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EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is November 17th, 2010. This interview with Dr. Jeff Hoffman is being conducted in Houston, Texas, for the NASA Johnson Space Center Oral History Project. Jennifer Ross-Nazzal is the interviewer, assisted by Rebecca Wright. One of the things that we didn't talk about last time was the use of virtual reality trainers for the Hubble [Space Telescope] spaceflight mission [STS-61].

HOFFMAN: That's a very interesting subject because we really pioneered that as far as crew training. I don't know how I first ran across [David J.] Homan. They'd been doing a bunch of work with virtual reality, and I was always fascinated with virtual reality as a technological tool. I don't remember how I first saw it, but it occurred to me that this could be a good way to test out certain things that were difficult to do underwater or in some cases could be done before we ever got in the water. Obviously water tank training is the best we can do for EVA [extravehicular activity], but time in the water is expensive because you have to pay all the facility charges, the divers and so on. It's silly to go in there just to figure out if I need to stand on the right side or the left side of a door in order to get access to the compartment.

Also Hubble was unique in that it was such a big instrument. Obviously we're used to that in the [International] Space Station now, but in the old days we were just working inside the Shuttle's cargo bay and you could fit the whole thing in the water tank. Hubble was taller than the tank's depth so we had to split it in half. The actual access with the manipulator arm was not

realistic, it was not geometrically correct. We had some real questions about some of the work that we were going to do up at the top of Hubble with the magnetometers and also some of the contingency tasks if the sunshade couldn't open. We actually did go down at one point to the [National] Air and Space Museum [Washington, D.C.] because they have a full-size mockup of Hubble, and we all got in a cherry-picker [hydraulic crane] so we could drive ourselves up and have a look at the magnetometers. But again that wasn't geometrically correct, whereas they had a proper geometry model in the virtual reality facility, and we could actually get in there and see with the arm fully extended how much could we actually reach.

Claude [Nicollier], who was figuring out how to work the arm, could look at the joint angles. I think that's the first thing that we started to do, and then we realized that there were a lot of other things that we could use it for. Virtual reality back then was not nearly as sophisticated as it is now. The computers were much slower. There was about a one-second time lag, so if you turned your head suddenly the visual scene would catch up with you one or two seconds later. You had to learn to use the virtual reality and move slowly. But that's okay because in EVA you move slowly anyway. I found it was quite useful. A lot of people came and took a look at it, obviously became convinced as well, because it's become a pretty widely used training tool.

Now the one thing we talked about with Homan, the guy who was running it—he was concerned that we not get it made into an official training tool in the sense that the other simulators were, because then it comes under configuration control and the training division would take hold of it, and you would lose the ability to make rapid modifications. In some ways it was the flexibility of the virtual reality facility that made it so useful in those early days. We'd come up with suggestions, they'd implement them, the next day we'd go back and try it out

again, and it didn't have to answer to the training bureaucracy. I don't know how things work today because it's pretty much a part of the standard training for EVA, but we started it out. I was quite pleased to see how useful it became, and I followed it through the subsequent years as they improved the capabilities.

Now you have the ability to get two people working together. They have the spider, the Charlotte facility robot in the Virtual Reality Lab, where you can actually move masses around that are simulated to behave like they do in weightlessness. It's really very powerful. Virtual reality is only going to improve as time goes on, so I think we started something that really was pretty useful and important.

ROSS-NAZZAL: So only one person could use the virtual reality at the time when you were using it?

HOFFMAN: Only one person could put the helmet on. The other people would sit around and look at the computer screens. Of course the person who was driving the arm had the controls so that the arm was properly simulated. Nowadays, everybody can participate. Also now you can get in the virtual reality DOME [Device for Orientation and Motion Environments] and fly the SAFER [Simplified Aid For EVA Rescue] unit around. There's all sorts of things we do in virtual reality now that we didn't do back then, but you had to start somewhere.

ROSS-NAZZAL: I thought it was an interesting concept. Dick [Richard O.] Covey had told us that you and Story [Musgrave] were called the odd couple. Can you tell us about that?

HOFFMAN: Odd because we were different or odd because of Story? Story was a unique person. Did they call us that to our faces? I'm trying to remember back then. I'm not surprised, I'm not surprised. We had our own way of going about things, and Story definitely was one of a kind. I also had my own way of doing things. I'll have to ask Covey about that the next time I see him. I could make up a reason, but I can't honestly remember whether it's because Story and I were so different, or just whatever. I appreciate your letting me know that.

ROSS-NAZZAL: I just thought there might be an interesting story there.

HOFFMAN: There might be. I'll have to go and look at Covey's history, see what he has to say.

ROSS-NAZZAL: Yes, look at his transcript.

HOFFMAN:. Or I'll ask Story the next time I see him.

ROSS-NAZZAL: He had also mentioned that at some point you guys had signed some insulation that you ended up installing into the telescope.

HOFFMAN: Was it insulation? I think it was the covers for the magnetometers. On our second EVA, which was the third day of EVA operations, we installed two new magnetometers. The original magnetometers—there were two of them—were never designed to be removed and replaced, because they were never supposed to fail, and they both failed. You couldn't take them off, so the Hubble people designed two new magnetometers that were to be installed on top of

the old ones. That's the first day that we went up to the top of the telescope. That was actually considered a really good deal, because that's the farthest away that you could ever get from the Shuttle without being on a SAFER and flying around. Obviously in the Space Station now it's a little different. But to go all the way up out of the cargo bay, you're 50 feet above the Shuttle. We knew it was going to be a unique view so we were really looking forward to that.

As we were installing the new magnetometers—I was standing on the arm that day, and Story was free-floating—I noticed that some of the insulation was peeling off of the old magnetometers. One of the things that we had always agreed to do was to inspect Hubble wherever we were. We wanted to look to see if there were any micrometeorite penetrations, anything that we could see. It was interesting because other than the magnetometers, the only other thing that we saw peeling off was the actual NASA logo. It was the old worm logo. We used to joke about that because at that point the worm was not supposed to be used anyway. Sure enough, the worm logo was peeling off. Other than that the insulation was in pretty good shape, so we were a little surprised when the second servicing mission [STS-82] went up in February of '97 and found major peeling of the insulation. Ever since all the crews that have gone up have taken up new insulation to put on the spacecraft.

But anyway, the insulation on the old magnetometers was peeling off. I called that down to mission control, because we wanted to let quality control know what we were seeing. They were concerned that the insulation might actually float back into the telescope and contaminate the optics, so they came up with a plan to make some insulating covers. On the fourth EVA, which was the second EVA for Tom [Thomas D. Akers] and Kathy [Kathryn C. Thornton], after they had accomplished installing the COSTAR [Corrective Optics Space Telescope Axial Replacement] and the other critical things, they had enough time left over that they actually

removed some insulation from some of the equipment that was in the cargo bay and brought it inside.

In the meantime, the in-flight maintenance people had come up with a plan to cut a certain pattern, fold it up, and tape it in order to make covers that we could put on the magnetometer. Claude and Ken [Kenneth D.] Bowersox did that. We were cleaning up our spacesuits and relaxing. After a spacewalk there's a lot of stuff to do, and we were doing our own thing with the suits and getting ready for the next day. Claude and Ken manufactured these magnetometer covers.

Then we took little tie wraps, and the in-flight maintenance people had sent up a set of instructions as to how we were to install these. It was a little bit of deja vu because on my first flight [STS 51-D] we had to make the flyswatters. I thought, "Gee, this is back here, been there, done that." Of course what it meant for us was we were going to get another trip up to the top of Hubble, which was neat. That day Story was standing on the end of the arm, and I was the free-floater. That was a new experience for me, because it was really exciting going up to the top of the arm.

We did get them installed. I still look back and see myself free-floating. Every once in a while I would actually let go. Of course we're attached by stainless steel cable, so I'm not going to go floating away. But it was a unique psychological experience actually to let go of the handhold and just float alongside. The tether wasn't pulling on me so I was really a free-floating satellite. I was surprised at how different it felt psychologically when I was holding on. When you're holding on and you push your body is moving, because you're pushing against the Shuttle, and the Shuttle is your point of reference—or in that case the arm. When you let go, you're completely free-floating and I immediately became a free-floating satellite. You're 400

miles above the Earth and particularly at night, sometimes I would turn around so that I couldn't see the Shuttle and just look at the stars and let go and float there. I was just lost in space. That was something I'll never forget. That was a unique experience. The magnetometer insulation covers were installed properly. We certainly haven't had any trouble with them since.

ROSS-NAZZAL: Do you remember signing them?

HOFFMAN: Oh, yes. There was a little concern—we had talked about should we write our names or anything inside the telescope somewhere, and we decided no that would not be good, because maybe it could cause some organic contamination. We figured that since these were going on the outside it would be okay. So yes, we took a magic marker and signed the inside of them so it wouldn't be visible to anybody else, but we knew it was there. That was nice.

