NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY JENNIFER ROSS-NAZZAL
HOUSTON, TEXAS – 12 NOVEMBER 2009

ROSS-NAZZAL: Today is November 12th, 2009. This oral history with Dr. Jeff Hoffman is being conducted for the JSC Oral History Project in Houston, Texas. The interviewer is Jennifer Ross-Nazzal, assisted by Rebecca Wright. Thanks again for making time for us this afternoon. We appreciate it as always. I thought we'd continue talking about STS-61. One of the things we hadn't talked about was all the negative limelight that NASA was receiving because the Hubble Space Telescope's mirror hadn't been ground properly. Did you have any sense, you and the crew, that boy, we really need to succeed?

HOFFMAN: It's hard now almost 20 years after the launch of Hubble, over 15 years after our repair mission, and Hubble has done such incredible things, that if you didn't actually live through it, it's hard to remember what a disaster it was for those first few years after Hubble was put in orbit in the spring of 1990. It was over the course of that summer that the spherical aberration was discovered.

Hubble was the butt of jokes on late-night talk shows. It was denounced in the US Congress. There were cartoons of the great disasters of history. Right next to the Hindenburg was Hubble. Yes, it was a disaster. NASA's reputation was really on the line. It was a disaster for NASA; it was a disaster for the astronomy community. So many people had worked on Hubble, and so many other people were planning to use Hubble. It's really hard to know what would have happened had we not been able to fix Hubble.

When we were training at Goddard [Space Flight Center, Greenbelt, Maryland] during one of our sessions we were invited to come down to NASA Headquarters [Washington, DC] to meet with Dan [Daniel S.] Goldin, the administrator at the time. He told us quite frankly that NASA's future was in our hands. That was at the time when we were waiting for Congress to approve the construction of the Space Station. It had narrowly, I guess, escaped getting canceled by one vote the previous year. It was by no means certain that things would ever go ahead. Particularly, everybody recognized that assembling the Space Station was going to take a lot of EVA [Extravehicular Activity], and sophisticated EVAs at that, of the sort that we were getting ready to do for Hubble. So if we went up thinking that we could fix Hubble and then it turned out that we couldn't, how could people trust NASA to build a Space Station? That was the attitude.

Like I say, what would have happened had we not been successful? I'm glad I don't have to answer the question. It was clear that it was critical, and that's why I think working on Hubble was in a sense so unique. I talked about how everybody at NASA was pulling in the same direction. Intercenter rivalries? Forget it. Whatever we can do to make Hubble a success we'll do it. That's also why we had so many of these investigative committees; everybody was sending committees to make sure that NASA was doing the right thing. They insulated us from that. I think I talked about that the last time. Randy [H.] Brinkley was made—I think they called him mission manager, I don't remember exactly. But we did, when we needed to, talk to the committees. I think I mentioned how we got the tools moved inside.

Like I said, people went to bat for Hubble in a way that was really unique. It was just if anyone could think of something that could be done to make the probability of success higher, we'd do it. That doesn't usually happen in a lot of missions, just because of constraints of time and money, but for Hubble they pulled out all the stops. Of course, people were concerned. NASA always likes to have 100% success. We had a very ambitious mission. There were a dozen different things that we had to fix; it wasn't just the optics. The solar arrays had to be replaced, tape recorders, electronics units, fuses, gyroscopes.

So this was the other question, "Maybe there's just too much." Some of these things were going to be too difficult. We weren't going to be able to get them done. We would run over time. Maybe they should split the mission in two, and we should just attempt half of it that way we would have a better chance of getting everything done. We pointed out that we didn't think that was a good idea. Obviously from a personal point of view we wouldn't like to see the mission cut in half, but from a technical point of view, if you removed half the tasks from a mission, how do you know that you've not left the ones that we're going to fail at? At least if you have more things for us to do, we have a better chance of at least getting some of them done. That's the way we looked at it. In the end, that idea prevailed. It really didn't make sense to cut the mission.

We thought we had enough time, if things worked. We had enough time to accomplish everything. Of course in fact [we] did. I guess we'll talk about the details of the mission in more detail later. We knew how important it was, but I have to say it didn't make us work any harder. Any mission you train for, you train to your limit. Nobody wants to mess up in their mission. So we had more resources and more people pulling for us and things that we could get done, but did we work any harder because of that? We couldn't have, because we were working to the max, but I had worked to the max in my earlier three missions. I think everybody else had as well.

ROSS-NAZZAL: In Story [Musgrave]'s book there was a quote. He wrote, "At times during the preparation the only peace I could find was in the dental chair." I thought that was an interesting quote. What are your thoughts about that?

HOFFMAN: Well, it was nonstop, there's no question, the training. I was able pretty well throughout my astronaut career to leave my work at work when I went home at night. So I don't think—and my family I think would back me up on this—that I was under any particular stress. Obviously we did have to spend long periods of time away from home when we were training at Marshall [Space Flight Center, Huntsville, Alabama] or up at Goddard.

That's just part of the job, but I didn't feel under a high stress, but that's just my personality. I work hard, and then I go home at night and leave it. Maybe Story is a little different. That's different personalities.

ROSS-NAZZAL: What was the publicity like for the mission? Was it different from the other flights you'd flown?

HOFFMAN: There was tremendous interest of course both in the popular press and also among the astronomical community. I remember I wrote an article for *Sky & Telescope* magazine, specifically how we were going to fix Hubble, and I described in detail everything that we were going to do in the mission. The plan was I was then going to write another article for *Sky & Telescope* showing what we actually did after the mission was over. Because the mission was so successful, and everything worked I just wrote a paragraph saying, "We were planning to write an article, but just read the article that I wrote about what we were planning to do, and that's what we did."

There was a lot of publicity in the popular press. We had the normal number of interviews. They protect the crews from that pretty well. TV shows covering what we were going to do.

ROSS-NAZZAL: Any *48 Hours* specials or anything like that covering your mission?

HOFFMAN: I'm trying to remember, I don't think we had. I know the BBC [British Broadcasting Corporation] did a really nice program on our mission, but I think it was all using NASA footage. I don't have any recollection of being followed around by a non-NASA camera crew. I may be wrong but I don't specifically remember. I know Discovery [Channel] followed this recent crew [STS-125] around, and they're doing a big thing. I guess *NOVA* showed that about a month or so ago.

ROSS-NAZZAL: Tell us about the crew relationship.

HOFFMAN: Well, Story had gotten appointed first as the payload commander. Of course many people had worked on Hubble. I think I talked last time about how probably everybody in the office would have liked to have been on the mission because it was such an important mission. Story had been working on EVA for a long time; he was very accomplished. I know that Bruce McCandless and Kathy [Kathryn D.] Sullivan had been working with Lockheed on plans for the repair mission. Bruce certainly played a very important part early on because when they were developing some of the initial ideas they needed somebody from the Astronaut Office, and Bruce had been working with the telescope since probably back in the ’80s I guess, maybe even earlier. So he played a very important role, but he was not on the mission.

During that summer I guess Tom [Thomas D.] Akers was asked to work with Story in the water tank, so we thought maybe that meant that Tom had a good chance of getting on it. When we all finally got appointed, I remember at one point Kathy [Kathryn C.] Thornton said, “Well, you know, guys, everybody else is going to hate us now.” They didn’t, but it was just the way of acknowledging that we had really gotten a plum of a mission. Our relationship was very good. I’ve been very fortunate in my crews; we never had any major personality conflicts. I respected the other people.

Story has a very strong personality. I found I could work with him very well, in fact we were spacewalking partners. Dick [Richard O.] Covey was an experienced commander and everybody respected him. I was never in the military so I don’t have this ingrained respect for command the way it’s drilled into you in the military. Fortunately, I’ve never been in a situation where I had to work for a commander whom I didn’t respect, and who was telling me to do things that I didn’t think I should be doing. That’s happened. I’ve heard stories like that. It’s rare; it’s rare, but it does happen. There have also been situations in which people on crews just didn’t like each other or were very difficult, had poor relationships.

