okay. The thing to do is to fly two orbiters and fly the rest of the *Mars Observer* instruments, and then fly two landers, or fly two landers and then fly two orbiters that would recapture the *Mars Observer* data."

Well, Al Diaz, who was at Headquarters at the time, is now director of Goddard, said, "No. You've got to fly an orbiter and a lander. You can't fly two orbiters. That's too dull. You've got to fly an orbiter because you've got to keep flying these *Mars Observer* instruments. So you've got to have an orbiter and a lander." With $150 million a year, that's $300 million per twenty-six-month period, which means each spacecraft and each mission can only cost $150 million, which is a little more than half of what *Pathfinder* and MGS cost only twenty-six months later. So there's no time to develop any new technology. You pretty much have to go with what you've got.

Mars Global Surveyor didn't develop any new technology because it was using previous *Mars Observer* stuff. *Pathfinder* developed a new computer and the airbag system and all that sort of stuff, but only the computer was really transferable because it was the only thing that was far enough along to be used. The telecommunications system [from *Pathfinder*] was used, but it was just basically a *Cassini* radio anyway so it wasn't any new development.

Without any time or money to develop new technology, now we're going to cut the budget in half, and we're not going to let you use a lot of commonality because you've got to fly an orbiter and a lander. Lockheed Martin came in with a very aggressive proposal to make as much commonality between the orbiter and lander as they could, and that was the way they were going to save money. They also proposed, for instance, to go out and hire a bunch of young people so they wouldn't have to pay them very much and things like that. In order to get their budgets down to get into the cost estimate, they really cut a lot of corners.

John McNamee, who had been the [*Mars Surveyor '98*] study manager and who came up with a very creative way of doing this procurement in the face of all of this complexity—you know, Lockheed Martin came in within the budget so there was no way he could refuse to give them the job, but he kept all of his reserves for spacecraft problems because he knew that the spacecraft was going to have problems. He knew they were underbid. Everybody knew they were underbid. So he kept his staff extremely small, which meant he had no capability to go in and bail out anybody.

Usually, the way JPL works is they have a staff, like a radio person who can go in and help out the radio people with the contractor if they need it and so on. Well, he couldn't do any of that. All he could afford was bits and pieces of people to do reviews and things like that. So it was very thin in terms of oversight on the JPL side, very thin in terms of experience on the Lockheed Martin side, although the [Lockheed Martin] project manager was an extremely experienced guy. Then, underneath that, was a lot of inexperience and, you know, young people.

They just worked their tails off, and everybody just killed themselves, literally. Paul Sutton was the spacecraft manager on the lander, and he worked the whole project with terminal cancer, and I can't remember if he died before launch or before they got there. John [McNamee] was working twenty-four hours a day. Everybody on the project was just killing themselves.

But Headquarters kept adding things: "Now here's your instrument payload for the lander. By the way, we want to fly this Russian instrument. Well, it's just a little Russian instrument. By the way, we want to fly this camera, which isn't part of the payload. Well, that's just a little camera." Each time it was, "Well, it's only a million dollars," or, "Only $2 million," or, "Only a couple of kilograms," but that was all the reserve there was. And they absolutely would not listen. We were trying to tell them, "You're killing us here."

Then they came in, another thing was, and this is Al Diaz's [idea] again, there's going to be a new launch vehicle procurement called the Med-Lite. So Mars is going to be the anchor tenant on this new launch vehicle, which means that it can only weight half as much because that was what they were shooting for, was a cheap launch vehicle that would launch smaller payloads. So now not only is it half the money, [for the missions] it's half the mass. Well, you don't cut mass down without money, generally, and if you're going to cut mass down, then you've got to cut instruments down. "Well, no, you can't cut the instruments down," and so on. So it was just completely impossible.

Actually, I thought we'd make it. I thought '98 would squeek by. But 2001, they had even more instruments and more requirements and no more money. At that point I wrote a paper in 1998 and published it, or gave it at a conference, where I said, "Here's the cost per experiment for *Pathfinder* and *Mars Global Surveyor*. You cut that in half for the '98 missions. You cut it in half again for the 2001 missions. You've got this steep curve, and there's only four years between *Pathfinder,* MGS, and the 2001 mission. The 2001 mission has got more experiments than MGS and *Pathfinder* together, because it was supposed to have an orbiter and a lander and a rover and instruments on each one of them, and the budget was not going up." So at that point I retired. Nobody would pay any attention at Headquarters, and I think they were just feeling a tremendous amount of pressure from the Administrator and weren't going to take him on.

BUTLER: Weird.

SHIRLEY: And my management wouldn't pay any attention. It was very sad.

BUTLER: Unfortunately, it did turn out badly for the program on both of those, the *Climate Orbiter*, the *Polar Lander*.

SHIRLEY: Right, it did. They lost the orbiter and the lander and the two, deep space two little microprobes, which were paid for under a separate budget but were flown by the lander. Of course, just to complete the story, the orbiter was lost because of an English to metric unit conversion problem where Lockheed Martin sent the propulsion parameters in English units and JPL assumed they were in metric units.

The reason that wasn't discovered was that there wasn't anybody watching. They were shorthanded at both ends. They had far too many things to do and just didn't check. I mean, the JPL people sent an e-mail to the Lockheed Martin people, saying, "Are you sure this is right?," and the Lockheed Martin people never replied, and the JPL people didn't follow up. Then, when they were tracking it, they noticed a discrepancy all along, but they kept explaining it away in various ways. So it wasn't until the big final [engine] burn [to get into orbit] that the discrepancy really came up and got them.

The other thing that contributed to the problem in a big way was the *Mars Global Surveyor* aerobraking. When MGS launched, shortly after launch when it deployed its solar panels, they discovered that the solar arrays, one of them had broken, and they depended on the solar arrays for doing the aerobraking. So they tried all kinds of tests and things all the way to Mars, and then they finally decided to go ahead and aerobrake. [Aerobraking is dragging the spacecraft through the upper atmosphere so friction slows it down and reduces the size of the orbit.] They tried going in and aerobraking, and the solar panel straightened itself out, and everybody was happy.

Then the next lap, it actually went over center, like hyperextending your elbow. So at that point, they popped back up out of the atmosphere and said, "No, no, no, we can't do this."

After much analysis and everything, Glenn Cunningham, the project manager, made the decision to go back and aerobrake but to do it at a much less pressure so it wouldn't put as much stress on the wing, because if they lost that solar panel, the mission was lost.

So the scientists did just a terrific job of analyzing the atmosphere, and they would be in there at every pass trying to predict whether the atmosphere would bloom or not and how big it would be and how much pressure it would exert on the solar panels. So it was an incredible amount of work, and it took an extra year. The trajectory analysts were very clever and figured out they could get into the orbit they wanted, basically by flying backwards, if they waited a year. Well, that meant that the team was totally tied up flying *Mars Global Surveyor* instead of practicing for the two '98 missions.

So the experience base for '98 was much lower than they had planned on it being because they planned on, "MGS is going to go into orbit. We'll have this whole year to practice and get ready for '98." And they didn't *have* that time. So they're trying to do MGS and '98 with the same team, which, if you really passed over MGS, might have worked, but it didn't.