ROSS-NAZZAL: That's cool. So they were brought back by the subsequent crew?

HOFFMAN: No, they're still there on Hubble. Those magnetometers, the original set, were never meant to be removed. As I said, we installed the new magnetometers on top of the old ones. They clipped onto the old magnetometers. I think the new ones that we put in are still functioning. I don't know what the problem was with the old ones. They failed pretty soon, the first couple of years, but the new ones are still working.

ROSS-NAZZAL: I thought that was an interesting story. Your crew actually won a pretty significant award after you came back.

HOFFMAN: The Freedom [Forum Spirit] Award, which was $100,000, which we were not allowed to accept, being government employees. We jokingly asked if we resigned from the government could we accept the award, but they said no. It was nice, we had a big black-tie affair. What we did was to donate the award to the NASA scholarship foundation so that it could do some good for some people. We got a lot of awards for Hubble. Monetarily that was the biggest one, but we got awards from *Aviation Week [& Space Technology]* and from the AIAA [American Institute of Aeronautics and Astronautics]. We all realized of course that it was an award to the whole Hubble team, but as astronauts you're at the top of the pyramid and so we got a lot of the public recognition.

ROSS-NAZZAL: Was NASA thrilled with the success of the mission? I know last time we had talked about you meeting with [NASA Administrator Daniel S.] Goldin and he said, "You've got to succeed."

HOFFMAN: The whole future of NASA, as we talked about then, was very much tied up in the mission. I still give a lot of talks about Hubble. The thing is Hubble has been such an incredible success that it's hard to recapture the despair and crisis back in the early '90s when Hubble was the techno [technological] turkey, the big failure, Hubble and the Hindenburg, all those things. So I always start my talks just reminding people of the history of Hubble.

Hubble has gone on to be probably NASA's most popular mission. Everybody knows about Hubble all over the world. Ask somebody on the streets of Shanghai [China] to name a telescope, and they'll probably name Hubble. It's been a great story, because four other crews

went up. The thing that I think has been so significant is the demonstration that by servicing you can keep updating the technology. So it's not just that we were able to fix it when it was broken, but Hubble after the fifth and final servicing mission is now on the order of 1,000 times more sensitive than it was when it was originally launched. Even if it hadn't had the optical problems, the instrumentation continues to improve.

It's Moore's law, which applies to computer memory, but it applies to detector technology as well. The sophistication of the detectors that are in Hubble now is just several orders of magnitude better than it was back in the late '70s, '80s when it was originally designed. That's only possible through servicing. After the first servicing mission people said, "Well, wouldn't it have been easier just to make another telescope and put it up?" But would NASA ever have paid for five Hubble Space Telescopes? Because that's what we've basically gotten. It just doesn't happen. Big missions like that don't get done every two or three years. Whereas by servicing, that's essentially what we've gotten.

ROSS-NAZZAL: Last time when we talked, or maybe it was the time before, you mentioned that you volunteered to fly on Mir [Russian space station]. Can you tell us about that?

HOFFMAN: When Norm [Norman E.] Thagard started the whole process I had been intrigued with the idea of flying with the Russians. Find out about how they do business, as well as getting a chance to spend months rather than weeks up in space. My wife, who's English, had also asked me, "Well, isn't there any way that you could figure out how to get NASA to send you over to Europe?"

I said, "Well, Moscow is in Europe, right?" Little did she know, so she said yes. Maybe I made a mistake by taking her over there. We had an Association of Space Explorers meeting in Russia I think the summer of '94. She wasn't real pleased with what life was going to be like for us, because that was in the early days. Things are a lot better now, but it was pretty rough, both in Star City and in Russia in general. It was still the early days after the fall of the Soviet Union. The economy was terrible; there was a lot of poverty and crime. Life was pretty rough in Star City.

It turned out that back then they were still basically flying the same Soyuz that they'd been flying for a couple of decades. They had never had the social pressures that NASA did to increase the availability of spaceflight. I think NASA was told to make the Shuttle available to 95% of the US population, so we could take anywhere from a five-foot fifth percentile Asian American female to a six-foot-four 95th percentile Northern European American male. The Russians never did that. They just kept flying the same capsule, and they chose their astronauts to fit.

Well, it turned out I didn't fit. In fact, it wasn't just my height. There's all sorts of anthropometric measurements. Your thigh length, your sitting height, your chest diameter. I failed a few of those. But not only me. It turned out two thirds of the US Astronaut Office couldn't fit the Soyuz. I know Wendy [B.] Lawrence was too small. Scott [E.] Parazynski, I think, was the first guy to get sent back, and I'm taller than Scott. So he was too tall, and Wendy was too small.

NASA ended up giving the Russians quite a bit of money to redesign the Soyuz so now a much larger percentage of the Astronaut Office could fit. Now of course since the Soyuz is our

main transportation, we're selecting people to fit the Soyuz. They tell me that I'm just on the ragged edge now. They haven't taken all my anthropometry, so I'm not sure if I would fit or not.

My wife had a big smile on her face when I came home one day and said, "Well, we can't go to Russia." So instead of studying Russian I started studying French and ended up getting sent to Paris [France] for four years. Which was not a bad deal.

ROSS-NAZZAL: Were you planning ahead at that point?

HOFFMAN: I had been thinking of the different things that I might want to do. Actually, after the Hubble mission, I knew that if NASA decided to refly the Tethered Satellite I wanted to do that. They had basically told us that they would fly the same payload crew just because it was such a complex mission.

Ever since my second flight I had a lot of interaction with European space activities. The instrument pointing system for the ASTRO mission was built in Germany. Of course the Tethered Satellite and the EURECA [European Retrievable Carrier] were both European. Hubble—European Space Agency had 20% of that. So I had spent a lot of time over in Europe both preparing for flights and in postflight visits. I had gotten to know the then NASA European Representative and jokingly had asked whether he was planning to stay there forever. He'd been there for quite a while. He said well, if he was ever going to leave he'd let me know. It was before my second tethered flight that he told me that yes he was going to be coming back.

So yes, it was something that I was thinking of. Actually it was just after getting back from the Tethered Satellite second mission, I think it was actually at our postflight celebration when George [W. S.] Abbey, who was center director at the time, came up to me and told me

that I should come and see him because they had another flight opportunity for me. I said, "Well, I'd like to come and see you because there's some other things to talk about." I mentioned to him that it'd be great to fly again but on the other hand I was interested in the NASA European Representative position and would like to apply for that job. So could he hold off on the flight assignment? Then there was a long silence as only people who know George Abbey can totally appreciate as he pondered that. I was waiting in anticipation when he finally said, "Yes, I think you'd be good in that job." I breathed a sigh of relief, went on and applied, and got the job.

At that point I had to choose between Paris and space. I got a little help from my wife on that one, but there were no regrets. I would have loved to have flown again. It wasn't like I was tired of flying in space, but I knew that I would never get another opportunity to be the NASA European Representative. It seemed like a good next step in my career. It certainly turned out to be, and it was a wonderful experience. I have no regrets.

ROSS-NAZZAL: What a great opportunity, live in Paris for four years.

HOFFMAN: It was, yes. We had a lovely apartment on the Avenue de l'Opéra, and I worked in the US Embassy. That was a great time to be in France actually, the late '90s. The initial negotiations for the Space Station were all complete so there was no more hassle about that. Halfway through my stay there in '99 was when we actually started to build the Space Station, so we hadn't really started to run into any problems while I was over there. In fact, the entire four years I was there there wasn't a single crisis. Relations were very good. Everybody liked the

United States at that time. It was before the Iraq war and all. The dollar was nice and high. It was a great time to be an American in Europe.

I think I did good things for NASA. We got some new projects started, and I certainly was able to learn a lot about the space scene in Europe, which was absolutely fascinating. It was a diplomatic position—it was not technical—although I was certainly able to use my technical background to good advantage. It was different from anything I had ever done before, and probably will ever do. Definitely an experience I am very happy to have had. I wouldn't have given that up for anything.

ROSS-NAZZAL: Do you want to talk about that now? Or do you want to talk about your last mission?

HOFFMAN: We can talk about the last mission I suppose and then go back if you want.

ROSS-NAZZAL: That sounds good. Tell us about the reflight of the Tethered Satellite.

HOFFMAN: Well, first of all there was some question as to whether it should be reflown. Obviously there had been some serious technical problems on the first flight. NASA called a nonadvocate review after the Hubble mission, so we organized ourselves and I worked a lot with the project people at Marshall [Space Flight Center, Huntsville, Alabama] who were redesigning some of the equipment to avoid similar failures.

Of course it was unbelievably embarrassing when we discovered the cause of the tether jam. I think I talked about that last time with those extra bolts that had been put in at the last

minute that jammed the mechanism, but there were some other failures as well so there was a significant amount of redesign.