We spent a lot of time together, particularly the four spacewalking crew, so we got to know one another pretty well. We knew one another’s families, everybody got along well. Among the spacewalkers I wouldn’t say we’re super close friends over the years, but we all liked one another. We got along fine. Tom and Kathy had flown together on a previous flight. I was very close with Claude Nicollier, I think I mentioned he and I had already made one flight together, and we ended up making a third flight after Hubble. He and I still are close friends. Covey I knew pretty well because we had worked together on the STS-2 chase team. He and I were in the same plane, so we had spent a lot of time together. I knew him pretty well. Ken [Kenneth D.] Bowersox is a nice guy, easy to get along with. As I say it was a pretty compatible crew and everyone got along.

We were all interested in making sure that everything worked. In terms of spacewalking, there are times when physical strength can be important. Kathy recognized she wasn't as strong as the men, but she went to the gym and worked out just like the rest of us. You figure she might not be as strong ultimately, but nevertheless each one of us needed to be as well prepared as we could possibly be. She went out with Tom, so if there ever was going to be something that needed a particular amount of strength, Tom could do it. In general Hubble tasks were very well designed and didn't require a lot of physical strength. They required a lot of technical coordination, being very careful in how you moved things around, and not messing anything up, but raw physical strength wasn't really required.

You never can tell. Like on the most recent Hubble mission when—I forget which one of them it was—but they had to actually rip off a handrail in order to get access to the bolts. Physically just move it back and forth and rip it off. That required a certain physical strength, so you never know. That's why we were training, because we wanted to be as well prepared as we possibly could be.

We spent a lot of time together. I think I talked last time about our trips to Marshall, going to the gym after work, and hanging out in the hot tub. We spent a lot of time together. It was pleasant time; I thoroughly enjoyed.

ROSS-NAZZAL: Dick Covey had told us, and you had told us the story last time about Story getting frostbite, but he had mentioned that Story almost got kicked off the flight, and there was an actual backup crew member appointed, Greg [Gregory J.] Harbaugh, for a while.

HOFFMAN: Right. Greg was tailing us, because given a mission like that—if somebody did have to drop out you would like to be able to replace them. I'm trying to think back. I don't think he made a lot of water tank runs with us, at least not that I remember, but of course that did give him an edge in his familiarity with Hubble. He did fly on the second servicing mission.

ROSS-NAZZAL: Was there ever any concern that Story would remain on the crew?

HOFFMAN: Yes. When we saw his fingers, they were terrible, they were black and purple. It looked horrible. When he went off to Alaska to see the frostbite specialist, we didn't know what was going to happen. Well, whatever it would have taken, we would have done the mission. I assume we still would have been successful, but Story had played a big role. We were all pulling for him and hoping that he would be cured and could come back to the crew, which fortunately he was.

ROSS-NAZZAL: Now last time you had told us that you had planned to launch on December 1st but that things didn't go well.

HOFFMAN: There was too much wind. It was crosswind. We were sitting in the Shuttle, and we could feel it rocking back and forth as the wind blew. We finally ran out of time. As I said, my second flight had been on December 2nd, so I thought December 2nd was a good time to launch anyway. That day it was a very nice evening, and the winds had died down. It was actually 4:00 in the morning. You're going up to do a rendezvous, so you have to launch right when the orbit of Hubble passes overhead. One of my brothers, who was at the launch, told me that actually about a half an hour before our launch they saw Hubble fly overhead, which is what it's supposed to do, but he said that made everybody think NASA must know what they're doing.

A night launch is very spectacular. Any launch is pretty spectacular, but visually a night launch is something special, both for the spectators but also when you're inside. When the boosters separate and the separation motors are firing right at you it's really pretty spectacular. You can see the light out the top of the windows; so it was a fine launch.

Right away we got busy; there was no time to rest. The flight deck crew had to go catch Hubble. That was another thing, normally when you're training, four people ride up on the flight deck. Very often the MS1 [Mission Specialist 1] position, which is to the right rear; the flight engineer is behind and between, that's MS2, behind and between the pilot and commander. MS1 is off to the right. Normally MS1 will train for ascent and entries with the other three. Unless you run into very major problems during ascent and entry, you don't really need the fourth person, but he's there just as a backup to read checklists. If you're in the simulators it's very nice, because in one ascent they might hit you with 20 different problems. And so there's plenty to keep four people busy, but hopefully during the real flight that doesn't happen.

We decided that because of the criticality of the EVA and the amount of time it was going to take us to train for it that the flight deck crew was just going to be the three: Dick Covey, Ken Bowersox, and Claude Nicollier. They would train for the ascent and entry, and we didn't go through that training. That gave us more time for our EVA training.

The other thing, we were able to eliminate some of the training that you need to go through when you have first-time fliers. We spend a lot of time rehearsing flight day one, for instance, just because it's the first day you're in space. A lot of people are disoriented. Some people are not feeling good. It's such a new environment that it just is a really good thing to have gone through all the activities you're planning to do over and over again. We usually have three or four run-throughs of that first day: getting out of your suits, reconfiguring the Orbiter, getting things ready for orbital operations. Just so that when you get up into space if you're not feeling good, if you are disoriented, you can fall back on your training and just look at the procedures and, "Oh yes I know what I'm doing." You don't really have to think about it too much. That can make a big difference, but we didn't have to do that because we all knew what we were doing. Again the fact that we were all veterans allowed us to really concentrate on Hubble.

Also, all of us knew the difference between the water tank and real spacewalking. The water tank is very close in many respects but it's not identical. Some people have had difficulty, because they've gotten used to doing things a certain way in the water tank. Then you get into space and find well the water was providing a certain stability for me. All of a sudden you get up into space, and you're flopping all over the place. Again that was one of the reasons for having a veteran crew, which we don't do anymore. We understand Hubble now, and so we have new people on each of the subsequent Hubble flights, but again the first mission was something so critical that that was just one of many things that was done.

We got up into space and basically everything was going well. Now for me it was the first time that I would ever have done multiple EVAs. Tom and Kathy had been on a multiple-EVA flight before on the INTELSAT repair mission, I forget what the mission number was. We spent a lot of time working on those procedures. It turns out to be rather complicated and time-consuming because you don't just get your spacesuits out, use them, and then put them away. After each EVA, you have to clean them; you have to change out the lithium hydroxide carbon dioxide scrubbers. You have to make sure that the batteries are charged, which means that some batteries are being charged and other batteries have to get put in the suits. You have to keep a record of everything.

I was surprised at how much time it took just managing all of the reconfiguration of the spacesuits. Of course we didn't find that out until after the first EVA. The first couple of days, we're getting all of our equipment ready, sorting out our tools, doing the initial checks of the spacesuits, basically getting all our tools set up, and at the same time conducting the rendezvous and proximity operations to Hubble.

I'll tell you, it's an exciting process when you're doing a rendezvous, and you first pick up the object as a tiny point of light out in the distance, and then it gets gradually brighter. I would always have the powerful binoculars out wanting to get as good a view as possible. When it got close enough that I could actually make out some details in the binoculars and could see it's not just a point of light, it's an actual object, it's a building sense of excitement as it gets closer and closer, or we get closer and closer to it, because we're changing our orbit to catch it, not the other way around.

As it got close enough that I could get a good view of the solar panels, I could tell that one of the solar panels looked a bit odd. It was bent over. We knew that the solar panels had been having trouble. Every time they went from night to day or day to night there was a thermal stress, and they would start to vibrate. As it turned out, that thermal stress had actually broken one of the stiffening rods, so the solar array was bent over.