Then, the lander, nobody really knows why the lander failed. The landing at the south pole was a great thing for science because it was going to be the polar cap, you're going to be able to see if there's any water there, but we know nothing about the conditions at the south pole. Whereas *Pathfinder* landed in a flood plain, where there's terrestrial analogs and we could go out to Eastern Washington and walk around in an area that looked like what the scientists expected *Pathfinder* landing site to look like. The engineers could get a feel for it, and you could design things. At the south pole there is no terrestrial analog for a mixture of water ice and dry ice that sublimes out of the ground. What's left? Is it fluff? Is it hard? Does it have holes in it? What is it?

For some time they thought, well, maybe it just sank out of sight or it hit something that was unpredicted and so on, but then they determined, in testing the 2001 spacecraft, that when it deployed the landing legs, it turned the rockets off, the jets, the retro-rockets off. Then it would just crash because it would turn off the rockets too high. The reason that had happened was because they'd done a system test of the lander and then discovered a wiring problem, fixed the wiring problem and didn't redo the system test.

The wiring problem had masked a software error, and the software error was such that when the little—there's little sensors on the legs, that when the feet touch down you want to turn the engines off because you don't want it hopping around the planet. So the little sensors were designed to turn the engines off when they touched the ground. But what they discovered was, with a high probability, when they deployed the legs, the sensors triggered, and that turned the engines off. So they think that was the failure mechanism.

Nobody knows what happened to the two little microprobes, and the review board said they never should have launched because they tried an incredible breakthrough in communications technology and so on and so forth in building a radio that would fit in a pencil and withstand 40,000 Gs and still be able to communicate. I mean, big job. They probably just bit off more technologically than they could chew, but there was this tremendous pressure to new technology, advanced technology, push, push, push. In fact, Sarah Gavit, the project manager, overran her budget by $5 million, which she should have done because there was no way. I mean, they just couldn't finish it for $25 [million]. So she went to $30 [million] and it still didn't work, but nobody knows why.

Finally, after all the blood cleared and all that, a lot of people were just really devastated. They went back and redesigned the program, and Scott Hubbard, from Ames, valiantly volunteered to go to Washington and lead the redesign effort. They came up, I think, with a fairly sensible set of things to do: cancel the 2001 lander. I think they should pull it out again and use it later instead of wasting it, but at least they could put all their resources into the orbiter so the orbiter should be in pretty good shape.

Then the 2003, they said, okay, now we'll do a rover, a little larger rover, which is what they originally planned to do in 2001 until Johnson Space Center came in and said, "Now we want you to fly these human preparation experiments."

Backing up to 2001, JSC came in and said, "We have these experiments we want you to fly to get ready for future human missions." Code S said, "Fine. Send money." JSC said, "What does it cost?," and Lockheed Martin and JPL estimated $56 million to accommodate these instruments. So they said fine because you had to put bigger solar panels on and everything like that. They said, "Fine. We'll do that." Well, OMB [Office of Management and Budget] came along and said, "Wait a minute. [International] Space Station is overrunning by $200 million. You're going to spend $56 million on a future Mars mission? Forget it." So they scooped up the $56 million.

So [Dr. Wesley] Wes Huntress, as the head of Code S, said, "Fine. Thank you very much. We won't fly your experiments."

Dan Goldin said, "Oh, yes, you will. You must fly the JSC experiments, even if you have to take off science."

So they ended up taking off the large rover with the payload that had been selected through the Announcement of Opportunity process. They put on the clone of *Sojourner*, the little rover whose name was Marie Curie. They were going to clean her up and fly her to Mars. Then they said, "Well, we'll go ahead and fly the instruments from the rover, the big rover, the *Athena* rover that isn't going to fly, on the lander, and we'll fly these other instruments." So pretty soon it was right back up to being this huge endeavor that was, again, not really doable, even when you took the big rover off because you've added everything else.

When they canceled the big rover, then that meant [Dr. Stephen] Steve Squynes [of Cornell University], who was the principal investigator for the big rover, got bumped to 2003. They said, "Fine. Don't worry, Steve. We'll fly your rover in 2003." So now, okay, now you've got a rover in 2003, no orbiter, single thing, added more money to the budget, and everything should be fine. Then Dan Goldin says, "Oh, let's fly two."

Well, you say, "Okay, fine. Building two can't be that much harder." But they're not going to land in the same place so they're not really identical, and they're not going to launch at the same time. Now you've got two missions to fly and two missions to operate on the surface with the same small group of people. So once again, they plowed right back into over-commitment.

Then 2005, now they're going to do—so now they're staggering orbiters and landers, which makes sense, and the 2005 orbiter is going to be looking at things like the size of your tape recorder there or that notebook, which means that it's going to completely overwhelm the capability of the Deep Space Network to get all that data back.

So they've been talking for some time about putting kind of a Mars deep space network in orbit around Mars. I don't know what the status of that is. Anyway, so this 2005 mission is going to be generating vast quantities of data, but at least they've added more money to the budget. They're being more ambitious, but at least they are adding more money. Now, whether the money's keeping up with the ambition I don't know.

2007 looks crazy to me because they've gone to, now, a *Robby*-sized rover that's going to go twenty kilometers instead of one. They've got scout missions that are going. Then 2007 also is going to land accurately and hazard avoidance and a big rover and then they want to fly several small missions all at the same time. So now it's started to just explode again. It's this pattern that goes on forever and doesn't seem to be able to—anything can be done about it.

BUTLER: Is there any way to help avoid that over-commitment pattern? If you were able to show with *Pathfinder*, with *Sojourner*, with MGS, set goals, set a budget, keep it reasonable, and it's totally doable will return great information?

SHIRLEY: NEAR, the Near Earth Asteroid Rendezvous [built by the Johns Hopkins Applied Physics Laboratory], they knew what they could do, they didn't use any new technology, it was a doable mission, they had good, experienced people doing it, they only tried to do one. You can do it, and it's just if you spend enough money up front to define the thing and then really just stick to your contract, all these things can be done.

I don't know what you'd have to do. You'd have to have an administrator who was mainly concerned with staying within budget. The Congress loves Dan Goldin. They think he's great. I watched some testimony where he was confronted with the fact that he was told well in advance that the '98 missions were under-funded, documented and I sent it to them [Congress] myself, documented stuff, and he said, "Ah, people came into my office whining about not enough money. I just threw them out," and [Representative James] Sensenbrener ended up, "Yep. You're the best politician on the hill, Dan. You're doing a great job." So he's got no incentive. He's over-run everything, and he hasn't been fired. In fact, he's outlasted—he's on his third President now.

So I don't know what it would take. I don't think President [George W.] Bush is interested in having somebody in charge of NASA who's really going to do something with in. I think he wants it to go in the direction—military and commercial is what he's interested in. The [President William J.] Clinton administration, [Vice President] Al Gore's protestations to the contrary, was not very interested in space. The budget declined all the time under the Clinton administration.

Until space becomes an important element for people to vote on—and people don't vote for space. They vote for welfare or the economy or the energy crisis or whatever it is, Social Security. They don't vote for space. So I think the only way that it's going to really work is to have a commercial component to it, and it's going to take a long time. We're not going to fly commercial missions to Mars any time soon. That's why I'm not very sanguine that we're going to have human missions to Mars. I mean, 2030 at the earliest, and that would take more, I think, than people are willing to put into it.

I was on a show. It was a British show called "Destination Mars," and they had [astronaut Eugene A.] Gene Cernan and I on at same time, you know, different interviews but talking at the same time. Gene really expressed it well. I said that the Apollo program just jump-started NASA way ahead of where the normal course of events would have taken it, and it's been trying to recover that ever since, and it completely discombobulated—you know, Wernher von Braun's plan was very deliberate: "We're going to do this, then we're going to do this, and we're going to this," and Apollo just leapfrogged all of that and set up a set of expectations, an infrastructure, and pigs at the government trough and all that sort of stuff that I think has really resulted in a big disservice to being able to go into space ever since.