I think there was a strong scientific case to fly the tether. It was a fascinating mission both because of the technology of how to control these long tethers in space and also the interesting ionospheric physics that would be done with all the experiments which were attached to the satellite and to the Shuttle. I think there was a good case for the value of the mission, and the engineers who redesigned the equipment put together a good case to show that they really did understand the sources of the failures and had properly addressed them.

In fact the nonadvocate review found that, yes, this was a mission that was worth doing. Because of the complexity of it, the Astronaut Office decided that the core of the payload crew—which was Claude Nicollier, Franklin [R.] Chang-Diaz and myself—should refly. Which was great because we were all good friends, and that was then going to be my third flight together with Claude, my second flight with Franklin. I still don't think any other two astronauts have had three full flights together. I know there was a pair of Russians in the early days who had two and a half flights together, because on one of their flights they launched separately, did a rendezvous, and then came back together. That's something that NASA history can check. I'd be interested if any other two people have had three flights together. But as I say, we were all good friends, and our families knew one another so it was nice. Certainly I think from our families' point of view—of course there's always a certain stress when husbands get assigned to another flight, but since the families all knew one another I think that made it a lot easier and more pleasant for everyone.

We worked hard at it. We had the same flight director, Chuck [Charles W.] Shaw, and Andy [Andrew M.] Allen came back. He had been the pilot on the first flight, so he was now the

commander. Then we took on Umberto Guidoni as the payload specialist, who we had trained with on the first flight. We had two payload specialists, and Franco [E.] Malerba had flown as the first Italian in space, but we all knew Umberto very well. Then we picked up a second Italian who was flying as an ESA [European Space Agency] astronaut as our flight engineer, Maurizio Cheli. Very nice guy. Scott [J.] Horowitz as the pilot. We all got along very well together. It was a lot of training.

The other aspect of that mission which was interesting was that they gave us a materials science payload. Because they were growing crystals, it required an extremely quiet Shuttle. It had been flown, I think, twice before. It was always flown on a single shift flight where the crew was asleep, and while the crew was asleep they would operate the payload. When the scientists discovered that we were going to be a two-shift flight, so somebody would always be awake, they were pretty upset. Just because of the tight scheduling it couldn't be moved to another flight. The two shifts were the flight shift—with the commander, pilot, Umberto, and Maurizio—and Claude, Franklin, and I were on the second shift. We said, "Look, we can be quiet."

One of the things that they had on board were some accelerometers to measure the acceleration level in the Shuttle. I said, "Look, what we need is some feedback. If you can set up a computer display that will show us the accelerometer reading so that we can actually see any disturbances that we're causing, we can—like biofeedback training—make sure that we keep quiet." And they did. They took workstation programs and put them onto a PC [personal computer] so we could actually see the accelerometer tracings. Very quickly we learned what activities were causing disturbances, and we would stop those. They told us after the flight that

it was as quiet as they had ever seen it. They could see the vernier jets firing. They made more noise than we did.

In order to accomplish this, though, they had to declare that these eight-hour periods—when the other shift was asleep—were the so-called quiescent periods. They weren't allowed to give us any other experiments to do, any jobs. So for the best part of a week for eight hours a day we just had to float and look out the windows. I felt as if I were a space tourist. It was really quite extraordinary. You basically had to float, because any time you touched the wall, you would cause a disturbance.

It was really a very unique experience because of the physiological sensation when you're just floating and you're totally relaxed—I found that without any feedback from your body if you're truly relaxed you could actually almost lose a sense of physical reality. I would just be floating there as a disembodied consciousness, which was really a very unique and pleasant experience. I discovered that sensation on my first flight, but I never got so much of an opportunity to actually experience it as during those quiescent periods.

Our families back home were saying, "Don't these guys have any work to do? What's this quiescent period? I thought they were supposed to be doing stuff up there." In fact the scientists were growing crystals, and I'm told that the experiment was quite successful. They were certainly very pleased with our quiescent periods. It all worked out nicely.

ROSS-NAZZAL: Tell us about the deployment of the Tethered Satellite.

HOFFMAN: Of course all of the crystal growing took place after the tether. We did the tether at the beginning. We had had on the first tether flight a lot of problems just getting the tether

started. The upper umbilical wouldn't come loose. This time all those problems had been solved. Amazingly we turned everything on, the tether started on its way, and everything was beautiful. It started moving away from us. When it got a few hundred meters away we turned off the nitrogen jets, which are what provided the initial tension. Once the tether gets long enough, gravity provides tension and that pulls the rest of the tether out.

I don't remember how far out it was when the first shift had to go to bed. That was the whole idea of having two shifts. We always wanted somebody up and awake when the tether was deployed. Once the initial critical part of the deployment was successfully completed, the other guys went to bed. I think at that point Andy stayed awake. He was on a split shift in the early part of the mission, because we needed either the commander or the pilot to be available at all times to fly the Shuttle in case something happened and we had to get away from the tether.

We just watched it gradually deploy—I say gradually. Actually as the tether got longer and longer it was going out faster and faster. It's moving pretty fast, a few meters per second by the time it gets all the way out. What was fascinating to me was that the tether developed a very large bend in it. It was like a huge arc through the sky, it wasn't going out straight at all. I was speculating whether this was an interaction with the magnetic field, because we were flowing current at certain times and the current flowing interacts with the Earth's magnetic field. I thought maybe that's what was pulling it out.

I figured that this was a phenomenon which should be recorded, so in addition to the TV cameras on the Shuttle I was taking pictures through the window. Now just going back in history to the first tether mission, I saw the jam in the tether through the lens of the camera. When the tether jammed, the satellite started coming back at us just because of the elasticity.

The tether lost tension, it started to get little ripples in it, and that's how I knew that something was wrong.

Now the tether was out over 19 kilometers. It was within one kilometer of its final length, at which point we were going to put on the brakes and just let it sit there, and start all the experiments we were going to do. I was recording this huge arc in the tether through the camera when I started to see little ripples in the tether. It was this horrible feeling of déjà vu, "No, this can't be happening again."

At first I thought it might be another tether jam. There are several things that can cause a loss of tension. The most likely, of course, is that the tether has broken. Now if it breaks at the bottom, it will fly away from you and you're not in any danger. But if it breaks at the top you've got 20 kilometers of tether coming snapping back at you, and we had practiced for that eventuality in the simulator. You've got to then cut the tether at the bottom and fly away from it. Immediately after I saw that the tether had lost tension, I threw the camera away again just like I did on the first mission. I flew over to the rear window, looked out and saw that, yes, indeed the tether had broken at the bottom, so we were in no danger. I called down to the ground immediately, "Houston, the tether is broken."

My youngest son gave me a lot of grief. He said, "Dad, you missed your real opportunity, you should have said, 'Houston, we have a problem.'" But I wasn't really thinking in those terms at the time.

"Houston, the tether is broken. It's broken at the bottom. We're in no danger." We concentrated as much as we could on photographing what was happening so that they could reconstruct it. It was really like getting hit in the stomach realizing that we were losing the tether, but as I say, I knew we were not in any physical danger.

There were a lot of little shreds. It turned out later on I was able to hook up a very powerful train of optics, telephoto lenses, and take a close look at the broken end of the tether. I could see that it was brown and charred so we knew before we ever came home that it almost certainly had been a short circuit that had melted the tether, which in fact was what had happened. Had it happened at night we probably would have seen a big glowing ball going at the end of the tether because apparently at the time it was pulling over an amp of current, which actually answered one of the fundamental questions that the scientists wanted to ask, how much current could you pull through the satellite. We were speculating a quarter of an amp, a third of an amp. We had decided at the end of the deployment of the tether we would actually run it up to a half an amp, but it was actually several times that. It was quite interesting from that point of view.

There were a lot of little bits and shreds of melted tether globs that were floating around. If you go on YouTube you can find a lot of references to the UFOs [unidentified flying objects] which were photographed by STS-75, because in fact what happened was that all of these were rather close to the TV camera so they were out of focus and they looked like these big disks. As they went in front of the tether, just because of the strange optics of the situation, it looked like they were going behind the tether because the tether was so bright that it basically washed out the pixels. The UFO community has had a ball with that. I occasionally get emails asking, "What about these UFOs that you guys photographed? Is this another NASA cover-up?" There were no UFOs, but there were a lot of little flying globs of solidified tether material.

It took a while to sink in what had happened. Of course the strangest thing was when the three guys who'd been asleep came floating up to look. We decided we would not wake them up. We would just let them discover for themselves. They came up and had a look of

amazement when they looked out the window. "What happened to the tether?" Of course we had to tell them that it broke. I actually thought that we bore up to the shock pretty well, although I'm told by my friends—we had to do a press conference—they said we were not looking very happy, which I guess I can believe, although I thought we were trying to keep a stiff upper lip.

I remember I had had a correspondence with Arthur [C.] Clarke at the time. He had written the book *Fountains of Paradise,* which was about the space elevator. In fact in the most recent edition of that book he mentioned our flight because the tethers were the first step towards a space elevator. I remember one of the questions we got in the press conference was, "With all the problems you've had with this tether, why do it?"