I reported that to the ground. Again it didn't really surprise a lot of people. We had anticipated problems with the solar arrays before we ever went up, and we had actually developed a procedure for throwing away a solar panel if we had to. The idea was to fold them up or roll them up and bring them back home, because we'd like to be able to examine them and see what they were like after three years in space, but if we couldn't get them rolled up we would just leave them in orbit. They're big enough that they're not going to be a hazard to navigation, because you can track them on radar. So that wasn't a problem. It's one thing to talk about it. It's another thing when you actually look, and you see the solar array all folded over and realize that hey, this doesn't look real good.

Other than that it's a beautiful instrument. That was one of the other things that we all agreed, was Hubble is just beautiful, because it's covered with reflective silver, or I guess aluminized Mylar probably, but it's a silver color. It reflects everything that it's flying over, so it could be reflecting the black of space, or the blue of the ocean, or the variety of colors from deserts, brown and red and yellow, or the dark greenish brown of the jungles. It was constantly changing and beautiful to look at.

It also was very very bright, reflective, when the Sun would be in the field of view. When you look at pictures from our flight film, a lot of times the crew inside the Shuttle is wearing sunglasses. Some people said, "You guys just trying to be cool or what?" In fact it was very bright looking at Hubble all the time, and particularly [for] the arm operators. Claude wore sunglasses most of the time during the day just because of the glare from the telescope.

The final phase of the rendezvous Covey flew manually. He tried to eliminate all the relative motion between the two spacecraft so that it appears to be floating motionless above us, which is really kind of a magical thing. You look at this big telescope out there, and it's just floating motionless above the payload bay, and yet we're both moving at 18,000 miles an hour, five miles a second. I'm a physicist; I understand it intellectually, but it still is pretty awesome when you see it.

Then you reach out. Claude got the arm and reached out, grabbed it. That's when Covey radioed down, "We have a handshake with Mr. Hubble's telescope." Everybody cheered. The first phase of the mission had gone successfully. Lower the telescope down into the cargo bay and latch it so that you can release the arm.

That's when things really start to speed up, because it gets real serious now. We've got the telescope; now we got to go fix it, so that night Story and I got our spacesuits ready. All four of us worked together on this, because when you get a spacesuit ready you try to be each other's personal valet because there's just a lot of work to be done. When you're doing a spacewalk it really takes over the entire Shuttle. You look at pictures of the middeck of the Shuttle when we were getting ready for the EVA, and it's just totally crammed with EVA equipment. You can't really be doing anything else while the EVAs are planned.

One of the nice things, again because of the criticality of this mission, usually on most Shuttle missions they would have secondary payloads, little middeck experiments, medical experiments that they were asking us to do. We had nothing. It was great—no medical experiments. Not that I mind doing them; I've done plenty of scientific experiments on flights, but the point was that we didn't want to get our minds diverted from the major business of Hubble, so nothing else on the flight, period. Normally that would have been a very hard sell to the science and medical community, but everybody accepted it. "Oh yes, it's Hubble, so hands off."

You get up the morning of the spacewalk, get up early. Oh, I should say Covey was a very strict mom and made us all go to bed on time. Usually I like to float, look out the window, watch the Earth go by. They program eight hours of sleep into the flight plan. I don't sleep eight hours on the ground, much less in space, so I would usually spend a couple of hours looking out the window, but Covey said, "No, got to have a well rested crew. When it's lights out, the shades are going over the windows, and the lights are going out. You're going in your sleeping bags, and I can't make you go to sleep, but you're not doing anything else." We did. Actually, particularly once we started doing the spacewalks we slept fine. Pretty crowded, you've probably heard that from lots of Shuttle crews. When you have everybody on the same shift, and basically five of us were sleeping down on the middeck.

I've never been on a flight where anybody snored, which is nice. Could get a little bit close. Story camped out in the airlock. I was floating in one place, Kathy and Tom were against the wall. I like to sleep just floating free in the middle of the middeck. The majority of people seem to like to strap themselves to the wall just to give a sense of security. There's enough room, because you can be on the wall or the ceiling or whatever, but nevertheless it's pretty crowded.

Get up in the morning, I try to eat a particularly big breakfast, because I know I'm not going to get any food for the next eight hours or so. Then you just start getting ready. All the things you have to do to get ready for a spacewalk, starting with the heart monitors and radiation monitors you have to put on your skin, then your long underwear, and then the liquid cooling garment. You have to put the anti-fog on your space helmet and check the batteries and check your lights. There's just a whole lot of things that have to be done.

ROSS-NAZZAL: How long does that normally take?

HOFFMAN: The whole process is a little over two hours, because then when you've got all the preliminaries done then you get into the spacesuit pants, the lower torso assembly. In space, of course, you can get in your pants two legs at a time; you just float into them. That part of it is pretty easy, but then you have to float into the airlock and squeeze yourself up into the hard upper torso. That you can pretty much do by yourself, but [not] pulling the pants up and actually attaching them. The spacesuits were originally designed, as a design goal at least, so that you could put it on by yourself, but you really can't. One of the hardest parts is clipping the waist ring together. Since we always had extra people, somebody would be there to help us or sometimes the two of them.

Of course, all of us knew how the spacesuit worked. On other flights where you only have two spacewalkers, then a third person has to be trained in how to assist with spacesuits even if they're not going to use the spacesuits. We didn't have to do that because everybody knew how the spacesuits worked.

Then once you're in the spacesuit, you're still hanging on the wall. We've got all our tools arranged on our chest-mounted tool carriers. Then you have to flow oxygen into your suit, purge all the nitrogen out, and then breathe pure oxygen for 40 minutes to denitrogenate your blood so that you don't get the bends, because we're going to depressurize our suits from the ten pounds per square inch, about two thirds of an atmosphere, down to about three tenths of an atmosphere, or 4.3 pounds per square inch. If you don't denitrogenate your blood in advance of that you'll get the bends, so you just hang out [and breathe pure oxygen].

Most of that time we're doing communications checks and just talking about various parts of the procedure, so you don't end up losing a full 40 minutes. We try to make as efficient possible use of the time. We've let the air out of the airlock, and it's time to actually open the hatch and go out. There's still that sense of anticipation. Is it going to work right? Did we prepare properly? What's going to go wrong? We were fully expecting things to happen that we didn't expect. Would we be able to solve the problem? Were we actually going to get this done?

It's an exciting moment when you open the hatch. I was the first one out because of the way we were organizing our tools. I was going to ride on the arm, so Claude brought the arm right down to the airlock, because again we were looking for ways to save time. We had a bunch of tools on our chests but also a lot of tools on this long—we call it a fish stringer. This sort of thing where you hang lots of fish on when you catch them, so we had hooks on them with lots of tools. I could clip that right onto the arm so that they'd be there when I mounted the astronaut carrying unit that the arm then went to pick up.

So there we were; we were starting outside. The first part of the first spacewalk there's a lot of housekeeping things to do. You've got to hook up the astronaut carrying unit, which has the foot restraint, which the arm picks up. That also has a tool carrying unit, so it's a very nice unit which makes you a lot more efficient. We have to go over and put a cover over the low-gain antenna to protect it since we're going to be moving around the bottom of the telescope and several other things. You have to get your tethers hooked up properly, so you spend the first part of the first hour getting all these things done.

Then we actually went to work on the gyroscopes, replacing the gyroscopes, about half of which had failed. I think I described last time how we had developed this new procedure where I would position Story actually underneath the gyroscope inside, so this was basically not the final exam, which we had done in the water tank. This was now out in the real world, to see if what we had developed was really going to work. Sure enough, it worked, it was great. It's just a good feeling when you've done something and rehearsed it, particularly where we developed the procedure ourselves in that case, and it actually worked. I don't remember how long it took us, but we were right on the timeline.

Then our motto was, "Do useful work." The idea was that since our limiting factor was EVA crew time outside working on the telescope, we didn't want to waste any of that time. I was left there to close the doors, but Story went off to do some other work, so I was standing on the arm basically. The doors in the telescope gyro compartment are the biggest doors in the whole telescope. In fact they're asymmetrical; one of the doors is bigger than the other. We had opened and closed those doors, I don't know, 100 times in the water. We knew how they worked. There were several latches but there was one big handle. You turned the handle, and that basically closed the latches. Then you just had to throw a couple of bolts and tighten up the bolts, and then the door is secured.