Gene Cernan said it very well. He said "[President John F.] Kennedy just took a decade out of the 2000s and put it into the sixties," you know, picked it out and relocated it into the sixties, way out of its time. It's led to something that—I don't know what's going to happen to it, but I think that commercial space will come through and be able to do a lot of stuff. Space tourism, I mean, the Dennis Tito flight, although Dan Goldin hated it, is nevertheless, I think, a huge boost. NASA is very strange about its public relations, very strange public relations policies.

BUTLER: I've often wondered about that. In fact, I think I had a question here a little later asking about whether NASA should have a sort of different approach on things, where, you know, with the big successes and pushing those and even bringing up things about spinoff technologies that have worked for the space program, to try and keep that excitement up at a manageable level.

SHIRLEY: Well, they try hard on the technologies, but you can't sell the space program on the spinoffs. It's just not going to—I mean, there isn't enough. If you were going to develop Teflon, you'd set out and develop Teflon.

BUTLER: Sure.

SHIRLEY: Or Tang. The spinoffs are good, but that's not what it's about. It's about exploration and adventure and then the commercial practicalities, telecommunications, remote sensing, and so on. All that's just going to take a while, and with the infrastructure that was built up by the Cold War and Apollo program and everything, now you've got all these pigs at the trough, and the little piggies are trying to get [commercial space] in and having a hard time. So it's going to be interesting.

BUTLER: Hopefully, it'll all begin to come together as time grows.

SHIRLEY: Right.

BUTLER: If we could take a break here—

SHIRLEY: Yes, let's take a break. [Tape Change]

BUTLER: In your book you talked about—and this is going back a bit to the rovers—you talked about the robotic intelligence branch being separate from the robotics organization and then talked about how those two were integrated and actually how you saw that as not being a good thing for the intelligence group and that several people left.

SHIRLEY: Right.

BUTLER: So I was wondering about what that mission was.

SHIRLEY: Well, back when I first became the manager of the automation and robotics program, working for Don [Donald G.] Rea in Technology and Space Program Development in '84, '85, something like that, there were two groups of people on that. One was kind of the *Robby* group and one was the *Rocky* group.

The *Robby* group was led by a guy named Brian Wilcox, and he worked for a fellow named Steve Szirmay in the guidance and control section. They had two kinds of technology. One was called computer-aided remote driving, CARD, where an operator would sit in front of a console and see a 3D image of what the rover saw and then would plan a path and mark it with a pen on the screen, and then the rover would follow that path. So all the rover had to do was to follow a predetermined compass heading, basically, and turn where it was told to told.

The second thing they were working on was this artificial intelligence-based path planning: scene analysis, a lot of vision research, and looking at how you know what's in a scene and how you tell one thing's higher than another and so on. They were the ones that needed all this capability, computing capability, to do this artificial intelligence stuff.

So they really had two sets of technologies. What we envisioned was the cameras from orbit would take pictures of things to the scale of a meter and then, using that information, the operator would plan a safe path and kind of use the CARD technology to just indicate a general path. Then the rover would follow that general path and only have to avoid obstacles at a relatively small scale. If you made the rover big enough, then it wouldn't have to avoid any obstacles at all. So if the pictures were at one meter scale and the rover could handle one meter obstacles, then it wouldn't have to be very smart at all.

So they were looking at this whole wide spectrum, from where you don't have any [orbital] imagery and it has to pretty much figure out where it is on its own all the way up to where you've got all this great [orbital] imagery and now you can just charge ahead.

Well, Dave Miller's group was not really working on rovers at all. They were working on this indoor robot. They were working on artificial intelligence for indoor things. But when we were looking at this wide range of rovers, we said, "Well, it would be kind of nice to have an option to have a small rover with a simple technology." Dave was on the rover team back in '86, '87. So he and Don Bickler were talking about what could they do. I suggested they take their little *Tooth* brain and put it on *Rocky's* body. Well, Dave's group was working a lot with subsumption architectures, a lot with indoor robots and how a robot would follow walls and halls, and all that sort of stuff. So [Dave's and Brian's groups] they were really coming at it from two different directions.

Dave's group was in the information systems division, the information systems section, I guess, and Brian's group was in the guidance control section. So they were different organizations, had come up out of two different backgrounds. Brian's group had been around a long time, and they were taking semi-autonomous technology that was applicable to spacecraft and trying to apply it to rovers. Dave was coming at it from the theoretical research side, and his group was pretty new at JPL.

There was only so much money. So again, it was a question of fighting over the money. Let's see, how did the system work? At that point I was no longer working as the automation and robotics manager. I was the Mars rover study team manager.

The fellow who came in to replace me as automation and robotics manager was a guy named Chuck Weisbin. Chuck had come out of the guidance and control [section]. He was a robotics guy, had come from Oak Ridge, and his problem was that there wasn't enough money to go around so how should he spend it? I've forgotten all the details of why, but he ended up on the side of the guidance and control section people. They wanted basically to just take the money away that was being spent with Dave's group and spend it on their stuff. They said, well, the way to do this is just to organize so that Dave's group is under the guidance and control section.

Well, Dave's group wanted to be independent because they felt they would fare badly. There was just part "Not Invented Here" stuff, but they also felt they would fare badly and end up being second class citizens and so on like that if they were put into this other group.

There was much *sturm und drang* and all sorts of thrashing and heartburning. Finally, one of the top-level JPL managers, a guy named Kirk Dawson, who was—I guess he was, at the time, the head of the [JPL] Technical Divisions—and the way JPL is organized is it has people and it has—the Technical Divisions have the people, and the projects have the money, and the projects go and buy people from the Technical Division. So the Technical Divisions are in charge of keeping the capability, the competencies, going. Anyway, Kirk made the decision to take Dave's group out of the Information Systems Division (over the dead body of the Information Systems Division Manager), and put it into what was then called—I forget what it was called. Anyway, it was the controls and energy and all that sort of stuff.

I fought against it because I thought that Dave and company would be unhappy enough that they wouldn't stay, and sure enough, they left. But it was just power politics, which at JPL is less usual than some other places. So it was very disappointing.

BUTLER: I guess it's good that it's not as usual, but it was unfortunate in this case.

SHIRLEY: Yes. As a matter of fact, Dave is here at the University of Oklahoma now, and he and I are working together. That young man that came in with the [paper]—Dave and I are both on his committee, his master's committee.

BUTLER: Oh, that's great.

SHIRLEY: Yes. So I talked Dave into coming here.

BUTLER: That's nice.

SHIRLEY: A small world.

BUTLER: Well, it worked out, I guess, for the university then.

SHIRLEY: Right.

BUTLER: Well, we've talked in several instances about some of the leadership and management issues, and you mentioned at one point, both in your book and kind of once as we've been talking, about not having flight hardware experience and that causing some resistance. But it was a Catch-22, as you mentioned in your book. How was a person supposed to overcome—or were they not expected to overcome that?

SHIRLEY: Well, typically what happens at JPL is you get pigeon-holed fairly early, and you're a mission person or you're a hardware person. I was over on the mission side, you know, being an aerodynamicist and doing analysis of entry body shapes and things like that. So I was always on the mission side of the house and not on the hardware side of the house.