We had actually flown a copy of Clarke's book which we signed in space and we gave it to him later on. I was able to pull out the book, and I said, "This is why. Because someday we're going to have a space elevator, and this is the technology that's going to make it possible. Even though we had a failure here, ultimately it's still worth doing." Which I still believe. Unfortunately it was, I think, the nail in the coffin for tethers as far as NASA was concerned because they lost their appetite for any further demonstrations, which is a shame because I think there is a lot that can be done with tether technology and I'm sure at some point will come back. It will be resurrected. I'll look forward to seeing that.

We did get a couple of amazing sightings of the tether. Just because of the orbital mechanics of tethers, it went to an orbit where its apogee was about 140 kilometers above the apogee of the Shuttle. Gravity had pulled it straight. Even though it was all coiled and twisted as it broke, gravity straightened it out. Mission control would call us up and tell us when the tether was going to fly over us, so we actually have a few photographs of it.

It stayed in orbit for about three weeks, and then there was sufficient drag that it fell back to Earth. During that time it was visible on several occasions here in Houston. They had the same impression that we did looking at it. We live in the satellite age, we've all seen satellites fly over. They are tiny points of light. With the tether flying over, you saw a line, this luminous line moving through the sky. It was just eerie. It gave you goosebumps to see something with actual physical dimension moving through the sky.

We saw it a couple of times from space. I know the people on the tether team told me afterwards they had gone down to Galveston Beach [Texas] to watch it as it flew over and had a little tether party. They had the same feeling as we did. As it came over the horizon this line moving through space, it was just a very eerie feeling.

Very sad. There was a lot of good science that we didn't get to do. I think what I was most disappointed with was that there are all sorts of instabilities that you have to deal with when you're reeling the tether back in. We had spent literally hundreds of hours in flight techniques meetings and in the simulator figuring out how to damp out all these instabilities and do a controlled retrieval of the tether, and we never got a chance to see how well it would work.

In retrospect I still look on the Tethered Satellite as the most technically fascinating mission that I worked on. Hubble was clearly the most important and significant, but Hubble is something that people had worked on long before we got involved and there was a lot that we inherited from other people. Obviously we added a lot ourselves. Whereas with the tether, we did the whole thing, just one group of people. Nobody knew how to fly a Tethered Satellite. We had to figure it all out.

When they originally designed it—and I think this is one of the problems actually—the original designers did not realize how complex a process this was going to be. They originally

thought it was just going to be automated, and you just push a button to go up. In fact it turned out to be one of the most complex missions that we had ever flown with the Shuttle. One of the ways that you control the dynamics of the tether is by using the Shuttle as an active flight control element. So it was an absolutely fascinating problem in terms of combining ionospheric physics, tether dynamics, and flight operations of the Shuttle.

We were quite a tight team. We still every year exchange New Year's greetings, the Italians and the flight control people now. Jeff [Jeffrey M.] Hanley was the payload officer. Of course he went on to bigger things with the Constellation Program. I hope tether was not a curse that followed him. But that's another story. Jeff is a good guy, he had a difficult task with the Constellation Program.

All of us who worked on the Tethered Satellite project look back on it as an absolutely fascinating project. I'm just sorry that we didn't get as much out of it as we should have. It was not designed with enough appreciation of its real difficulty, which we eventually came to realize.

The fact that the tether broke—obviously somewhere there was a little breakdown in insulation. Whether that was a result of the tether having sat on the shelf for many years—some people speculated there's something called Teflon creep, which might have had something to do with it or whether it was there all along, we'll never know.

ROSS-NAZZAL: I was reading the *Roundup* [weekly JSC newsletter] today and they were talking about the Tethered Satellite.

HOFFMAN: Really? Today?

ROSS-NAZZAL: Well, an older version, not the current issue, but it made it sound like you had learned something about the satellite.

HOFFMAN: Well we did. As I say the satellite continued to send back information even after the tether had broken. The fact that so much current was able to flow was in itself very interesting and answered a lot of questions. We had planned to do a lot of controlled experiments, but of course to do them the satellite would have had to have been fixed with the brakes on. Ironically a lot of the scientists afterwards had said one of the reasons they wanted to go all the way out to 20 kilometers is because they wanted to be sure they could flow at least a third of an amp of current. The longer the tether is, the higher the voltage is. They said had they known back then what they know now about how well the satellite could collect current probably ten kilometers would have been enough to accomplish all of their scientific purposes. But again, who knew? It is ironic.

ROSS-NAZZAL: So for the rest of the mission you were just floating in space? Did you use any of your materials science degree with the payload?

HOFFMAN: Actually no. That experiment was out in the cargo bay, so it was a hands-off experiment; it was controlled from the ground. What we did do was a combustion experiment. That was really fun, because even back in my Boy Scout days I loved making fires. That was interesting, because as a young astronaut with a scientific background I was often assigned to work with scientists planning experiments in space, and one of the assignments I got was to go up to the Glenn Research Center [Cleveland, Ohio]. Back then it was the Lewis Research

Center. They had the Combustion Science Working Group, and I was the astronaut adviser helping them figure out how to do experiments in weightlessness with flames.

That was really nice, because some of those experiments—and this was back in the early ’80s—that I had worked on the original design of, now they were actually being flown in this combustion glove box. That’s quite fascinating, because combustion, flame propagation is very very different in weightlessness than when you have gravity, because you don’t have convection. Hot air doesn’t rise in space, because hot air and cold air weigh exactly the same, which is nothing. So instead of the flame going upwards, a candle flame is just a spherical ball. If you have a little breeze blowing, which we sometimes created inside the box, instead of the flame going downwind it went upwind, because downwind all the oxygen had been burned up, and there was no convection to feed it. Very counterintuitive.

Of course it’s very important to understand combustion in space not just for the basic science but for fire safety aboard spacecraft. We had a lot of fun burning things. We eventually burned all the fuel that they had given us, and we offered to start tearing up flight books and things but they said, “No, you’ve done enough.” We had a great time. Bunch of little kids building fires in space. That was fun. That we had to do during the active time period.

ROSS-NAZZAL: At this point I understand that you held the record for number of hours on board Space Shuttle, which was 1,000 hours.

HOFFMAN: I was the first person to complete 1,000 hours on the Shuttle, which I hadn’t really thought about. But Andy Allen, who was a test pilot, and Scott Horowitz said, “Well, in the test

pilot community that's really something when you get 1,000 hours on an airplane, especially if you're the first one." So we got congratulations coming up.

I had been told before that this would probably happen, and Franklin was number two, which was unique. Now it turned out that Franklin wasn't going to get 1,000 hours if we had come back when we were supposed to land, but we had a weather delay so we had one extra day in orbit. Then he was the second person to get 1,000 hours. So we have a nice picture of the two of us floating together holding a big sign saying 2,000. That was quite nice.

There's all sorts of records which people set which ultimately will get broken. Who's had the most EVAs, who's spent the most time in space. Nobody else can be the first person to get 1,000 hours on the Shuttle so that was a nice record. Obviously many other people had flown a lot of flights in the Shuttle, but this was fortunately a nice long flight. This was my longest flight. We were up for about 17 days, we had an Extended Duration Orbiter kit on board. Obviously I was at the right place at the right time on several occasions.

Luck has played a part in my career. We talked about how on my first flight we did the unplanned spacewalk. Then when Hubble came along and they said, "Well, you can only do a spacewalk on Hubble if you've done a spacewalk before," I had my EVA union card. There've been many other examples. On the other hand, part of luck is being able to take advantage of the opportunities, and I've done that as well. So no excuses, but I certainly have been very fortunate in my space career.

Then the other last thing was, as I had mentioned, I had already been thinking about applying for this job in Paris. I knew that there was a real possibility that this would be my last flight so it was a bittersweet feeling when we finally fired the engines and started the last trip back through the atmosphere. I know from a lot of friends that many people have this, when you

realize you're never going to be weightless again. Well actually I have in the parabolic airplane [KC-135], but that's not quite the same thing.

People often ask me, "Well, wouldn't you like to go up again?" The answer is sure. Yes, sure I'd go. I didn't stop flying because I was tired of it, as I said. But eventually you're going to go on to another career. I had five good flights so no regrets, but still there is a sadness to know that it is the last time.

ROSS-NAZZAL: Tell us about moving to Paris, when you arrived, and what your initial understanding of your duties were at that point.

HOFFMAN: I actually had a pretty good understanding of what the job was, because as I said I had gotten to be friendly with Jim [James V.] Zimmerman, who was the current representative over there. He had been there for over ten years. They don't let people stay over there that long anymore, but he was under the radar for a while. That's another story. In any case I knew that it was a totally different kind of position. I was basically a representative of NASA.