So I closed the door, I turned the latch, and I went up to the top to throw the bolt. I saw that the top of the door in fact had not closed properly. One of the sides was closed, but the other side was sticking out. I looked at that, and I thought hmm, they never told us about this on the ground that we might have a problem. I wonder if the door is warped because of thermal issues. There's various things that can cause structural warping. Unequal heating is one of them. The other is just taking something that's been built on the ground in one G and put it up in space and you remove the pull of gravity and things shift around because you've changed the force structure.

So I thought well, all right, maybe I didn't push on it hard enough, so I went down. I opened the latch, I closed the doors, I pushed, I closed it, I went up to the top. It still was not in the right position. Then I wasn't quite sensing that we had a major problem, yet. I thought about it a little bit more. I sort of wiggled on the door a little bit, and I saw it was pivoting around the center latch. Then I went down to the bottom and I saw oh, the bottom was closed properly. No problem, so what I'll do is instead of trying to close the door with the center latch I'll close the top of the door first, and then I'll hold it in.

Since I was standing in the arm I could exert a little bit of force at least with both of my hands, because I could exert the force against the manipulator arm. So I went down and I closed the top first and got that closed properly. I thought oh, we're fine now, then I went down to the bottom and the bottom was open. "Oh." Now I realized we've got a real problem; the door is warped and it's not going to close properly. Of course if the door doesn't close properly, we lose the telescope for both thermal control reasons and light leaking in.

I was wondering when we were going to have our first major foul-up, and here it is, and it's just in the first day. This is not setting a very good precedent for the rest of the mission. Anyway, I played with the door a bit more until I really understood what was happening. I realized that there's no way I could close the door myself, because we had a chance maybe if we could push both on the top and the bottom of the door at the same time. The door was about, I don't know, six feet, maybe eight feet, tall. I don't remember exactly, but too much for me to be able to get both the top and the bottom at the same time.

So I called Story over to help. I said, "Story, I'll take the top and I'll push on the top and close that. You push on the bottom, and that'll work fine." When I pushed on the door, I could get my part of it closed. While I was holding it closed with one hand, in order to stop it from opening again, I had to then take the bolt and throw the bolt into the proper position, which I did with my other hand.

What we found though, was Story was floating free. Nowadays when they do this, knowing what the problem is, they mount a foot restraint there, but we didn't have a foot restraint. It wasn't positioned, so Story was free-floating. The only way he could exert a force to push the door in was to push with one hand but with the other hand he had to be holding on to the telescope itself so he could pull on it and exert a force. Otherwise you push with one hand, you just go floating away.

Then he could use his third hand to throw the bolt, only he didn't have a third hand. It was basically a five-handed job, and we only had four hands. We tried a few times. I think he tried pushing with his head once. It just didn't work, so now we were getting more concerned and we reported the problem to the ground, and they started thinking about what we might do.

It's an interesting problem when you start thinking about robotic operations, because it really gets into situational awareness and a real appreciation of what the problem was, because we described it as well as we could. We took pictures of it; we sent them down. The ground had several suggestions of what we might do, including something they talked about, working up the zipper type, where we would start at the bottom and slowly work our way up. I kind of knew from having experimented with the door that I didn't think any of that was going to work. We thought one of their suggestions might even hurt the door, but we were very careful.

In the meantime, we were thinking of what we wanted to do. We came up with the idea of using—it's called the payload restraint device, which is a kind of a webbing tool with a ratchet. It's the sort of thing that moving men use when they want to strap down furniture. You put the webbing over something and then you ratchet it down. The reason we fly it, it's a contingency tool, which if we have a payload in the Shuttle's payload bay that we're going to bring back to Earth, and for some reason the latches don't close properly, in order to make it safe for landing we'll put this big strap over it, and then we'll ratchet it tight.

That ratchet can put something like 2,000 pounds if I remember right, so it's a pretty husky device. Well, our idea was that we were going to use it to help close the door by wrapping around a couple of knobs. Instead of Story actually pushing on the door—well, he could hold on to the door with one hand and move the ratchet with the other hand. That would gradually bring the door shut, but then it would stay shut so that he could then remove his hand from the ratchet and flip the bolt when the door was finally in place.

Well, we told the ground what our plan was. A lot of people in the Hubble organization were concerned that we were going to break the telescope by putting too much force on it with this payload restraint device, so they asked us to try some other things, which we tried. They didn't work. We said, "No, we'd like to do it this way, because we think this will work."

I don't want to suggest that we actually got into a shouting contest, but there was some pretty spirited discussion that went on. Finally Milt [J. Milton] Heflin, the lead flight director, made the call. He said, "Well, you guys." Well, actually he was talking to the team on the ground. He said, "We sent these guys up into space, we trained them, they know what they're doing. In the end we got to trust them." So we got a go-ahead to use our technique, and it did work. We got the door closed.

ROSS-NAZZAL: How much time had you spent from the start of trying to close it till—

HOFFMAN: Well, it was the best part of an hour, maybe even a little more than an hour. When I think back to, for instance, had we had to go back to the tool chest and get all those tools out, it would have taken another half hour. All the things we had done with the gyroscope procedure itself. The original technique which had been presented to us would have taken another hour. We never would have gotten the job done, because what they told me after I came inside, we were out a little over eight hours total for the EVA. My battery was starting to fall off at that point, so I was going to have to come inside pretty soon no matter what. In the end, it did work. Of course now they have a door-closing simulator trainer at JSC and special techniques for doing it. Nobody will have that problem again. They didn't in fact, because they were prepared for it.

So that had put us behind the timeline. You get back. There's a lot of work to do cleaning up your suits. One of the things we did—the EVA team that was going to go out the next day basically took our suits. They helped get us out, and then they did the preparation for the next day so that we could go and wash up and have a nice dinner. Then we would get together and talk about it. Also after every EVA we had a conference with our flight surgeon. It's not normal to do this every day but we did, because they wanted to find out, again for risk reduction, what sort of condition were we in, were we feeling exhausted. In particular if there was a problem with equipment for the other team, were we capable of going out the very next day? Because normally you don't do EVAs two days in a row, the same people. That's why we had two teams.

I have to say after each of the EVAs I always felt like I could have gone out the next day. They were not physically exhausting, because they were so well designed. You weren't out there fighting equipment all the time. There was a lot of complex things that you had to do. Some of it was difficult and delicate, but I never felt physically exhausted. Although I will say I slept pretty well that night. We got to bed a little bit late as I remember. We were concerned that if every EVA took that long we were going to be falling further and further behind. That was not a good thing to contemplate.

The other thing that happened the first day is after our EVA was over, then it was time to roll up the solar arrays in preparation for removing them and replacing them. As we had feared, the solar panel that was all bent in fact did not roll up properly. The other one rolled up fine, so one of them was no problem, but [with] the other one we knew we were going to have to put our contingency plan into effect. Tom and Kathy would have to dump it. As I said we had prepared a plan for that. Kathy took out a handhold, which she attached to the solar array. She was standing on the arm. Tom released the electrical and mechanical connections, then Claude moved the arm and Kathy and the solar array as far away from the Shuttle as possible.

It's a good example. Again in many cases, I look at the way we work as a demonstration of humans and robotic systems working together. We had actually done some thinking on a fairly preliminary level and had even tried out one or two procedures in the water tank. Suppose the arm broke. The arm has a lot of redundancy built in; you'd have to have multiple failures before it would be completely out of commission, but nevertheless, if it did, could we do the mission? I think we convinced ourselves that we could have at least gotten some of it accomplished. Whether we would have been able to get it all accomplished—because it would have taken a lot longer—I don't know. Luckily it was something we had prepared but we never had to use it because the arm worked just fine.