Normally, when people become project managers, they will come up through the hardware side of the house. For instance, they'll start out as a widget builder of some sort. Then they'll become a subsystem lead person. Like you might start out working on the radio, and then you become the radio lead engineer, and then you might become the telecommunications systems engineer, and then you become the spacecraft systems engineer, and then the project manager, and then the Assistant Laboratory Director. People never work their way up to Director. Directors are always science oriented, interestingly enough.

So I wasn't in that chain. People like John Casani, Tony Spear, Tom Gavin, who's now head of flight projects at JPL, all those people came up through the hardware-related chain. I was trying to make a transition from the mission side over to the hardware side. Now, people have become project managers, like Norm Haynes and Bill O'Neil, but what they do is they take over a project when it's in operations. Like the current project manager for the 2001 mission is a guy named Dave Spencer. I think he's the project manager. Anyway, he's running the project. He's the mission navigation guy.

So, during operations, those are the people you want because they understand how to fly the mission and how the navigation works and everything. So Norm Haynes and Bill O'Neil came up through the mission side and became project managers, but they never really had flight hardware responsibility. It's very rare for somebody to come in from the mission side and have flight hardware responsibility, because unless you've been down when you were twenty or twenty-one years old building your widget, they don't figure you know how to do it.

Now, actually, while I probably couldn't build a widget, I can't do a trajectory analysis anymore either. Once you get into management, it's more important to understand management than it is to understand hardware, but JPL and, I think, a lot of NASA and military, you know, the whole thing, what they do is they take the best engineer and make him a manager, often without any management training whatsoever. Unfortunately, the best engineer is often not the best manager because what they want to do is keep being the best engineer.

People like [John] Casani, for example, are great engineers but they can't let go of the details of the engineering. So they're always in there making technical decisions that they really ought to be leaving up to the technical people, who are right on top of the job. It demotivates the technical people, and it often will make bad decisions by the manager, who just is not in touch with everything.

One of the advantages of not knowing anything is that you don't try to do that kind of stuff. So I know enough to know when somebody's making sense and not making sense, and I can be a pretty good judge of, "Does this fit together, does this make sense?" But I don't try to get in and design the circuits or anything like that.

That actually was quite useful. Number one, it leaves you free to really let your people have the responsibility for doing it. Number two, it keeps you from making stupid technical decisions. Now, a lot of people think that a manager who doesn't do that is not a good manager. It's interesting. You'll find your technical people who don't respect a manager who's just a manager because they can't out-technical them. So you get into this interesting problem.

What I did was focus on setting up the team environment and everything so that it would actually work, and I knew enough about automation robotics from leading the automation robotics effort for several years that I knew kind of how to tell the difference between something that would work and something that wouldn't work. And then, I knew enough about how to set up a mission from having worked on some to knowing how to do a work break-down structure and knowing how to divide up the work. And I knew a lot about JPL so I knew which outfits were responsible and how to pick the best people. Just from having a lot of experience at JPL I was able to put together a really good team.

Interestingly enough, it wasn't the A-team, except for Bill Layman, who was the chief engineer, and he was definitely A-team. But all the rest of us were kind of B-team, C-team kind of people because the A-team was all working on *Cassini*. The big projects get "the best" people. Actually, there's lots of best people around. I thought the rover team was absolutely terrific, and the *Pathfinder* team was very good, the *Mars Global Surveyor* team was very good. So as long as you have good management and interesting work to do, most everybody will step up.

BUTLER: You talked in your book a little bit about your management and your building the team like a cell and how that worked. But through all of this, starting with the rover, there was resistance to the idea of it and then to getting it on *Pathfinder* and integrating those teams. Then, when you moved up to being program manager for the entire thing, getting the different groups to work together—

SHIRLEY: Largely unsuccessfully, I might add. [Laughter]

BUTLER: Oh. Okay.

SHIRLEY: It was my failure.

BUTLER: How would you build these teams?

SHIRLEY: The model I came up with, the cell model, was designed to try to break down this hierarchy. Even here at the university, which universities are very non-hierarchical by nature. I mean, the individual faculty member is sort of an independent entity and so on. But there's still a very strong hierarchical—people are accustomed to being in hierarchies. I didn't want to have to tell everybody what to do all the time. I wanted everybody to be able to really bring their own creativity and everything to the team. So I said, "Okay. Well, if we have a biological cell—"

Actually, I think I had the cell idea first, but I heard a talk by David Baltimore, who's the president of Caltech [and a Nobel Laureate], and he's a biologist, so he talked about a cell. He said, a cell is basically a bunch of chemicals that need to work together to create life processes, and in order for them not to drift away into the fluid medium, they need to have something around them to hold them together. So you put this layer of grease around them called lipids, and that's the cell wall.

I said, "Well, gee, you know, a cell wall, what's its function? It's to let nutrients in and to keep bad chemicals and attacking viruses and stuff out." So if you think of the manager as the cell wall, now the job is to bring the money in and to keep the micromanagement out and the creeping requirements and all that sort of stuff. So that's what I spent all of my time doing. Then, within the cell, you can have the various chemicals interacting with each other without the wall needing to get involved.

There are four teams [on the rover]: the controls team, the power team, the telecommunications radio team, and then the mobility team. We kept it to just four because it was a small project and we couldn't have a lot layers of management. And we didn't want to have to have a lot of silos for people to have to go across. So we put all the moving parts and structure and thermal control and everything, which had to be highly integrated—we couldn't afford to have the structure designed independently of the thermal control system, independently of the motors, and so on. So we had people clumped, and the team was only thirty people so [if] we had four clumps, [that's] a manageable size in each one.

Then they could work together. We negotiated contracts with them where they said, "This is how much money you've got. This is what you're going to do for it. This is the schedule." So we worked on integration all the time. We worked on, "Okay. Is everybody's schedule working? No, something's changed. Now we've got to change everybody's schedule. How are we going to do that?"

So we spent a lot of time on integrating the process and making sure that we were going to come out with what we wanted to on time. If something broke down, then we had to replan everything. We spent a lot of time planning, keeping track of the budget. That's the kind of stuff that I led, was making sure that the planning was done, that things matched up well.

Bill Layman, the chief engineer, spent a lot of time on making sure the system-level design actually worked. So "If the controls guys want to do something this way, does that fit with the power guys?" and making sure that they communicated about all the technical details.

It really worked fine, but it was more of a facilitation, communication, leadership kind of process than it was a, "Do this now, do that now, do that now." Everything was negotiated as to what could be done.

It worked out really well because we had reserves. At the beginning we allocated all our reserves. All our money was allocated out with so much held in reserve because we knew things were going to go wrong. Then every time we'd run into a problem, before I would give anybody reserves we'd meet as a group and see, "Okay, what's the best way to solve this problem, what's the best way to spread Donna's money around," and so on. So it wasn't Donna's money; it wasn't just handed out to people. I think the team really felt team-ish.

Now, when we got up to the program level, that was much, much more difficult to apply for several reasons. One was that the three projects didn't want to work together. They had no incentive to work together. They were going to be rewarded for whether their individual project worked or not. There was no stick you could bring to bear to say, no, it's more important that the overall program be optimized than that your project worked. Part of that was because NASA really refused to recognize that it was a program and they continued to dole out money and set up missions on the basis of individual missions and choose payloads from NASA Headquarters on the basis of individual missions and approve your project manager and so on. So it really was impossible to make trades between projects. The line-item budgets were—even though it was supposed to be an overall line item, nevertheless, each project was a line item [for the program] so you couldn't move money around between projects.