The interesting thing is you get to meet a lot of very very important and influential people. I think a lot of people here—familiarity breeds contempt—forget the cachet that NASA still has all over the world. To be the NASA Representative in Europe opens a lot of doors. On the professional side, I would meet periodically with the heads of all the different space agencies in Europe: the European Space Agency, German Space Agency, Italian, and French. Those are the big ones. I also spent a lot of time with the British National Space Centre, and then went to a lot of the smaller space agencies on a less frequent basis.

I could call up the head of one of the big European space companies, "Could we come over? I'd like to find out what's going on." Everybody would be happy to see me and interested to find out what was going on at NASA. Of course I had to do a lot of work keeping up to date. That's probably where my background as an astronaut was very useful, because I had a lot of contacts, and I knew what was going on. And also I had a lot of scientific background so I had credibility both on the human space and on the scientific side. Of course in the diplomatic field business information is the currency. You get information from other people, they expect to learn things from you, and I knew a lot of what was going on.

The other thing that I found, which I guess I didn't totally appreciate so much when I first went over, was how much I would learn about NASA, because everybody from NASA would come through Paris. I knew a lot about human spaceflight and I knew a fair bit about NASA science, but, for instance, I had never had much to do with the Earth observations part. The head of NASA Earth observations was coming through. He wanted to go up and visit the tracking station up in northern Norway. My job was to accompany him. He was an associate administrator. So I got to know a lot of people in other parts of NASA which I had never been exposed to as an astronaut, and that was fascinating.

Of course there was also the social side of it, the life in the diplomatic corps in Paris. The interesting thing for the NASA Representative was being treated as "head of agency." In the embassy there are many different agencies. It's not just the State Department. You have the Department of Agriculture, you have the Department of Defense, Treasury, and then independent agencies. If you're head of agency, you have a certain status at the embassy. I was head of agency, even though I was the only person there from NASA—me and my personal assistant, who was a Parisian woman, who had been with NASA for a long time over there. I went to the

weekly ambassador's meeting, and that was fascinating, because I learned a lot about how the State Department functions and what happens at embassies.

It was just a very new experience for me in many ways. Of course there's a very active social life. As the head of NASA at the embassy I got all the invitations to the diplomatic events and the Paris Air Show, which actually was one of the big jobs. It's actually quite hard work, because there's always a big NASA delegation that comes over, and it was my responsibility to make all the arrangements for them.

Also Dan Goldin, who was NASA administrator, made quite a lot of trips to Europe, and I was responsible for doing all the organization. At one point he was invited to give a speech at the Pontifical Academy of Sciences at the Vatican, and he had to cancel because something else had come up, so they asked me to give the speech. Not only did I give the speech but I got to meet the Pope. Everybody said, "What's a nice Jewish boy doing shaking hands with the Pope?" It was great. I really had a lot of opportunities. I think I told you about getting to meet the Queen.

ROSS-NAZZAL: Yes, that's right.

HOFFMAN: We met prime ministers over there—because when Goldin came over as the head of NASA he had entrée even at a higher political level than I did. We just did a lot of very fascinating and fun things, as well as I think doing a good job for NASA. As I said, it was a good time. NASA was not having any problems with our international relations at the time.

Just about the time I was getting ready to come back in 2001, we were starting to have the first round of major financial difficulties with the Space Station. That was after George [W.]

Bush had been elected president. People were starting to get concerned about American unilateralism. If there was any problem that NASA had in its relationship with the Europeans, it was this sense that sometimes NASA would do things without proper consultation. Of course when it comes to the Space Station I always had to remind them, "Well, you guys, really you only pay for 8% of the Space Station so you don't exactly have the same vote that we do." Nevertheless, when you have a partnership you have to keep everybody informed.

There were some tough times right towards the end, but again I was on my way out. Things were a lot more difficult for my successor when for a while there was some talk about major descoping of the Station. In the end of course things have worked out very nicely. I think our relations are very good on the Station. It's been a very successful partnership.

I think the one thing that we did not succeed at—John [D.] Schumacher, who was the head of international affairs at the time, he basically accompanied Goldin on all of his trips. We tried to get the British government to join the Space Station Program. Ever since Margaret [H.] Thatcher [former Prime Minister], Britain had refused to get involved with human spaceflight. We had several meetings with Lord [David] Sainsbury who was the science minister at the time, but he just didn't want to do it. Only just recently, I was quite pleased to learn that Britain has actually formed a formal space agency rather than just a coordinating committee. The select committee in Parliament has suggested that they need to reevaluate their attitude towards human spaceflight. It's been a long time coming.

The other interesting thing was there was a new minister of science in France, Claude [J.] Allègre, who was adamantly opposed to human spaceflight. Of course France was an active member of the ISS partnership. I know when Goldin came over for the first time and we had set up a meeting with Minister Allègre we were thinking, "How are we going to deal with this?"

What we came up with was well, we'll agree to disagree about human spaceflight, but we're both interested in Mars. So we actually started plans for a joint US-French Mars sample return mission, which as it turned out was a bit premature. As we got further and further into the planning, the level of complexity of that mission became more and more apparent, and eventually it just went beyond the budget of the two space agencies. We're still talking about doing it and I'm sure we will at some point, but it gets further and further off into the future. But that was a fascinating thing. We did manage to come to a good understanding with the French despite having this disagreement about human spaceflight.

My French was quite good. I worked hard on it before going over, although I'd never studied it in school. That was the other aspect of my being over there. Once the media discovered that first of all the new NASA Representative was an astronaut and second of all he could really speak French, I did a lot of media work. Even to the point of doing radio talk shows and TV interviews, so I got a lot of publicity for NASA and NASA's projects. I think from what I've been told that was fairly unique for the European representatives. I think the astronaut business played a big role there as well as my linguistic ability.

And I also speak German, Italian, and Spanish. We actually had a representative in Spain because of the tracking station there, so I didn't spend as much time in Spain as in the other countries. I spent a lot of time in Italy, did a lot of media stuff there as well as technical work with the Italian Space Agency.

ROSS-NAZZAL: What a great job.

HOFFMAN: It was, it was indeed. Everybody who saw me, they would say, "Jeff, you have the greatest job in NASA."

And I said, "Well, the best job on the ground anyway." I've been lucky. I've had the best job both in space and on the ground, so I've been very fortunate.

ROSS-NAZZAL: I'm sure your wife was quite pleased too, to be back in Europe.

HOFFMAN: After putting up with five spaceflights and what, nineteen summers in Houston, I thought it was at least a nice little bit of a reward. Four years in Paris was really quite extraordinary. I never looked at it as something we were going to do forever, so I did start thinking about the future. I started my life in academics, and I had actually maintained a lot of contacts at MIT [Massachusetts Institute of Technology, Cambridge]. My interests had shifted away from astronomy, because I really hadn't done any research in astronomy for years. On the other hand I had spent a lot of time working with engineers and solving engineering problems, so it became apparent that if I was going to go back into academics it made sense to do it as an aerospace engineer.

It turned out fortunately that MIT had created a new kind of position called the professor of practice. I couldn't just go in as a regular tenured professor because I didn't have the appropriate academic publication record. There may have been some other universities where I could have done that but really I had enjoyed being at MIT, and I really like Boston [Massachusetts]. So I thought I'd try for one of the top universities, and MIT School of Engineering had recently created this position of professor of the practice, which was specifically meant for people who had spent their career in the government or industry and did not have an

academic publication record which you would really need for a tenured professorship. I was going to retire from the government so I had a pension and the actual tenured professorship wasn't so important. To be appointed professor of the practice, you have to go through a similar procedure as getting tenure. In other words I had to get letters of support from people all over the world testifying to my accomplishments and so on. Then the faculty have a meeting with the engineering council. I was eventually granted the professorship, and things have worked out great. I've been at MIT since 2001.

It's a very high-powered place. In fact I'm working harder now than I probably ever worked at NASA—in a different way. I shouldn't quite put it that way. When you're getting near a spaceflight, the number of hours per week that you put in is pretty huge, but it's all very focused. Everything is towards one single goal, and you have a lot of people who are working helping you. In particular you have a scheduler, so every day you get a paper saying, "This is what you're supposed to do at this time," and you don't have to worry about it. If I do what's on the list then everything will get done. Whereas now I've got at least a half a dozen different research projects going on, lots of different graduate students, and I'm responsible for it all. I don't have a scheduler telling me what I have to do and when I should do it. There's just a lot of work. It's a very high-powered place. It's very exciting.

Of course the biggest challenge for me in the school of engineering is I was not educated as an engineer, so by the time that the undergraduates are seniors they know more about classic engineering than I do: control theory, structures, and things like that. But that's not what they brought me there to teach. There's plenty of other people who do that. My experience is in space operations, satellite design, spacecraft design.

One of the things that I was concerned about was losing touch with the space program, and one of the great things about MIT is that we do have a lot of contacts with NASA both in terms of consulting as well as research grants. In many ways I've been able to keep in touch with the space program, and actually in many ways have had some input and influence on it. It's been very satisfying, plus I like working with the students. They're really smart, and I have to work hard to keep up with them.