The arm was very good when you had to move large objects around. That's what would have been really difficult, if you didn't have the manipulator properly functioning. For doing fine positioning, your hands work much better, so it's a combination. Use the arm for the gross positioning and then your body and finally your hands for the fine movement.

So that's what happened. Claude moved Kathy as far away from the Shuttle as he could get her using the arm, then at the right time—I think it was at sunrise—the ground gave the go-ahead to release it. She released it. Then we had to fire our maneuvering jets to get away from it, because Hubble doesn't have any propulsion. The solar panel was just inert. That was really spectacular, because when the exhaust plume from the reaction control jets hit this solar array—this was a big wing, they're very very large and fairly light material—and it started to oscillate up and down, it looked like the wings of a giant prehistoric bird just flapping out in space. Then it started turning somersaults.

I have to say we were all pretty mesmerized. We were just looking at it as it slowly turned somersaults and disappeared into the distance, then we heard a voice come over the radio. It was Tom who had been hanging out in the payload bay. He said, "Isn't somebody supposed to be reading me the procedures? We have work to do."

Spell broken and we went back to work. They then installed the new solar array to replace the one that they had dumped overboard, and then they removed the other one. Basically everything went well. They also put in some new computer memory. That EVA was fairly short. It was just a little over six hours, if I remember right. That was really good, because that allowed us to catch up. It was relatively early compared to the way things had been the other night, so we could all have a nice dinner and hang out together and catch up, get a good night's sleep. We had agreed that had their EVA been as long as our EVA we would just be falling further behind. We weren't sure that that was sustainable for the whole mission, but it worked out, so luckily the second EVA was nice and short.

I measured myself, my height. On previous missions I had done that and found that when I get into space, I grow two inches. This is a common phenomenon; in fact they have to allow for that when they do the final sizing of the spacesuits because your body, your spine mostly, expands in weightlessness, so they usually add about an inch to the length of your spacesuit. That was fine for me, even though I grew by two inches. I like a nice tight spacesuit, where my shoulders and the bottom of my feet are basically compressed a little bit, because that way I don't float around inside the suit and I have good control over it.

What I found when I measured myself before and after each EVA, at the end of the EVA I had shrunk about three quarters of an inch because of that compression. Then of course it would come back in the next couple of hours. It's a little bit like being a spring. Your spine is a spring that's getting compressed and expanding and compressed and expanding. Luckily no physical discomfort. Some people have lower back problems. On two of my flights I did have mild lower back pain, but on this one I didn't, so I never did figure out why I had some discomfort on some of my flights but not all of them.

ROSS-NAZZAL: Did you have any fingertip or hand issues? Some of the astronauts complain about that.

HOFFMAN: No. I know people do, yes. No, I've always been very fussy about my gloves. I give the people who are fitting them a hard time, but it's worth it. Gloves are really really important. There was an interesting fingertip issue. They give us a water bag so that we can sip on the water. Oh, this was another thing I remember now when we were preparing our spacesuits. One of the things that they did for us, because again it was Hubble, and they wanted to be sure. We said, "Some of these EVAs may be pretty long, and it may be that we'll drink all the water in our drink bag. It'd be nice if we had slightly larger drink bags." So they specially designed and manufactured drink bags that were about half again as big as the regular ones so that we would just have that much more margin for our spacewalks.

We got into orbit. On the first day, when we were getting all of our spacesuit gear ready and inventorying it, we looked all over for these big drink bags. We couldn't find them anywhere, so I called down and said, "Sorry to bother you, but we just can't find the big drink bags. Can you tell us where they are?" About an hour later we got the call.

Said, "Well, Jeff, the good news is we've located the drink bags. The bad news is they're in Houston." So they had never been shipped.

ROSS-NAZZAL: It didn't even make it to the Cape [Canaveral, Florida].

HOFFMAN: Right. They never made it to the Cape. We made do with the small drink bags. It was okay, but they also give you a little candy bar food stick, which you have to sort of pull it up with your teeth and bite it off and leave enough so you can pull it up the next time, because it sits there in the sleeve. I find for me that after usually about the first five minutes or so my chin manages to hit it and push it back into the sleeve, so I can never get access to it. I don't get very much use out of it, but we fly it. I guess Kathy must have flown it too.

I was her valet when she was getting out of her spacesuit after the second day of EVA, her first EVA. When I pulled off her first glove, her fingertips were bright red. The first thing I thought was, "Oh my God, that's blood," because I knew that some people had problems with their glove. "Oh my God, Kathy, what's happened to your hand? Are you going to be able to do another EVA?" Well, it turned out that a piece of this food bar, which is red, she had bit it off, but some of it, a little piece, had floated away, and apparently had made its way all the way down her arm and had gotten into her fingertips and had gotten all mushed around and had colored them bright red, so that's what we were seeing. Not nearly as serious as it looked, but I got quite a shock when I pulled her glove off.

We've now done two spacewalks. The third spacewalk was particularly important because that was when we were putting in the Wide Field Planetary Camera, the second version of that, the WFPC 2, which was going to be the first piece of the corrective optics that was going in, so there were two major parts of the corrective optics. One was the WFPC 2, and there the corrective optics were built into the instrument itself, so what we really had to do was just remove the old instrument and replace it with the new instrument.

The second was the COSTAR, the Corrective Optics Space Telescope Axial Replacement, which basically had corrective optics built in for the three other axial instruments. That would be installed on day four by Tom and Kathy. Those were the two really critical things. If you remember my story from last time, both of them had failed to go in the first time when we practiced it at Goddard. As far as we knew we had solved the problems, although we still didn't know about that bolt in the COSTAR, but we had the hacksaws and the pliers and everything, whatever it was going to take we were going to do.

We had worked for a long time to figure out how to put in the WFPC. I should say that actually shortly before the mission I got a call from a good friend of mine at the Space Telescope Science Institute. Like many of my other astronomy friends, the first thing he said was "Jeff, can you guys really do this? Isn't it too hard?"

I said, "Well, we hope we can do it all."

He said, "Well, don't tell anybody I said this, but if you guys can just get in one of those, either the WFPC or the COSTAR, we'll be deliriously happy down here. Don't feel that you will have failed, if it didn't all work."

Again that was just an indication of the way other people were looking at the mission, but now it was time to put WFPC in. It's a very delicate process; at least we hoped it would be delicate. We wouldn't have to push very hard. WFPC 1 actually came out very easily, we undid the connectors and then undid the bolt. WFPC slid out very nicely, then we pushed it back in just to see what that felt like. Story had done a lot of work on [positioning] his foot restraint. I was riding on the arm again that day, but Story was going to have to fix himself at one particular location so that he could grab WFPC with one hand and then as it went in, transfer to the other hand. He's a perfectionist. He talks about how it's like doing ballet and you have to get it just right.

So we got all set up. I had to take the WFPC 1 after we got it out, move it over. Again the bulk motion is done by Claude moving the arm, and then he'd drop me. There's a temporary restraining bracket which we had to set up actually on the side of the Shuttle. It's a complex procedure. I won't go through the whole thing, but you have to set that up. There's no handhold on the WFPC itself. There's just a couple of bolt holes, so we fly the handhold, and you have to actually attach the handhold before you can do any of the rest of the process, but that's just the way it all works.

So we did that, and I got the WFPC 1 hanging over the side, then we opened up—I guess they call it the Orbital Replacement Unit [Carrier] or the ORUC. There's all sorts of acronyms. There were a bunch of boxes. The reason you have to have all of this equipment in boxes is for thermal control, because you can't let them get too cold or too hot, so we have to open up the box.

Of course they're all bolted in so they don't rattle around too much in launch, so it's a complex procedure. It's just like taking the instrument out of the telescope. You have to open it up, undo the latches, take off the grounding straps, and then I pulled it up to get it free of the box. The WFPC is a radial instrument; it goes in sideways. All of the instruments have little mirrors which intercept the main beam from the telescope. That's called a pickoff mirror. Those mirrors are very delicate, and their alignment is critical. The mirror was actually protected on the WFPC replacement unit by a protective cover which was latched on.