The second problem was that the project managers didn't like each other. Glenn, Tony, and John did not care for each other, didn't like each other's styles. [Actually, Tony and John did like each other but still didn't want to work for the program together.] I mean, I don't think they hated each other or anything like that, but they had their own way of doing stuff, and that was the way it was. Tony is very free-wheeling, very charismatic, a leader type. Glen is a very button-down-manager type. You know, everything in its place and everything planned down to the last detail, really an excellent manager.

Then John McNamee was, again, kind of a free-wheeling type but very much of a control freak. So he was going to be personally making all the decisions and in charge of everything, and he didn't want anybody working for him who was particularly strong, for example. He wanted people who he could tell what to do and they would do it. And the three of them were so consumed with just trying to get these very difficult projects done that when I would say, "I want to hold a meeting where we all come together and communicate about the status of the program," you know, "Well, I'm sorry. I've got to be out of town," or, "I've got this." So you could never get them to talk to each other. This egalitarian management system depends on a lot of communication, and if you don't have the communication, if you can't force the communication, it won't work.

The third thing was that I essentially had no authority over any of the project managers because your authority is you can fire them, okay? Tony and I got into such a flap at one point that…I was advised by the review board to fire him. So I asked my management, I said, "Can I?" and they said, "No, you can't." So we worked it out, and it worked out fine.

The management did start to pay attention to the fact that he just wasn't about to do anything that I asked him to do, he was so upset because he didn't get the [program manager] job. They did put some pressure on him to follow some of the review board's suggestions, like get a deputy so he got a deputy, because Tony's not going to do the budget and the schedules and all that sort of stuff, but Mike Ebersole would. Then things went much better because Mike was there to do the day-to-day management functions, and it worked out a lot better.

One of the other things was, we were so strapped for money we said, "Okay, we need one operations project that will operate all these different projects," and, of course, none of the three project managers wanted to give up control over their own operation. So I finally ended up having to make Glenn Cunningham the operations project manager because the *Pathfinder* was in a separate budget item. It wasn't part of the Mars *Surveyor* program. So there really wasn't anything much we could do, and they said, "No, there's no commonality here." So I just gave up on that one because it was way down the road [*Pathfinder* was too far along to change].

The '98 mission, however, I said, "Okay, we're going to set up an operations project that then is going to operate the '98 and a 2001 and the so on missions, because we can do that because it is part of the same line item, and operations is part of our line item." The only way that I could make that work was to put Glenn, who was the *Mars Global Surveyor* project [manager], in charge of the operations because that way he could operate *Mars Global Surveyor* and then set up a system to get ready for the future ones.

Well, part of the problem with that was that the contractors weren't used to working that way so Lockheed Martin was not very comfortable with doing things that way, and that took some time and energy. The other thing was that, where Glenn really understood orbiters, he'd never done a lander. His team were all orbiter people and flight people, and they wouldn't really believe that there was something different enough about a lander that they needed to start thinking about it really early. So there was reluctance for the team to pay attention to what *Pathfinder* was doing and adjust their system to *Pathfinder* or what *Pathfinder* was learning. So they came late to that.

It kind of got grafted on because what they did was, when *Pathfinder* was over, they brought over Sam [Thurman]—drat. I'm so bad with names. Anyway, they brought Rich Cook, Richard Cook, who'd been the mission manager on *Pathfinder*, as the mission manager for the lander, and Sam, who was the mission manager for the '98 lander, per se, brought him over to run the '98 lander part of the project. So they tried to graft the lander people onto basically an orbiter superstructure, and I don't think that worked very well either. I think there was misunderstandings on both sides as to the various difficulties involved and so on.

Like one of the things you asked about here, which I forgot to cover, was a day in the life of a rover. Actually, Roger [D.] Bourke, who was working on the early Mars studies, was the one that came up with this idea. He said, "Now, we're going to be operating on the ground, and it's not like operating in orbit at all. It's completely different. Things change all the time, and you have to respond and react all the time to changes in the atmosphere or changes in the terrain or something like that. So the only way to try to analyze what you need is to come up with some sort of scenario." So he came up with the idea, "A Day in the Life of a Mars Rover."

Then Bill Dias, who was working as, actually, a software guy on the project, said, "Gee, I can write a program, an Excel spreadsheet, basically, to say, okay, we land, we get off, we turn this way, we do that, and how much time it takes for each thing, and when the sun's coming up and when it's going down." So now you can map energy onto it, and then you can see, "Well, really, how long does it take to get to that first rock?" Now you can start to actually map out how long everything is going to take, and you can make things like, well, "How fast do we have to move?" Well, that affects their power design and so on.

So the fact that the lander had a scenario and the rover had a scenario—well, actually, the lander didn't have one originally, but Bill went over and helped the lander develop their scenario because he already had the tool set up. Now you've got a whole different way of thinking. Rather than things being where you expect them to be and being able to set up something where this orbit we do this, this orbit we do this, and have it all kind of run by itself, it's constant interaction, reacting to what the conditions are. It's a completely different mindset, and you set up your team in a different way. That was part of the problem, was getting those two cultures to work together.

I think for this non-hierarchical system to work you have to have several ingredients. One is that everybody has to perceive that the goal is a goal that's bigger than their individual piece or it just won't work. I think that whoever's running it has to be very much a communicator, coordinator type person as opposed to a command and control type person. And it takes enormous amounts of attention to the interactions and constant planning and re-planning and so on. A lot of people don't like to do that because that spoils their creative endeavor. Like software people don't like to document their programs, they just like to write code. So it's somebody who can have the vision of where we're going and how to set the system up so it'll work and then the willingness to get down enough in the details that you can see whether it's working or not and you can track it.

That's hard to do. Most of us are not trained to do that. It took me a long time to learn to do it. What you typically have is a person at the top who's a visionary and then somebody who's their person who actually runs the show, and that's the way Tony and Mike Ebersole worked, for instance. Here at OU, our dean is the real visionary, and then Jeff Harwell actually is the chief operating officer and runs the show from day to day. Then I do a lot of the planning, strategic planning and stuff like that. I'm sort of the change agent. But I have to get down to do detail work, break down structures and schedules and stuff, because they don't understand that. Academics are not trained to do that kind of thing. Unless you can show it to them, they don't really believe you. So you have to be able to do a lot of dirty work, too, if you're going to make these things work.

BUTLER: Sounds like you've figured out along the way how to make it work so that's great.

SHIRLEY: Yes. In fact, the nice thing is, if you do it right, you don't even have to be in charge.

BUTLER: That is nice. That is nice.

Well, looking at your involvement as program director and going back to the role of the media, here you had a lot of contacts, once again, with them, building on that earlier experience. Can you contrast the differences between the two?

SHIRLEY: Well, I was in contact with the media all along because there's always, like I was the voice of *Voyager* during the Uranus encounter. I was the voice two or three times, and I just had a lot of opportunities to interact with the media. And then, when you get higher up in the management you interact with the media just naturally. I mean, they're the people who do it, for a couple of reasons. One is they tend to have the big picture and so on. The other is that, frankly, the people need to be protected. The people who are trying to get the job done can't be swarmed over by media all the time. They even had a charm school for us at one point where they had people come in and videotape us talking and they would get people to talk to each other who don't have the same background and they were different cultures.