ROSS-NAZZAL: I can imagine. Tell us about the class that you pioneered about the Space Shuttle Program.

HOFFMAN: In our department, the Department of Aeronautics and Astronautics, every year there's a course in aircraft systems engineering. What they normally do is take an airplane and basically analyze it inside out, both how it was constructed and how it is operated. I had the idea, "The Space Shuttle kind of looks like an airplane, so maybe we could one year devote this class to the Space Shuttle." I had been friendly with Aaron Cohen [former JSC center director] over the years, and he had come up to MIT in 2004. I don't exactly remember what was the occasion, but we were talking and I asked him if he would be interested in doing something like this together, and he said great, because he was very interested in systems engineering. He taught that at [Texas] A&M [University, College Station] for quite a few years after he left NASA.

So the department appointed him as a visiting professor, and the two of us put together the course. Aaron of course was the project manager for the Shuttle. He still had lots of contacts with all the subsystem managers, most of whom were retired. Some of them were out living on

ranches in West Texas. He told me he'd pick up the phone and call them up and say, "Hey Joe," whoever it was, "this is Aaron Cohen."

"Oh, hi, Aaron, how are you doing?"

"I'm fine. You know the thermal protection system that you worked on?"

"Yes."

"Well, I've got one more job for you. How'd you like to come up to MIT and talk to the students about how you designed it and how it worked?" He said every single one of them accepted. There were one or two who came up who were still working at NASA. Most of them were retired. Aaron basically concentrated on the subsystems, and then I concentrated on the operations. We got Chris [Christopher C.] Kraft to come up and talk about his role. [N.] Wayne Hale [Jr.] came up to talk about mission control. Bob [Robert B.] Sieck from Kennedy Space Center [Florida] came up to talk about the launch operations. It was great. The graduate students voted it the best course of the year that year.

We knew that it was going to be unique. We were fortunate also. We got a grant from the Draper Laboratory which gave us the support we needed for the transportation to bring everybody up. I knew it was going to be unique. Aaron is no longer with us, same with some of the other people. Nobody's getting any younger. We had the whole thing televised, and it's now on MIT World so it's freely accessible to anybody [http://mitworld.mit.edu/].

Still every year I get a few emails from various parts of the world saying, "Oh, we saw this, it's great." I used to pass those along to Aaron while he was still alive. It was a wonderful experience for me, because I learned things. I thought I knew a lot about the Shuttle, but I got a chance to actually talk with many people I hadn't known well. I had known these people's names. For instance, Bob [Robert F.] Thompson was legendary. We were just young astronauts,

and we never got to talk to those high up people. Now I was meeting them as an equal. It was absolutely fascinating. That was definitely a highlight. It was a one-off thing. People ask me, "Are you ever going to do that again?" It's not the sort of thing that we could do, but luckily it is on the Web site on TV and everybody can enjoy it.

It was unique. I remember as a young astronaut, at one point—this was before the Shuttle was launched, when Chris Kraft sat us all down and told us to pay close attention to how we were going to get the Shuttle flying, because it's usually only once in your career that you will ever get to see a new space vehicle put into operation and learn actually how to operate it. Of course the Space Shuttle was so complex that it was a lot harder to learn to operate as well as to build it.

One reason why the Shuttle worked as well as it did was because the people who designed it were the Apollo generation. They knew they could do it. I asked every one of the subsystems engineers, "Well, you did a great job designing the system, and it worked just like it was supposed to, except the reusability. We were supposed to be able to turn the Shuttle around in a couple of weeks. How did we get it so wrong?"

And every one of them said, "Well, the reason is because we knew how to build spaceships, but nobody knew anything about reusable spaceships." Of course that went back to the very origins of the Space Shuttle and some of the political problems where NASA was essentially forced to, first of all, build as the first reusable vehicle not a small X-rocket but this huge Shuttle. It's extraordinary when you think about it. We didn't start out small; we went the whole nine yards. It had basically been decided for economic reasons to satisfy the OMB [Office of Management and Budget] that the Shuttle would have to fly 30, 40 times a year.

What we were going to launch 30, 40 times a year nobody knew, but it just had to. All the subsystems engineers said, "Well, they told us turn it around in three weeks. So we said, 'Yes, okay, we can do it,' without really knowing what was involved." Of course once we started flying the Shuttle proper engineering practice luckily took over and people realized that it actually was going to take a lot longer. In order to fly it safely we were going to have to spend a lot more time checking it, cleaning it up, inspecting and so on.

ROSS-NAZZAL: Do you have any involvement with Space Station today?

HOFFMAN: Actually I don't know if you're familiar with the SPHERES [Synchronized Position Hold, Engage, Reorient, Experimental Satellites] experiment on Space Station. It was actually one of the early successful research experiments, because during the time when the Station was being constructed it was hard to get science done or research. One of my MIT colleagues designed SPHERES. They're little spherical satellites about 15 centimeters in diameter, and there are three of them, and they're inside the Space Station. They're operated by carbon dioxide thrusters. It's a controls laboratory where you can basically send up control algorithms and program the SPHERES computers to test out different techniques of docking, rendezvous, and relative flight in ways that would be impossible if you were doing it with free fliers.

A free flier program, such as Orbital Express for instance, which I was involved in, involves real satellites which cost hundreds of millions of dollars. They were doing experiments in docking and fluid transfer, but you had to be very very conservative because if you try something and it doesn't work you'll lose them, and that's the end of it. Whereas with these SPHERES, you're inside the Station, so you can be very aggressive in trying out new techniques.

If it doesn't work, they bounce off the wall, the astronauts get them, refill the thrusters, put in a new set of batteries, and you're off and running again.

I got involved particularly because I'm director of the Massachusetts Space Grant Consortium. Space Grant is supported by NASA, and there's a Space Grant organization in every state. In Massachusetts we have seventeen different universities who are members, as well as the Museum of Science and couple of other nonprofits—a Challenger Learning Center and an observatory. One of the things we're tasked with is space education. What we have done now that's been incredibly successful is that in addition to using these SPHERES for research purposes, we've now made them accessible to students to program them, and we're running contests now.

In fact one of them is in the finals now. We're down to ten high schools, and they get to basically program the SPHERES. It's a little bit like a video game, only in three dimensions with real objects. I think in the middle of December this year the actual SPHERES will be in a competition up in space. This will be the third time we've done it. The first time it was a test, we just had two high schools in Idaho. Then last summer—I don't know if you were familiar with NASA's Summer of Innovation. It was a big program.

ROSS-NAZZAL: Yes, I saw that.

HOFFMAN: Massachusetts was one of the four states that were selected. One of our projects there was using SPHERES, and we call it Zero Robotics. It's an homage to the FIRST [For Inspiration and Recognition of Science and Technology] Robotics program, which has been very successful among middle and high schools building robots and having these competitions. We

call it Zero Robotics because they operate these SPHERES robotic satellites but in zero gravity. We wanted to see if middle school students could do this, so we basically made the user interface a little more user-friendly and less mathematical, and it was a great success.

Last summer we limited it to schools in the Boston area just for logistics. We had about 250 students for the finals. Shannon Walker was up in the Station, and she was operating the SPHERES. She would call it like it was a horse race, "The blue satellite is going around the corner, and the red satellite is catching up." The kids—they were wild, they were cheering, it was like they were at a [Boston] Red Sox game. It was great. It's been very successful, so I'm very interested in other possible educational uses of the Space Station, as well as the research uses.

I hope this'll end up being a continuing project. We've got a new continuing grant for at least two more years to run several more of these Zero Robotics competitions, and the SPHERES has been an incredibly successful research tool as well. Our MIT group is continuing to evolve SPHERES, again with good support from NASA and from DARPA [Defense Advanced Research Projects Agency] as well. It was originally a DARPA-funded project but they've turned it over to NASA now. I think the Ames Research Center [Moffett Field, California] now has the operational responsibility for SPHERES.

ROSS-NAZZAL: Interesting. Well, I just had a couple of general questions for you, the kind of questions we like to ask people. What do you think, looking back on your NASA career, was your most significant accomplishment?

HOFFMAN: Well, I'd have to always come back to the Hubble, because in the large scheme of things in terms of what difference did we make and what legacy have we left, Hubble just stands head and shoulders above anything else. For the Shuttle Program as a whole I look at the Hubble as being one of the great things that the Shuttle Program has given to the world.

ROSS-NAZZAL: What do you think was your biggest challenge?

HOFFMAN: From a personal point of view, I started out as a scientist, and spaceflight is really an extension of high performance aviation. It started out just learning how to fly T-38s, but that's just the first step in getting involved in a huge high-power technology program which was orders of magnitude bigger than anything that I had ever been involved in before. There are a lot of physical challenges, but I had done physical challenges before. I wasn't frightened of them, and I think I met them all.