Our first job, we had to remove the protective cover and that required a certain amount of force. We had practiced that a lot because I had to get in a position on the arm where I was holding the instrument partly against my body, partly against my legs to get it as stable as possible so that when Story went to remove the protective cover the instrument wasn't going to wiggle. If the instrument wiggled then when he was removing the cover it could bang against the mirror and basically break the instrument, or misalign the instrument, which is as good as breaking it.

We had worked very hard at that. It was very nice when everything worked as planned. Then I carried the instrument up, and Story got in the foot restraint. We had looked in to see; we didn't see any impediments in there. Everything looked good. Sure enough, it just slid right in. I was concentrating on what I was doing, I was looking over at Story a little bit, but it looked like he was pushing on his part. I was pushing on mine. It all went in, and then I tightened up the bolt.

That has a follow-on actually. I tightened up the bolt using a large power wrench called a Power Ratchet Tool (PRT). I tightened it up to the torque that they told us to. On the most recent mission when—who was it? Drew I guess, Drew [Andrew J.] Feustel went to undo that bolt that I had put in 15 or 16 years ago, it wouldn't come out. He was using what they thought was the same torque, but he was using a different tool. The problem is that that bolt will break if you torque it too much. If the bolt breaks, you'll never get WFPC back out.

So he tried it a couple of times with the torque limiter. It just wouldn't come out, even when they increased the torque on the torque limiter. They finally decided well, look, if the bolt breaks we're no worse off than we are now, because WFPC 2 is in there already, so just take the torque limiter off and see what you can do. He did, and in fact he was able to get the bolt out. WFPC 2 is now—actually I think this week it's going to the [Smithsonian National] Air and Space Museum [Washington, DC], so I got to go down there and see it.

I took a bit of grief that week from having put the bolt in. Actually it was an interesting thing, because I contacted the EVA people here, because we had followed the procedure. It turns out that there's a wide range in the calibration of these torque devices. It's easily possible that I was at the upper end of my torque, and he was at the lower end of his torque, and that's why it didn't work. It all ended happily. WFPC 3 is in there now and it's doing great work. In fact all the major stuff that we put on the telescope: the solar panels, the WFPC 2, the COSTAR, have now been removed, but that's good. That's the way Hubble was supposed to be. It's constantly being upgraded.

WFPC 2 was finished, and that gave us time to go on to another task, which we were really looking forward to, because this was to mount two new magnetometers on top of the old magnetometers. This was an interesting situation, because those two magnetometers were never designed to be replaced, in fact they couldn't be removed. They were never supposed to fail. There were two of them. In fact, both of them had failed.

We couldn't remove them, so they designed two new magnetometers that could actually clamp on top of the old ones. They're all the way up at the top of the telescope. This is at the extreme limit of how far you can go up on the arm. The arm is pretty much straight pointing away. Boy, what a spectacular view up there. We were lucky that it was just the way it worked out. It was on EVA day three that Story and I got to do it. Of all the things, I think that was the most spectacular view and the most impressive location to be. You're as far away from the Shuttle as you can get unless you're flying on a maneuvering unit.

It went well. Now I did notice that some of the paint was flaking off the old magnetometers, and I reported that to the ground. They started on a plan to make some covers for them. We got the new magnetometers installed. We came back in, third out of three days successful.

I was really excited, because we'd gotten WFPC 2 in, and that was the big thing for the astronomers. I told Story, "What a great day." Story was just frowning.

He said, "I feel terrible."

I said, "What are you talking about?"

He said, "The placement of the foot restraint wasn't right." He said, "I couldn't reach the way I wanted to reach."

I have to say I was kind of amazed. "Story, it was a success. We did it—[we installed] WFPC 2."

"Yes, but my plan didn't work right." That's just Story. He had planned to do it a certain way and it didn't work quite that way. He was just really upset, not that we didn't celebrate that night; everybody felt really good. I think he got over that pretty soon. I just mention it. I was surprised because I was so happy. The fact that Story wasn't as elated or at least that there was this other thing that was getting in the way, that got my attention. I thought that was strange.

Fourth day EVA, that was the day of the COSTAR. Again, all sorts of things possibly could have gone wrong, but everything worked perfectly. By the way, there were some other smaller things that we were doing on various days. I had to replace a couple of fuses which had been improperly installed before the launch. We had a tape recorder device that we replaced and one or two other things.

Plus, whenever we had a little extra time, we would try to go and get a head start in the next task. In fact, on the first day, when I was trying to close the door, I think Story was off doing some work on the solar arrays, trying to get a little head start for Tom and Kathy the next day. Again, it was this philosophy that we wanted to make the best use of our time, stay ahead of the timeline, don't waste time, do useful work whenever you possibly can.

So fourth EVA out of the way, and we're ready for the fifth and last. On this one Story was going to be on the arm, and I was going to be the free-floater. There were a lot of little tasks that we had to do. One of them was replacing the Solar Array Drive Electronics, or the SADE. Again this was another thing like the magnetometers. There were two of them, so they were redundant. They were not designed for EVA replacement. Originally I guess the philosophy was it's unlikely that they'll fail. If one of them fails we've got a second one, so don't worry about EVA.

Well, one of them failed, and then people started to get scared, because it's very different once it's up in space from when you're designing it, because you've paid the bills already, so you don't have the option of saying, "No, we won't make it EVA-repairable." But they said, "If the first one failed maybe there's a problem, and the second one is going to fail too."

In fact actually after our mission was over the second one did fail, so the second Hubble repair mission had to replace the second SADE unit. Luckily, they had a much easier job than we did, for the following reason. This unit had a whole set of, I think, eight different connectors. It was like the old SCSI [Small Computer System Interface] connectors on old type computers where you have the long plugs with little two-millimeter screws at each end. Those screws are supposed to be captive screws, the way they're designed. On the Earth, they are. You screw them out partway, and there's a little break in the threads and they just sit there.

Well, the first problem was that just getting access—there was a small screwdriver. These were tiny little screws, but the small screwdriver that we had to work with turned very very fast, so it was very hard to get it on the screw and get it to keep there. The only tool that we had, which turned slowly enough that we could control it, was this big ratcheting tool. That's like swatting a fly with a mallet. It was just a tool much too big for the job we needed to do with it.

We played around with both of those tools. We did manage to get the screws out. The thing is that once you remove the connector, now it's just floating on its wire. The two little screws are resting in the connector, then you go to take out the next connector, and of course because you're moving around the wires are shaking. The connector that has already been removed is shaking around. The screws start to move, and they do a little dance. Half of them go clockwise, and that's fine, but the other half go counterclockwise, and they unscrew themselves.

First we saw just one little screw floating around, so I guess Story went, picked it up, put it in his trash container, then we saw two or three more screws. Grabbed them, put them in the trash container. The problem with the little trash bag was when you opened it up the screws were floating around inside it. Now because of our experience, they redesigned the trash bag so that once you put something in it couldn't float out, but that was hindsight. We didn't have that.

Once we got enough screws in that bag, we would open the bag to try to put another screw in, and a screw would float up out of the bag. At one point Story reached for a screw, didn't quite get it, tapped it, and it started floating down towards the payload bay. You don't really want loose material around the payload bay, because it could get caught in some of the mechanisms, maybe it would mess up the doors from closing. I grabbed for it, and I just missed it. Now I was free-floating so I had more freedom of motion than Story did, but we were all kind of hanging on to the arm, but I was sort of hanging on with one hand, reaching out. Claude said, "Just keep reaching out, Jeff, I'll move the arm, and we'll catch up to it." He started moving the arm, but even at full speed the arm was moving at just the same speed that the screw was, so it was about just a couple of inches beyond my reach but I couldn't get it.