Anyway, we knew that *Pathfinder* was going to attract an awful lot of attention, media attention. We didn't actually know how much. One of the things that I did with the rover was I knew the rover was going to attract a lot of interest. I mean, it's cute, so cute. As my daughter would say, "C-u-u-te." Also, we wanted to attract a lot of interest because we wanted to help convince Tony and the scientists that they needed the rover. So we took every opportunity to get in the media.

We got our big break with Al Sack, who was the ground operations manager for *Pathfinder*, the guy who set up all the ground computer systems and all that, had a friend who worked for *Road and Track* magazine. He got *Road and Track* to come out and do a story on the rover as thought it were a car, because *Road and Track*, every April in its April

Fool's issue, does—like one year they did a team of huskies. They had the length of it stretched out on the page and then they had all the statistics: top speed and zero to sixty and so on. It's a big spoof story. So they did that and came out and took a whole bunch of pictures of the rover, and other media picked up on that, and pretty soon we had quite a bit of coverage.

Then the rover sandbox. We had a rover, and it was working, and so that became where all the visitors were sent. So I was kind of the tour guide for this and I spent a lot of time with congressmen and media people and mucky-mucks of various sorts and schoolkids and you name it, giving talks, telling them about the rover, demonstrating the rover, and so on. The natural thing was, when *Pathfinder* came along—I mean, I was the program manager so I wasn't involved in the operations, and Norm Haynes was my boss so we figured, well, the two of us will go try to deal with the media and keep them off the backs of the people. So Mary Hardin was the public relations person, or the PR person, who was trying to set up media things. She decided to give me to CNN [Cable News Network], that we were going to get really good coverage from CNN and they wanted their best talking head. So I was given to CNN, and it worked out really well. I mean, we struck up a lot of rapport with John Holloman, who later killed himself in a car accident. John, [Zarrella] starts with a Z, lives in Florida.

BUTLER: I know who you're talking about, but I'm drawing a blank, too.

SHIRLEY: Anyway, he's the Miami bureau chief, but he's also, because he's on the space coast in Florida, he does a lot of space stuff. So he came up and did most of the anchor work.

We really hit it off and had a great time. Then the producer [Veronica McGregor] and I hit it off so I ended up doing a lot of CNN spots. But there was just a feeding frenzy of media so I was on everything: ABC [American Broadcasting Company], NBC [National Broadcasting Company], NPR [National Public Radio], you know, you name it.

So Norm and I were really eaten alive by the media for a few days, and then, by that time, the team could come out, and they were eaten alive by the media. It was a real media circus. We set the record for the number of hits on the Internet for a day [47 million] and the record for the month. It was 570 million hits. And '97 doesn't sound like very long ago, but the Internet was still relatively new. So it was the defining moment for the Internet. They said that the defining moment for radio was Pearl Harbor and [President Franklin D.] Roosevelt's speeches, the defining moment for television was the landing on the Moon, and the defining moment for the Internet was *Pathfinder*.

The other thing it illustrated, which Johnson Space Center really doesn't want to believe, is that people were just as interested in robots as they are in people. So the kind of attention we got made it clear, if you have something fun and cute and adventurous and the first time, it doesn't have to have a person in it. NASA doesn't want to hear that. They really don't want to hear that.

BUTLER: More money can go into the human side of things.

SHIRLEY: Right. Well, you've got this big infrastructure to support.

BUTLER: The *Pathfinder* was, as you said, cute—or not the *Pathfinder*, *Sojourner*—cute, attractive, it had human characteristics. But did you, even knowing those things going into it, did you imagine the amount of attention, even to toys being generated?

SHIRLEY: Well, yeah. We'd been working on the toys for quite some time. A woman named Joan Horvath at JPL was part of our commercialization group, and she got the idea of trying to sell it as a toy. Now, we'd been approached a number of times by people who wanted to market it as a toy, but nothing had ever really happened. So Joan went out and got with Mattel [Inc.] and got all the licensing agreements done and everything like that. Of course, there was a lot of opposition: "Well, this is so undignified, a Hot Wheels toy." And I pushed it real hard, and we finally got it through. So by the time it landed, Mattel had taken a risk, gone ahead and produced a bunch of these packages—like that one over there—and had them out there, and then it was just a frenzy. You couldn't get them.

BUTLER: You couldn't find them. I couldn't find them.

SHIRLEY: Oh, yes. I had grandmothers calling me up, pleading, "Oh, my grandson has to have one of these. Can you get one?" I said, "I can't get them for my own child." Yes, it went even better than we thought. We knew it was going to be good, but we didn't know how good it was going to be.

It's very interesting because NASA Headquarters public information, for instance, if there's a Shuttle launch, they cover it the whole time. It doesn't matter what else is going on. Most of the time nothing's happening. It's just pictures of people sitting at consoles. But they do it twenty-four hours a day as long as the Shuttle's up. Now, I don't know what they're going to do with the station.

BUTLER: It'll be interesting to see.

SHIRLEY: And, of course, they do get pressure from—like they don't want to do produced video. They came in and said we couldn't do the blue rooms anymore because that was produced video and only the media could do produced video. I don't know whether that was pressure they got from the media or where they got it. So again, you know, political pressure does everything.

It was a lot of fun. It was a good experience. Of course it was good for me personally. Because of all the exposure I ended up getting a book contract and getting to be a well-paid speaker. So I was able to retire without starving to death.

BUTLER: That's always a good thing.

SHIRLEY: It was a good thing.

BUTLER: Looking back over your career, both at NASA but even before that, when you were a student earning your degrees, you experienced a variety of discrimination, I guess, is the word, as a woman, and you talked a bit about that in your book. You mentioned that persistence, determination, creativity, and flexibility were some of your keys to success.

SHIRLEY: Right.

BUTLER: Aside from that as advice, is there anything that you recommend to young women? They're still trying to break into a male world today.

SHIRLEY: Well, things are a lot better than they used to be. There's an episode in the book where my horny old boss at McDonnell Aircraft was chasing me around, a married guy, and how I finally got rid of him by subterfuge and trickery. But I don't think that the overt sexual harassment of professional women—I don't think it's quite as bad. I mean, you hear a lot more about it, but it used to be there wasn't any sense in reporting it because nobody would do anything about it so it didn't make any difference. My impression is that the really bad stuff, for the most part, is a lot better than it used to be.

Anybody who makes it through college in one of these technical fields, I think, has the tools to be okay because getting through college in these fields is not easy. But I was the only woman in all of my classes, and now we have—at the University of Oklahoma, for instance, only about 20 percent of our engineering students are women, but in industrial engineering it's 52 percent. Industrial engineering has four female faculty members [out of a total of ten].

So the more women we can get into faculties and into positions of authority—I mean, there's a book called *Taking Women Seriously*, which did a study about which colleges produce the most successful women, and it turns out to be mostly women's colleges. They've analyzed all the characteristics of those colleges that result in this, and it's the critical mass of students—I mean, I don't know if you've ever been the only woman in a group of men—

probably—but the dynamic is completely different when you have four or five women or when half the group is women. It's a hugely different dynamic than when you have one or two.

So, critical mass of students, critical mass of teachers, because women really do teach differently, educate differently, react with the students different, for the most part, than men—on a bell curve average.

And then, the administration, deans, members of the board, and so on—now, I'm the first female dean in the history of the College of Engineering at the University of Oklahoma, and that's just the case, because a lot of engineering, traditionally, up until the last twenty years, has not had very many women in it. So if you're going to get old enough to be dean, you know, there weren't very many of you. But the head of Rensselaer Polytechnic [Institute, Troy, New York], for instance, is a woman, the president, Shirley Ann Jackson. You're getting more women deans, women college presidents, and so on. So I think that's going to be a big help.