I think that was actually one thing. When people would come and visit, and especially people from other countries that were interested in establishing space programs, I think the universal first response they get after seeing what it takes to run the Shuttle Program here is, "My God, I had no idea it was so complex. There's so many things you have to do, so many people involved, and so many things that need to be done."

And as an astronaut you have to learn something about all of it. We were generalists. We had to know at least a little bit about everything, and then you learn a lot about a few things. Never to the level of depth as the systems experts, which is why we have mission control, but it was fascinating from that point of view. Just the breadth of knowledge that by the time I was flying as an active astronaut, and I realized how much I had actually learned was extraordinary.

ROSS-NAZZAL: What contributions would you say that your class, the TFNG [Thirty-Five New Guys], made for the program?

HOFFMAN: Well, of course we brought women in for the first time, and that's what got I think the biggest media attention. I think when I came into the Astronaut Office it was totally dominated by military test pilots. Now Peggy [A.] Whitson, a female scientist, is the head of the Astronaut Office. It's extraordinary, and our group started it. We were thirty-five people coming into an Astronaut Office which was down to only twenty-five. So we were the new Shuttle Program, and the first of it.

I was fortunate. I stayed—I wasn't the longest. I guess actually Shannon [W.] Lucid is still here amazingly. I stayed for quite a while, so I got to see the Shuttle go through its early birth pangs, unfortunately its first tragedy, and then really into its heyday. I was very fortunate, thinking back. We were flying six, seven, eight flights a year. We were putting 50 people a year into space so we could support an Astronaut Office of 150 people. The Shuttle is now in its old age, and it's coming to a halt. The attitude around the office and the whole Center now is very different, "What are we going to do?" Human spaceflight is going to be the Space Station now, but as far as launch vehicles it's never going to be the same around here. We'll be putting four, five American astronauts a year up on the Space Station.

The other thing of course—even these last five, six years or so almost all the flights, with the exception of the Hubble flight and tragically *Columbia* [the STS-107 accident]—had *Columbia* gone up to the Space Station they would have known that they had a problem and they wouldn't have tried to come home. Other than that and the final Hubble mission all of our

missions have been Space Station construction flights. On the one hand that was good because originally that was the idea. We would have a Space Shuttle so that we could build a Space Station. On the way there, before we actually had a Space Station, the Shuttle was really used for an extraordinary variety of different missions, and I was lucky to be a part of that. All my missions were different. We did a phenomenal variety of different things, and I think that was unique. We're probably never going to have another vehicle like the Shuttle in that sense.

It was far from a perfect vehicle. Were we to do it again, probably would have done it differently. Given what we built, it was remarkably successful. Unfortunately we didn't always operate it properly and that led to the two tragedies, but I was very lucky to be able to take advantage of the Shuttle in all of its manifestations as a multipurpose vehicle for science experiments, satellite launching, EVA, Hubble repair. It's really quite a ride.

ROSS-NAZZAL: I had a couple of other questions since you have some time. Were you ever on the astronaut selection committee?

HOFFMAN: I was.

ROSS-NAZZAL: Would you tell us about that?

HOFFMAN: Yes. I think only once was I on the selection panel, in 1991 although I was on the committee a few times for reading applications. Mostly because for most of the early '90s I was really busy flying, so I didn't have any time. I was actually on the interview panel when Don [Donald R.] Puddy was the head of Flight Crew Operations. That was very interesting, to see

from the other side what I had gone through. It was interesting in that the selection panel had a certain number of people with science and engineering backgrounds and other people with pilot backgrounds, and what I came to appreciate even more than I had before was how many qualified applicants there are. It became very clear that the most important thing we were trying to do was not to make a mistake and let somebody in who wasn't going to work out. You don't have to go searching for qualified applicants.

I always tell this now, because so many of my students and other people come up and asked me, "What do I have to do to be an astronaut?" I have to explain to them that no matter how good you are, being an astronaut has to be your Plan B, because you've got to plan your regular career. Don't make critical life choices just on being an astronaut, because no matter how good you are there's a lot of other good people.

It was important, I think, to have a variety of backgrounds on the selection committee because I could listen to people from a science background coming from a university or laboratory environment and get a good sense of where they were coming from and were they going to fit in. Would they be happy in the Astronaut Office? Whereas when a pilot came in, I had no way of judging their background. Similarly, the pilots didn't really relate to the scientists who were coming through.

Trying to figure out whether the people were going to fit in, be happy, and be able to work as part of the team was much more important than I had originally appreciated. We always emphasize that as an astronaut you've got to be a good team player, and it became clear if there was any hint of an overweening ego, that was the kiss of death. Yet it was an interesting dichotomy because in order to get to the selection process in the first place you had to have had a

very successful career, and that usually means you're a hard worker, you're a type-A personality, and that usually involves a strong ego, so you're looking for this balance.

It was a humbling process as well because it's like we were controlling the gates to heaven. All the people who came through, they just were so passionate about wanting to be astronauts.

ROSS-NAZZAL: Do you have a sense when you go in that we're going to select this many pilots, this many mission specialists, and then we want a geologist, so many engineers?

HOFFMAN: Yes, that's how we did it back then. There was a rough idea. We didn't know exactly how many we would be allowed to select. So what we did was we had a rough idea and we made a prioritization list. Basically we took a look at the office and asked, for instance, "Do we have enough life scientists?" That plays a role, but it's not ultimately determining. If somebody was really super qualified, even if we didn't particularly need that specialty, they could still get selected. On the other hand if we needed a specialty but there was nobody who was absolutely outstanding you don't reduce your standards.

I do remember Rick [Richard M.] Linnehan. He was the first veterinarian selected. When we saw, you know, "Veterinarian, oh, that's interesting." It certainly made us take a second look. Of course Rick was very qualified. At the time we thought there would be a lot of animal experiments on the Space Station, which was something we were thinking about in the future although we weren't building it at the time. As it turned out we're not doing a whole lot of animal experiments, but again that's another story.

ROSS-NAZZAL: Did race or gender play a role in your decision making?

HOFFMAN: Not for us. Although it's a funny sort of thing. You know that if you don't select any women, and you don't have a sufficiently diverse group it's not going to be acceptable. On the other hand at no time did we say, "Well, we need more women" or "We need more blacks" or "We need more Hispanics." I think maybe in the initial screening they make sure that a sufficient number of qualified people are coming through.

It just didn't turn out to be a problem. I don't know what goes on behind the scenes. I'm sure people do look at that. It's the world we live in, and there are certain requirements which NASA has to live up to. It never became an issue for us on the selection panel, although as I say I'm sure people were looking at the final list to make sure that it was sufficiently diverse, but nobody told us, "You need a certain number of women." As I say, it's the world we live in. Somehow you learn to deal with these things.

Luckily there are a sufficient number of highly qualified people applying that you could meet any sort of requirements you wanted to. You could say, "We want the whole group to be made out of left-handed Hispanic women," and we could still find enough qualified people that it wouldn't be a problem.

ROSS-NAZZAL: One of the things I know we haven't really spent a lot of time talking about, but I thought maybe in the last few minutes here if you wanted to talk about some of your PR [public relations] trips to Europe. You had mentioned, I think last time or maybe it was the time before, that practically after every mission you got to go to Europe and go to Switzerland.

HOFFMAN: That was one of the nice things about flying with European astronauts, particularly in the early days when it was pretty new for the European Space Agency. They would take us on these gala trips through Europe, and they know how to do it in style. You stay in five-star hotels and you're chauffeured around in Rolls-Royce limousines.

I've spent a lot of time in Europe, and when I travel by myself I don't stay in five-star hotels and I don't drive around in Rolls-Royces, but nevertheless I had grown up in an environment where I could put that in perspective. I did notice that there were some of the people who had come maybe from small town America who were just totally blown away. I keep saying, as I kept saying to myself and my wife, the way you have to approach these trips is it's great, enjoy it, just don't get used to it because you're going to come back to Houston and you're back at the end of the line and back doing your job.

It was a great experience. In addition to the ESA connection we had Claude from Switzerland. At the end of each European postflight trip where we would have gone to a bunch of different ESA Centers, then we would go to Switzerland for another week of being wined and dined. Of course Claude was a total hero there, and everybody knew him. That was always wonderful.

Probably the greatest thing we did there—after our first Tethered Satellite flight—at the end of the trip to Switzerland we went to Zermatt where Claude had worked in the observatory. I had been there many times skiing and climbing, and we both loved Zermatt. They flew us up to the top of the Matterhorn in a helicopter. Then we got the idea, wouldn't it be great on our next flight—because we knew we were going to go on the Hubble flight together—we'll take a piece of the Matterhorn up with us into space, and then we'll make another trip back to Zermatt and present it to Zermatt village. We did, and sure enough we came back the summer after, and

they arranged for us to climb the Matterhorn together with one of my sons and one of Claude's daughters.