It's a good example of how a well trained crew can figure out quickly how to do things, because Ken Bowersox, who was the backup arm operator, went over to the computer. The way the arm works, if it's carrying anything, you set a little bit in the computer that says the arm is loaded, so the software puts a limit on the maximum speed. What he did was he reprogrammed it on the fly to tell it that it was unloaded and that there was nothing on the arm, so immediately it speeded up, then I was able to catch the screw. For the rest of the flight that was the great screw chase. It was really exciting, but we got it.

I have to say, working with these little two-millimeter screws in very tight confines when they ended up not being captive, we were kind of at the limit I think, Story and I both agreed. We were at the limit of what our capabilities were working in a spacesuit. Had it been just a little bit worse, we might not have been able to get it done properly, but we did.

Then there were some other things. I had to go inside the telescope to install some equipment for a future instrument installation. Golly, I think we had about five. Oh, but the other thing, in fact the highlight of that final day, had to do with that flaking paint from the magnetometers. What the ground decided was that they wanted to make some covers, so on the fourth EVA after Tom and Kathy were finished with their regular work, they went and they actually cut some Mylar insulating material from one of the boxes out there and brought it inside. Then Ken and Claude actually fabricated [them] according to plans sent up by the ground into covers that Story and I would then put on the magnetometers.

So that meant on the fifth day we had to—sigh—go all the way up to the top of the telescope again to install those [covers]. It again was a spectacular view from up there, but even more fun for me, because I was free-floating that day. Of course, we're both attached to the arm by our stainless steel tethers, but every once in a while I would just let go.

Of course you don't float away because I didn't push myself away, but by letting go, it basically broke the physical bond between me and the Shuttle, because the tether was loose. It wasn't pulling on me. It was a remarkable psychological transformation. Instead of being attached to the Shuttle, all of a sudden, not just physically but psychologically I became a free-floating satellite. It surprised me the first time how different it felt psychologically.

I grabbed on. "Oh yes, now I'm part of the Shuttle." I let go again. "Oh, now I'm a free-floating satellite." It was really exhilarating, particularly at night. I tried once. I actually turned my back on the Shuttle and I let go, so it was just me floating in space. All the stars around, I felt really like I was alone. If I had really been alone I would probably not have been quite so sanguine about it, but it was a very moving experience. I'll certainly never forget it. We were very lucky the way that all worked out.

Job is done. Cleaned up. Removed the low-gain antenna cover, removed the tethers. Get the astronaut carrying unit off the arm, get it all put away, get the payload bay cleaned up for reentry. Then we were ready to get the telescope ready to be deployed the next day. When they went to put down one of the solar arrays it didn't move, but that's what we're out there for, so we put it down manually. They said, "Why don't you just wait out there for another half hour, 45 minutes while we deploy all the other appendages, the high-gain antennas?"

"No problem, we'll stay out as long as you want." I think it was on that EVA that Story actually dropped his tool bag, and it floated away. I didn't see that because I was doing something else, but I remember hearing them talk about it. He went to try to get it, but that's happened from time to time on EVAs. People have dropped things.

ROSS-NAZZAL: That's interesting because—what flight was it? There was a flight where somebody had dropped a tool that they needed.

WRIGHT: Heide [Stefanyshyn-Piper] dropped it.

ROSS-NAZZAL: Yes. They made a big fuss over it in the media.

HOFFMAN: I think here it didn't get a lot of attention. People didn't talk about it. There was so much else going on. There was actually one, it was one of the earlier flights actually before the Hubble mission. It was I think even before *Challenger* on one flight where somebody had lost a wrench. The wrench started floating towards the rear end of the Shuttle, but the Shuttle commander just fired the jets and the Shuttle moved backwards and it was by magic. The tool was floating away. All of a sudden it stopped, and it came back, so the astronaut just reached out and grabbed that. That may have been Bruce McCandless, but I wouldn't swear to it. I don't want to lay anything on him if it wasn't actually him.

It happens. It shouldn't. Everything is supposed to be tethered. You get embarrassed if that happens; it can be serious. I think it was the fifth EVA, because it was the trash bag, that's what it was, with all the screws in it. I'm thinking we got it back, but we might not have. I'm going to have to go back and review that, I don't even remember now. That's scary.

When we finally did come inside, again that was the last EVA, and we had accomplished everything, plus the magnetometer covers, which hadn't originally been planned. Again I was feeling real excited. Story was really excited too, so we gave each other a hug and everybody hugged each other. We were really happy. Obviously we didn't know for sure whether it was all going to work, because the optics had to work, but we had done our job, so we celebrated. We always liked to have a nice dinner, but particularly that night it was just a very good feeling.

Then the next day, we deployed the telescope. Claude did a brilliant job, releasing it without imparting any impulse to it, so that it just stays just really steady, then we flew away from it. There was a special technique that was developed so that we didn't plume the telescope like we had done that other solar array.

We went into an orbit slightly lower. Now on subsequent flights they've actually done fly-arounds so they could take pictures of Hubble from various angles. We didn't do that, we just flew away from it. We were in a slightly lower orbit, so we were going slightly faster than the telescope, so every orbit it would move away from us slightly to the west. Our orbit was going from west to east. Every time we would go around the Earth and the Sun would rise in the east, Hubble would be on the other side of us, and it would be illuminated by the rising Sun. It was like seeing the Morning Star, except the Morning Star, Venus, is always in the east, but Hubble was in the west. Every single morning I could see it out there. Of course it got smaller and smaller as it got farther and farther away, but right up to our deorbit burn a couple days later Hubble was still out there visible every morning when the Sun rose, 15 times a day.

Actually, Hubble is a high orbit. It's the highest that the Shuttle ever goes. It's about 100 kilometers or 200 kilometers higher than typical low [Earth orbit]—the Space Station for instance, or most of the places where the Shuttle goes. As a result, our orbit was about 95 minutes rather than the typical 90-minute orbit that everybody talks about. Normally you talk about 16 sunrises and sunsets per day, but we only got 15 because we were in a higher orbit. It also meant that we were much closer to the South Atlantic Anomaly, which is a region of enhanced radiation off the coast of South America out in the Atlantic Ocean. That's why they had us wear these special radiation monitors. In fact, in one Hubble mission you get as much radiation as you get on a six-month Space Station mission, just because you're that much closer to the radiation belts. One or two rads, so it's not a health hazard, but it's just interesting that that's just one of the results of Hubble's being in a higher orbit.

The reason it's in a higher orbit is because its pointing accuracy is so great that they—although it's basically a vacuum up there, there is a residual atmosphere. That's why satellites eventually—the ones in low Earth orbit—eventually their orbits decay and they fall out of space. Even that residual atmosphere would have an impact on Hubble's pointing capability, so they wanted it as high as possible. They didn't want it up in the radiation belts of course because then we wouldn't be able to service it. It was a compromise between being as high as possible to reduce the atmospheric effects and being low enough that we could service it without an undue dose of radiation.

So Hubble is [back] in orbit. The mission had been long enough that we were entitled to a half day off. We played around a little bit, but actually most of that time we had to do housekeeping, because with seven people living in a small area things get messy. You've got to put all your trash away and start getting ready [to come home]. I guess we also had some time for telephone calls with our family. I think we had a press conference, all the things you normally do towards the end of the mission and just enjoy watching the Earth go around.

Got some beautiful pictures. Claude spent a lot of time with the Shuttle payload bay TV cameras, which are low-light-level TV cameras. He recorded city lights all over the world at night in the Northern Hemisphere, because we launched at night in the Northern Hemisphere, so the Northern Hemisphere was always at night during our mission. It was December. The entire Northern Hemisphere was completely without clouds. What's the probability of that? As a result, we just got these extraordinary views of city lights.

City lights are remarkable, because it's the best way of really getting appreciation of the geographical distribution of human civilization. During the day, if you fly right over a city you can look down, and you can see structures and roads and things, but as things move out towards the horizon you lose the contrast. The human eye can't really make out a city when it's out towards the horizon.