As far as what to do if you're a girl and you want to do these things, you have to recognize that you do have to be tougher than if you're going to be in social work or something like that to get through school. Now, once you get into the world of social work and you're out there on the streets with the horrible things that go on, you know, then that's another thing altogether. And the math and science is a turn-off to a lot of girls, and it's very poorly understood what goes on but girls are just fine at math and science until they hit like junior high, and then they don't want to do it anymore.

There's a theory that part of it is that it's an individual achievement kind of thing and women like to work in teams, they like to work in groups, and that most school work is set up to be individual achievement. You know, you can't do homework together, you can't do tests together. And it's very competitive, which appeals to boys but it doesn't appeal to girls. So most of the pedagogical system is set up to be boy-biased, to be male-style biased.

Then there's been studies done of when women get into college in engineering, because there aren't usually very many women in there, and the style of teaching is often confrontational. You're expected to be tough to make it through. I had this argument with a professor here who says the job of the initial engineering class is to wash them out, whereas most of us think the job of the initial engineering class is to keep them enthusiastic so they'll stay in engineering. So we finally agreed that it should be fun enough that they'll realize that engineering is worth all the pain. So it's hard enough to show them that engineering is tough but fun enough that they should realize how rewarding a career it is.

We're working very hard, and I think most universities are working very hard, on how to get more women involved. But gosh, it's in the water. My daughter came home from nursery school—she was in a very progressive, egalitarian nursery school—came home saying something about, "Oh, girls can't be doctors. They can only be nurses." And her doctor was a *woman*. But she had somehow gotten this. So we went to the nursery school. The nursery school people were appalled. It's a very, very difficult question. But if you're going to do it, you've just got to be willing to put in the work.

It's a lot of work. It's a very rewarding profession. Science, math, engineering are all extremely rewarding, and they're really helping professions. People don't realize that. They think things like schoolteaching and social work and nursing are helping professions, but engineering—I mean, clean water, that's a big engineering problem. Clean air is an engineering problem. Taking care of the environment—one of our biggest enrollments of girls is in environment science, not civil engineering. Civil engineering, environmental engineering, and environmental science are all in the same department. The girls come in, and they become environmental science people because they see that as a helping kind of a thing. Industrial engineering has a lot industrial psychology, working with people, measuring human performance, things like that. That attracts the girls.

And in chemical engineering, we have a lot of girls in chemical, and I don't quite understand that one. Anyway, just mainly hanging in there, realizing it's a really good profession when you get into it. As far as when you're a kid it's really tough. You know, being different is so hard in junior high. It's just really hard. Fortunately, a lot of schools now have gifted classes. They have clubs for kids who like things that are not just run-of-the-mill kinds of things. So maybe one day.

BUTLER: Some time for growth and balance to develop.

Talking about kids and getting them interested in science and engineering and space, you've been involved since leaving NASA with some projects: the Mars Millennium Project, learning technology—if you could talk a little bit about some of these projects and what it is that they do that helps keep kids motivated and helps give them a focus.

SHIRLEY: One of the reasons I wrote the book was to be a visible role model. How many books are there about engineers? Almost none. And no autobiographies, unless you count the astronauts. [Actually Flight Director's Gene Kranz and Chris Kraft now have autobiographies.] So I really wrote it partly hoping that kids would read it and high school kids would read it and see what engineers really do and get turned on by it.

The Mars Millennium Project was really interesting. There was a weekend event where I was a paid speaker, and there were a lot of rich and famous people there, and one of the people who had been invited was Secretary [Richard W.] Riley, who was Secretary of Education under Clinton. He had his chief advisor with him, a guy named Terry Peterson, and Terry's wife, Scott [Shanklin-Peterson], was the acting director of the National Endowment for the Arts [NEA]. So we had Department of Education, National Endowment for the Arts, NASA. And they were very excited. I gave a talk about the Mars projects. They were excited about that and saying, "How can we use this to get kids interested in math and science?"

I said, "One of the problems is that people see engineers as being total geeks and nerds and not being interested in the arts or in the humanities or anything like that." It's generally not true. I know a lot engineers who are artistic and play instruments and things like that. But that side never comes across. So kids who are basically artsy are turned off by the idea of engineering. They think somehow or other that art and engineering can't combine. So we kicked around the idea of this project that would focus on art and engineering on Mars.

So they called up about six months later and said, "We're going to do it." The Secretary had gone for it, and they'd found some funding from the J. Paul Getty Museum. We spent about another six months getting it up and going. We ended up with sponsorship from the Getty Museum, Education, NASA—I said, "Well, we've got to get NASA in," and they were kind of reluctant, but when they found out everybody else was doing it, they sort of had to do it. We got Hillary [Rodham] Clinton interested in it so it became a White House

Millennium project. There's Hillary over on the wall there [Dr. Shirley gestures to photograph].

They said, "You've got to be the spokesperson for it because you do the best job of talking about all this stuff." We got a website up, and they hired a PR firm who basically ran the project, got a website up, [NASA] developed a teacher's guide and sent out thousands of copies of it. We had, I think, 100,000 copies printed up, and they all went like hot cakes.

The teacher's guide was really well done because it had projects that could be done by everything from kindergarten through twelfth grade, and it was designed to be able to be done by Boy Scouts, Girl Scouts, you know, you name it, troops, church groups, anything. The point was they had to design a colony on Mars in the year 2030 of a hundred people, and they had to take into account not just the usual NASA stuff of how do you design the domes and that kind of stuff but to think about how would you entertain yourselves, how would you govern yourselves, what kind of people would you take, how would you get along with each other, what kind of sports would you do, what kind of art would you do, and so on.

Then the NEA sponsored a video called "Windows on Mars," which came out, I think, rather well, and it was done in a news format, where I'm the anchor and all the news reporters are kids. There's four sections, and it all features interviews between engineers and scientists and artists about what it would be like to live on Mars. There's an architect talking about how you build houses on Mars. There's a dancer talking about how you dance on Mars to the scientists who've been up in the "Vomit Comet" [KC-135 aircraft] at three eighths gravity and can tell you what it's really like to experience three eighths gravity. And what music would sound like on Mars. It's a really neat video. We sent out a lot of those.

Then the kids sent in their projects and put them on the web. We ended up with 500 kids' projects on the web, and we figured that probably hundreds of thousands of kids have been involved in this project.

They're still getting 25,000 hits a month on the website, even though it's run out of money and with the Bush administration we don't have much hope of government funding anymore. So we're actually looking for private funding to keep it going because places like the Adler Planetarium [Chicago, Illinois] put a lot of resources into it and various pockets around the country have used it as a real rallying point for their science projects.

The point is to try to get people who are interested, who are not scientists and engineers, to understand that it's not frightening and it's not scary and actually it's essential and that scientists and engineers are not scary and nerdy and going to destroy the world.

Part of the problem, of course, is that media portrayals are all negative. You very seldom see a positive media portrayal of a scientist and especially not an engineer. They even claim that these people are scientists when actually they're engineers. Nobody understands the difference between a scientist and engineer.

So I think it was a small step, but I hope it made some difference in some kids. We'll see.

BUTLER: Oh, I imagine it did. Kids have so much enthusiasm, and if they have an opportunity like that, it—I remember events from when I was growing up that had that kind of impact, had that kind of excitement to them, space-related things or things like that. I'm sure they enjoyed it.