And we did the same thing actually after my last flight (the third flight with Claude), because I have two sons, and the older son got to climb with me the first time. Then the younger son said, "Dad, that's not fair." I said, "All right, we'll climb it again." Which was the fourth time that I had climbed the Matterhorn. What was wonderful was on that final climb, my son's guide was the son of the guide that I had climbed the Matterhorn with the very first time when I had climbed it with my father back in 1963. So it was a real closing the loop. There were many wonderful experiences we had like that. That was probably the most unique though, those trips to Zermatt.

We also had a couple of incredible trips to Costa Rica with Franklin. If he wanted to be president of Costa Rica, no problem. Everybody in Costa Rica knows Franklin. It's a very different kind of a culture than the glamour of Europe, but it was wonderful. The people were so friendly, and Franklin is a rock star basically in Costa Rica. It was wonderful. I speak very good Spanish, so I could take part in a lot of the talks as well. That was nice and very much appreciated.

I don't tend to talk a lot about it, because people shouldn't get the idea that this is the center of astronaut life, but it certainly is one of the perks. Definitely we were very lucky because of the European connections with all these flights. When I look back, after my second mission, the ASTRO mission, which was basically American, I gave a talk to the American Astronomical Society because it was an astronomy payload, but that was not nearly as neat as some of the European tours that we had.

Of course from the European point of view, it was very useful to them. And we did our best—I don't want to give the impression that it was just all wining and dining, because we had to work hard. It could be a very grueling schedule. We had to often work hard to build a little free time into the schedule, because they wanted to make the maximum use of us. We would sometimes give two or three presentations per day with a lot of traveling, because human spaceflight does not have the same cultural position in Europe that it does here. It got started here as part of the Apollo Program, and it's an accepted part of American culture, something that we do well, we're proud of. Yes, NASA always has to worry about its budget, but NASA basically has a very big budget compared to the European Space Agency. Five times bigger, and the fact that we have a human spaceflight program is accepted. It's not something that we have to continually rejustify even though we always have to work on getting the budget for it.

Whereas in Europe, it's not part of their cultural history. It's been a big fight to get European countries to accept the expense of human spaceflight. So it was our job basically to be ambassadors for human spaceflight, and we worked hard at it. It was great fun, we enjoyed it. We certainly ate well, drank well, and had a jolly time, but we worked hard as well. I think we did a good job for the European Space Agency in promoting human spaceflight, which is the reason why they brought us over there.

Of course we were in the early days of European human spaceflight. I'm told things are not like that anymore because they've been doing it for a long time and you don't always get that sort of a tour when you come back from a flight. But we were, again, at the right place at the right time with the right people, so we took advantage of it.

ROSS-NAZZAL: Rebecca, do you have any questions for Jeff? Any parting thoughts? The only thing I don't think that we talked about today was your work on STS-82—you were CapCom [capsule communicator]—which was a [Hubble] servicing mission.

HOFFMAN: Yes, that was my swan song. By that time I knew that I was going to be going over to Europe. I guess I didn't when I first started working on STS-82, but I was hoping to get the European Representative job. As I said, I had asked not to be assigned to another flight pending the decision, but working on STS-82 seemed like an obvious thing to do, to transfer knowledge to the next Hubble crew. Now the one thing was—and I may have mentioned this before—after we got back from Hubble our management said, "Guys, you did a great job, but this is such a good deal that we have to give other people a chance. So none of you are going to fly on Hubble again."

They asked me to work with the STS-82 crew to go in the water tank with them, go through training with them. I think I was able to pass on a lot of information. I was basically the backup crew. In case one of them got sick, then I would have gone. Backup crews almost never fly, so that didn't happen, but it certainly made sense. I don't know that it was originally planned, but I suggested that it would make sense for me to be a CapCom during the EVAs.

Actually the two CapComs were Chris [A.] Hadfield and Marc Garneau. They were both Canadians, so it was fun because CapComs always write their little notes for the shift handover. In each case their notes were not about all the things that had been done by the EVA crew, but all the great things that the Canada arm had accomplished on the previous shift. It was a standing joke. Obviously the EVA information was passed on as well, but there's a whole EVA crew in

mission control taking note of this. So that was good, it really was a wonderful way to finish up in the office because it got me back with Hubble and with EVA.

In the meantime I had also as a technical job—I was working with the EVA branch on advanced EVA technology, because at the time we knew that we were going to have to be building Space Station and that the EVA requirements were huge. We were going to need new techniques and new tools, and there was an EVA tiger team that was formed basically to develop these. I think there were like a half a dozen flights designated as EVA Space Station test flights. STS-75 was not one of them. We didn't do an EVA on that because of the tethers, and [STS]-82 of course was unique in its way.

Before I had gotten involved deeply with STS-82 I had spent a lot of time and had done more underwater work so I actually ended up getting a lot more EVA experience and basically transferring some of my expertise into developing the tools and techniques which ultimately made the construction of Space Station possible. That was also a nice way to end my astronaut career.

Had I stayed when George Abbey had offered me another flight, it was going to be for some of the early ISS assembly. It turned out that for a couple of years we were actually short of EVA-experienced astronauts. That's why in the end I was delighted that Franklin got to do an EVA on his sixth flight and ended up making a seventh flight. Jerry [L.] Ross got seven flights, too. Had I stayed I probably would have had seven flights as well, because they needed EVA astronauts.

I was also really delighted that Claude, who had made three flights with me but never got to do an EVA, in his fourth flight, on the third Hubble mission, he actually got to do an EVA. In fact that's another nice story. By that time I was over in Europe already, but when it came time

for Claude to make his fourth flight I called him up. I said, "Claude, I have to come over and see the launch." Not only did I see the launch, but I was close enough and I knew all of them, so they invited me to the beach house for their last night celebration. I told Claude, "I don't know about letting you into space without me, Claude." It was emotional. It was wonderful to see him go.

Of course that flight was the shortest Hubble mission, because they actually had to launch earlier than they were planning because the gyros [gyroscopes] had all failed and Hubble was out of commission for a while. That was the one they had to bring home early because of Y2K. That was December of 1999, and they didn't want the Shuttle up there when the whole world shut down. But Claude got to do his EVA, so that was very nice for all of us.

We still see each other. We're still good friends. It actually turns out that Franklin's oldest daughter lives in Boston and is a state senator, and my wife works in her campaign office. It was a unique coincidence that she happens to be the senator for our district. She was in a tough campaign the first time, and almost won but not quite, and then she won her second campaign and she was just reelected. Barbara works for her campaign office once a week, so we still have that indirect contact with Franklin.

ROSS-NAZZAL: Interesting connections. Well, any other last minute thoughts or general thoughts about the Space Shuttle as we're getting to close out the program?

HOFFMAN: Like I said, from a personal point of view, I've been a very lucky astronaut. I've gotten to do a lot of great things and am very grateful for the opportunities. I think I've worked hard and made the best of them. At MIT we have a group which has been working with NASA

Headquarters [Washington, D.C.] on analyzing the various plans for future human spaceflight architectures. It's been very productive and busy, because NASA's plans change every year so we have to go back and redo all the studies. We're really on a cusp of human spaceflight. It could go either way. I like the decision to try to develop commercial human spaceflight. With the Shuttle, we did something unique, and we learned to do something that was never done before. But low Earth orbit is no longer the frontier, at least for the United States, that it once was.

I think that if we really can develop a commercial human spaceflight industry it would be a great thing for the country, because it will be a new part of the economy that really could grow into something very big. I'd like to see a much larger number of people get into space. So I hope that Bob [Robert T.] Bigelow with his private space stations and Elon Musk—as well as Boeing [Company] and Lockheed [Martin] succeed. But it's not exploration anymore. Still, the development of commercial spaceflight would be something new, and that's what I'm interested in seeing in space.

I think it would be great for NASA's human spaceflight, if we really did have a successful commercial human spaceflight sector and NASA could buy rides into low Earth orbit at the marginal cost of operations, instead of having to support the entire infrastructure. Because NASA spends over a third of its budget just on maintaining the infrastructure of low Earth orbit spaceflight. If NASA could buy that service at the marginal cost, then it would be much less expensive, and NASA could use those resources for real exploration, which is what I would like to see NASA doing, not just continuing to run a taxi service back and forth to low Earth orbit.

It was new when we started doing it with the Shuttle, but we know how to do it now. NASA should be on the cutting edge, and what I'd like to see the next generation of astronauts

do is to be able to go places and do things that we couldn't do. People ask me do I regret that I couldn't go to the Moon. Obviously I would have loved to go to the Moon, who wouldn't have? But I got to do some amazing things. I wouldn't like to see people for the next 30 years just going back and forth to the Space Station. You want to see them go to asteroids and the Moon, Mars, and all the other things that we dream about. That's what I hope we'll be seeing over the next half century.

ROSS-NAZZAL: I think we're all hoping for a robust space economy, especially here in Houston. Well, thank you very much for your time. We appreciate it.

HOFFMAN: It's been fun.

[End of interview]