At night, with the city lights it's like looking at stars. No matter where you look you can see the city lights below you and the stars above you. Given that there were no clouds, it was just spectacular. Flying across the United States, you spend a half hour going across the Pacific, which seems like a long time when you're in space. I realize when you're in a jet flying over it, it'd be nice to fly over in a half hour, but it's a real excitement to come across the lights of the west coast and California. Las Vegas is ridiculously bright; you can see the Strip with your naked eye. Flying over Houston, I could look out one window and see the lights of Los Angeles and the other window and see the lights of Washington and New York, just a spectacular point of view. Could see meteors entering the atmosphere below us. We were very fortunate. We didn't have a whole lot of time to look out the windows, but it was pretty spectacular.

One more day, which is the predeorbit day, where you basically check out the Orbiter, the electrical and hydraulic systems, make sure everything is working right. That's mostly the pilot's job, and then we came home. The warmth of the welcome and the excitement of everybody that this mission had actually gone off so well, it was just a wonderful feeling. People were just overboard in their enthusiasm about how important this was. At one point people were saying we ought to have a tickertape parade on Wall Street like they did for Apollo, which we never did. That probably would have been a bit over the top.

They did tell us actually that more people had watched this mission than any mission since Apollo 11. We actually at that point were not living down here in Clear Lake. We were living up in West University, because my wife worked up there, and our kids went to school there, so I would commute every day. The cable system up there didn't carry NASA Select. It's hard to believe that in Houston. Down here [near JSC] they do but up there they didn't, I don't know if they do now or not.

Barbara, my wife, wanted to be able to watch the mission without having to come down to NASA all the time. I actually had to rent [a satellite dish], and this was in the old days when the dishes were six feet wide. Luckily the guy who came over, when he found out that I was going to be on the mission, he took 50% off the price, but then it turned out that it was on all the networks. It was on C-SPAN and CNN [Cable News Network] and so in fact we wouldn't have needed to do that, but we never anticipated that so many people were going to want to watch it.

Of course all my friends called after the fact to complain, "Why did you have to be doing your EVAs at 3:00 in the morning? Couldn't you have picked a more useful reasonable time?" It's hard to explain the laws of celestial mechanics the 50th time. The other thing of course, is I get home and Barbara said, "Well, you fixed the door on Hubble. The door to our kitchen doesn't close, so get to work. By the way, astronaut, the grass couldn't care less that you were up in space, here's the lawnmower. By the way, the washing machine isn't working." So it's nice to come back home, and that gets your feet back on the ground, because people ask sometimes what happens after a mission, how do you get back into life, but that's just one of those things. The mission is over.

Of course, the mission wasn't really over, because we had a lot of nice postflight trips ahead of us. In fact one of the nice things about working with European astronauts is that the European Space Agency does these trips in really good style. In fact my last three flights, we were always invited over to Europe, and then to Switzerland after that. So that was great, but the real critical thing was, were all these corrective optics going to work. You can't turn on the instruments completely for a couple of weeks, because you have to allow them to outgas, for all the residual atmosphere to get out of it. If you don't, then when you turn on the high voltage it can spark and break the electronics, so they really couldn't start testing it until the end of the month.

I'll never forget. It was the wee hours of January 1st. We had had people over for a party. Everybody had left. I think I was up alone in the kitchen; I was just cleaning up. The phone rang. It was an astronomer friend of mine from the Space Telescope Science Institute. He said, "Jeff, hi. Do you have any champagne left?"

I said, "Yes, I still have a half bottle in the refrigerator."

He said, "Well, crack it open, because we've just gotten the first pictures back from Hubble, and it works." Of course I think [United States Senator from Maryland] Barbara Mikulski insisted on making the first public announcement, so we weren't allowed to say anything publicly about it. That was the real good feeling, to know that not only had we had accomplished everything that we had been asked to do, but it actually worked.

We had no reason to believe that it wouldn't work, because from two separate points of view, both the astronomers and the optical engineers had analyzed the problem. They had both come up with the same conclusions, the same mathematical formula, the same recommendations. We had very high confidence that the fix was going to work, but nevertheless it was a very complex optical system. A lot of mechanisms had to work just right. In fact it did. As they say, the rest is history, because Hubble has gone on to do just incredible things.

So many astronomers have basically spent large parts of their lives using Hubble. Astronomy textbooks have been written over and over again over the last 15 years. Fundamental new discoveries in cosmology now with the dark matter and dark energy, much of which came directly out of Hubble observations, and when you look at the number of scientific publications that have come out of Hubble, it's far and away the most productive science mission that NASA has ever had, and continues to be really.

It continues to be, because it's serviceable. The other [Great Observatories], like Chandra [X-Ray Observatory] and Spitzer [Space Telescope], fantastic instruments, but what you find when you put a new instrument, a new observatory, into space is that initially you get a spike of new discoveries because there's a lot of things you haven't been able to look at, but it gradually flattens off. The rate of new discoveries decreases, because basically you skim the cream. The things that are most important that your new observatory is capable of doing you do, and then you go into things in more detail. There's still a lot of good science that you can do, but the rate of fundamental new discoveries tends to fall off. But with Hubble, every time we go up to service it, it's a new telescope. So that hasn't happened, because as it gets more and more powerful, more and more sensitive, things that it was not capable of observing now it can observe. The scientific productivity, if anything, has increased over the years rather than fallen off.

I guess the other comment I should make about it is as each Hubble servicing mission has come along, we've gotten more and more daring in what we've been willing to attempt, based on the success we've had in the past. In fact this most recent mission, the fifth and final servicing mission, where they actually made repairs at the board level and actually pulled out electronic boards, nobody would have dreamed of doing that ten years ago. People often have asked, "Well, what's the difference between this mission and our first mission?"

They're certainly not any easier. They're just as difficult. As I said, every mission they try something that's that much more of a challenge. The biggest difference I would say is when we went up, we didn't know if it could be done. A large fraction of the community really felt that it was too ambitious and that it wasn't going to be successful.

Rightly or wrongly, everybody now assumes that the mission is going to be successful, because we've done it before. It doesn't make the mission any easier for the crew or for the ground controllers, but I think psychologically that's the biggest difference, is that we assume now that we can do Hubble, we know how to do it, and that we can do these things.

It's been proven correct. Basically everything we've set out to do with Hubble we've accomplished on all the missions. There have been problems along the way, but we solved them. I still get a thrill looking at the Hubble pictures, especially the ones which were taken by WFPC of course, because I put that in. Hubble, it goes beyond individual people, individual crews. It's been such a saga over so many years, so many people have been involved in it. I think there's a real sense of community of people who have worked on or with Hubble, just because it's been such an incredibly productive instrument. Also from a space operations point of view it's pushed our capabilities beyond what anybody at one time would have thought was possible to do in an EVA environment.

It's important, thinking back on it, with the great success that we've had, it's hard to appreciate the leap of faith that was made when NASA first decided to do Hubble. To commit yourself to building a telescope that will be serviceable by astronauts, in spacesuits, using the Space Shuttle, this was a decision that was made before the Space Shuttle ever flew, so it was like when President [John F.] Kennedy committed us to going to the Moon and we hadn't even put anyone in orbit. It was just after Alan [B.] Shepard's first suborbital flight. That was a huge leap of faith based on good engineering judgment and belief in what we would be capable of doing, but nevertheless it was really a stretch.

I look at the decision to make Hubble a serviceable observatory as being a similar kind of a stretch. It was obviously the right decision. Of all the things that we've accomplished with the Shuttle, and we've done a lot of different things, I think that Hubble is probably the most significant and has had the biggest impact scientifically but also for the public. The public loves Hubble. When [NASA Administrator] Sean O'Keefe canceled the Hubble mission there was more outcry from the public than from the astronomical community. It was just amazing. People all over the world know of Hubble. Go to any city in the world, name a telescope, "Hubble," with very few exceptions. It's just been an incredible story. I was very lucky to be a part in it. I got to go.

ROSS-NAZZAL: It's probably about time.

[End of interview]