SHIRLEY: Another thing I do is, there's Dave Miller, whom I mentioned to you, and his wife has something called The KISS [Keep It Simple Stupid] Institute for Practical Robotics. What they do is they have these Lego robot kits, and they teach kids how to build robots, and then they have these robot contests. They're called Bot-Ball, and the robots compete against each other to collect ping-pong balls and things like that. It's really terrific stuff. I judge a lot of their contests and help them out in various ways. Now I'm using these kits to teach college kids.

BUTLER: Oh, that's great.

SHIRLEY: In my Introduction to Engineering class—well, actually, I've been teaching a lot of classes. I teach Introduction to Engineering and a class called "Managing Creativity," which is a combination of business and psychology and engineering and management. What I have them do is to come up with a problem, then they have to come up with a solution to the problem, and then they have to design a business to implement the solution with a business plan and a financial plan, how they're going to go get money and how they're going to market their product or service or whatever it is. Then they have to come up with an idea for a project to illustrate their business in some way.

This project is to build a robot, so then they have to go through all the project planning and budgeting and work breakdown structures and schedules and all this kind of stuff. Then designing and testing and they actually have to go through all this. At the end, they give a presentation on their business plan and their robot, and they demonstrate the robot.

BUTLER: That sounds great.

SHIRLEY: Yes. We've got them on videotape and everything. It really is pretty effective. I have a teaching partner, Alice Fairhurst, who teaches some of the classes with me. She and I got together at JPL and created this course. Now we've extrapolated it to the college level.

We break them up into teams to maximize the diversity of the teams. We do a personality-type inventory, Myers-Briggs for instance, and then we mix them up, with introverts and extroverts on the same team. So they have to experience teamwork and how to work with people who are not like them and appreciate the strengths of diversity and that kind of thing. Then they actually have to do this stuff. We don't tell them in detail how to do it; we tell them what to do, and then they have to figure it all out.

No matter how often you tell them that they have to communicate a lot because the people who are working on this part and this part, if you don't communicate, it's not going to work together, invariably they don't do that enough because they get so fascinated with their part. Then sure enough, it doesn't work.

We do a mid-term and a final, and usually by the mid-term they get a big shock and by the final they're in good shape.

BUTLER: That sounds really great. As a recent student myself, that is kind of like a fun way of learning, and it sounds like a lot would get across to them. It's very hands-on.

SHIRLEY: The main reason I came to OU was because the College of Engineering is doing some very exciting things. We have a strategic plan to basically bring ourselves into the twenty-first century and put ourselves in a leadership position. Our vision is to produce the engineering graduates most sought after by industry and investors. So we're not trying to be Tier One [in the U.S. News and World Report ratings like] MIT because the way that's done, a public university in a poor state could never achieve that, but we can achieve having our graduates be highly desirable and sought after.

One of the things I'm doing right now is leading a team, the reason Hazzen [Hejjo, an electrical engineering professor,] came in here was that we're working on developing a new core curriculum. Right now, when our engineers graduate, they have very little experience with computers. We want them to have a good solid foundation in computation because every engineering degree now needs an ability to understand the role of computation in whatever it is you're doing. We want them to be able to understand how to work in teams and how to communicate. Industry is telling us, "We're tired of getting these geeks that can't give a presentation and can't write a sentence." So we're trying to get our core curriculum refined so it's a lot more multi-disciplinary, has a lot more projects in it so they get this experience of the big picture while they're still working on solving the calculus equation and everything like that.

We're making some progress this summer doing that. We're going to write a proposal for a center to try to get funded by NSF [National Science Foundation] to have an Engineering Education Center. So we're slaving away.

BUTLER: Well, that sounds very exciting.

SHIRLEY: Yes. Yes. We've got a lot of multi-disciplinary research projects. We never used to have anything but just single-investigator research projects, and we now have several that practically every school in the college is involved in.

BUTLER: Oh, that's great. Great.

SHIRLEY: In fact, that's what's on the board [(the white board in the office)]. There's all these different things that people are working on, and this is my idea of how to get them to hook them all together into one giant project.

BUTLER: Oh, neat. It certainly sounds like it will fit well into the new century. A lot of opportunity, exciting opportunities, for you there.

Basically one last question, I think, to follow up, to kind of tie everything together. Looking back over your career at NASA, what would you consider your biggest challenge and then your most significant accomplishment?

SHIRLEY: The biggest challenge was the Mars Exploration Program, and I failed. I did not pull that off. I couldn't get the support of management, I couldn't get the support of the people, the concept of an integrated program was just too different from the culture, and I couldn't make it happen. So that was the biggest challenge and my biggest disappointment. It was extremely disappointing.

The biggest accomplishment, I think, was getting the rover to work. I mean, that was clearly something that I had a large part to do with, although there are those who'll say, "Oh, she was only on it for a couple of years." But that's okay because I know that I had a lot to do with it. It wouldn't have been there if it wasn't for me. I'm the one that put the team together and got it all planned and going and everything like that so it pretty much ran itself, to a certain extent because we had really good people. But when Bill Layman and I could both bail out with still two or three years to go on it and have it work as well as it did, I felt pretty good about it. So I think that was my biggest accomplishment.

I think just being able to accomplish as much as I was able to accomplish with a lot of strikes against me, mainly being female—the aerospace industry is a cold warrior kind of industry, and it's not easy for a woman to do well in it. There are no female center directors. There's only been one, Carolyn Huntoon, and she didn't last long. Carolyn Griner was the deputy of Marshall for a long time, never became center director. Plenty of opportunities to promote her but she wasn't. There are no women AAs [Associate Administrators] in NASA except things like public relations and policy and things like that. And the same is true across the centers, there's not very many females in power positions at all, and it's very true across the whole industry. If you go to the aerospace industry, you will not see any female faces except maybe human resources.

In JPL, Charles Elachi has now—I think there are two women [on the Executive Council]. Well, two and a half. One is kind of a token. She's an HR [human resources] person, but she has been put down under a guy, but she's still allowed to come to executive council meetings. But if you look at the really top-layer management, even at JPL, it's still almost entirely men.

So it's just—it's a very hard industry to break into and to do well in. Recently a guy did a dissertation, a fellow who works at Ames, Gery Mulenberg, I guess is his name. Anyway, he did it on project management and how project managers manage and so on. He had like eleven or twelve project managers. I was the only woman, and I was ten to twenty years older than everybody else.

BUTLER: Interesting.

SHIRLEY: So it just took me a long time to get through all the hurdles to get to be a project manager.

BUTLER: Well, hopefully the hurdles you went through will help inspire others.

SHIRLEY: Yes, hopefully.

BUTLER: Open some doors for them.

SHIRLEY: That would be a big accomplishment if, by existing and being out there, it does inspire other women to do it. That would also be a big accomplishment. That's a little harder to measure, as to how much personal impact you have on something like that. A lot of people come up and tell me that I'm their role model, but it might have happened anyway.

BUTLER: Well, I can say personally that you have impacted my career to a certain extent. I was reading your book while I was finishing my master's program and looked on it as, "Look what women can do in the space world. I can do it." It was right as I was finishing my master's project, was doing a group project, and it was just overwhelming. It was like, "Okay, now, she's been through it. I can go through this."

SHIRLEY: So you got a master's degree, in night school yet. Well, very good.

BUTLER: Thank you so much.

SHIRLEY: You're welcome.

BUTLER: It's been very interesting, and I appreciate you taking so much time out of your day for it.

[End of Interview]