HUBBLE SPACE TELESCOPE OPERATIONAL ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

PRESTON M. BURCH
INTERVIEWED BY CHRIS GAINOR
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND – 9 NOVEMBER 2015

The questions in this transcript were asked during an oral history session with Preston Burch. The text has been amended for clarification and for publication on this website.

GAINOR: Okay, here we go. So it's November 9th, 2015, and I'm at the Goddard Space Flight Center, and I'm with Preston Burch. I'm Chris Gainor, and I'm going to start off by asking you to just run me through your experience with Hubble [Space Telescope, HST], and anything that might have led up to it. Whatever you think relates to that.

BURCH: Okay. Well, so this is Preston Burch talking, and my career in space astronomy, if you will—well, my career in the space biz actually—started back in 1962, I guess you could say, when I had my first full-time job. I was going to school at the time. That's a long story, but anyhow, I worked as a lab technician. But actually, when I got my degree in physics in June of '66, I went to work for Grumman. The name of the company at that time was Grumman Aircraft Engineering Corporation. They made airplanes, but they also got into the space biz, and I worked on the Apollo program. I worked on the lunar module as a lowly test engineer. I was an environmental test engineer. To be more specific, I was a thermal vacuum test engineer. Also did some vibration test work.

But after a couple of years of that, I was offered an opportunity to come down to the Goddard Space Flight Center to work on a thing called the Orbiting Astronomical Observatory [OAO], and this was really the great-granddaddy of Hubble. It was, in my view, the true progenitor

I guess you could say, of what came along later. So that was in April of 1968 that I came down here and worked as part of the mission operations team that Grumman had put together to help integrate and test the control center and put the mission operations plan together; train the mission operations team, which I was part of, etcetera. So that was how I got started in the business. That's where I learned about Earth satellites, ground data systems, science data processing and that sort of thing.

So I won't bore you with my whole background, but I left the area in 1971 and came back in late '73, working as a contractor with a beltway bandit outfit, and I worked on a series of programs and projects. My first real acquaintance with the Hubble Space Telescope occurred in about 1983, when I was asked to do some requirements development work. TRW [Inc.] had gotten into big trouble on the SOGS, the Science Operations Ground System, which Goddard had contracted the TRW for, to provide a data system for the Space Telescope Science Institute to support the planning and scheduling of observations as well as the back-end processing of the data that came from the observatory. And TRW was having difficulty in the planning and scheduling area. And so I was asked to lead a team to straighten out the requirements on that. So I did that as a contractor. That was work that was done in a pretty short period of time.

But I had a lot of friends and acquaintances who worked on Hubble over the years, and I watched it progress for a while. Also, one of the interesting things was on the OAO project (again, going back to the '60s) the project manager in the late '60s time frame was a fellow by the name of Joe [Joseph] Purcell, and he started thinking about what the next evolution of an orbiting astronomical observatory would be like. He conceptualized a thing called the Large Space Telescope, the LST, and commissioned a number of studies on that and whatnot. And there were some features that were in common with OAO that were kind of carried into that study.

But in any event, when I decided to enter public service, which again was an April month, but this was in '91, I answered an ad for the deputy project manager for what was then the Hubble Operations and Ground Systems Project. So, I went to work for a woman by the name of Ann [C.] Merwarth. She was the project manager. And so the Hubble Operations and Ground Systems Project was responsible for the control center system at Goddard, the planning and scheduling system that went along with that. We were also responsible for the mission operations team, flight operations team at Goddard responsible for flying the satellite. We were responsible for the Space Telescope Science Institute contract, so all of that work. At one time there were over 500 people just at the Institute responsible for managing or conducting the science program as well as maintaining the Science Operations Ground System. And another critical element was the Hubble Data Archive that was called the Hubble DADS, the Data Archive and Distribution Service. When I came on board, they gave me about a month to find the men's room, and get sort of acclimated, and then I was asked to conduct a review of the DADS, which had sort of a locomotive that left the tracks, that was not doing well. It was under contract with Ford Aerospace at the time. And so we conducted a review, and it was really in bad shape. We wound up making a number of organizational changes on both the government side as well the contractor side, to get things back on track, where they needed to be.

So in addition to all that, the Operations and Ground Systems Project was also responsible for maintaining all of the flight computer software. This included the main computer in Hubble, which was the DF-224, which was, even then, an antique, but it was a relatively crude computer. And then there was the NSSC 1, the NASA Standard Spacecraft Computer Number 1, which was part of the Science Instrument Command and Data Handling system. So this was the computer that managed the five science instruments that Hubble nominally added at any time. And then each of the science instruments, in turn, had an embedded microprocessor that needed to be maintained. So, Goddard took over responsibility for the maintenance of all of that flight software, including the embedded micros, which needed test beds. We had a laboratory with test beds in it to support the continued maintenance of the flight software and the micros.

So that was a lot of work. And then getting ready for the servicing missions, we had to develop a thing called the SMIT [Servicing Mission Integrated Timeline], and for that we had a system called the SM PART [Servicing Mission Planning and Re-planning Tool]. Because during a servicing mission, time is of the essence, and (I'm sure you've heard this before) the most valuable resource we have on orbit is the astronaut time they have to spend in the cargo bay or the payload bay, actually working on Hubble.

So in recognition that we would probably have to change the plan as time went on, as we discovered things and recovered from things that didn't go quite as we expected, we needed to have the ability to rapidly re-plan all of these astronaut activities and make sure, with high confidence, that these things would fit within the allocated time, and to be able to communicate this for this enormous army of individuals that were on the ground, as well as the astronauts, about what was going to be planned for the next day. So that was another system that we were responsible for.

That was what the Operations and Ground Systems Project was all about. And then we, of course, had the Hubble Flight Systems and Servicing Project that was headed up by Frank [J.] Cepollina. Then these two major projects, the flight project and the ground project were overseen by a program office that at the time, when I joined the government in April of '91, was headed up by Joe [Joseph H.] Rothenberg, and his deputy was Dr. John [H.] Campbell. So that was the setting in which I found myself when I joined the government.

It was about a year after launch, and the shock of spherical aberration had worn off, and people were very focused on the plan forward for Servicing Mission 1 and getting things fixed. And people ask me sometimes, "What was it like?" And I said, "Well, we have high confidence." I think everybody felt we were on a solid path forward on this, and I don't think anybody thought that this wasn't going to work. We certainly weren't cocky, but we were confident that we had an enormous amount of work to do in a very short time, because we were doing things for the very first time.

There was a lot of infrastructure that needed to be put in place. We didn't have the servicing hardware, the carriers, the protective enclosures, crew aids, and tools. We hadn't done all this training stuff with the astronauts before, and we had not built an integrated timeline that showed how all the stuff was going to be done, and all the procedures, etcetera. And there were upgrades that needed to be made to the control center.

That was another interesting challenge. Over time and [as] technology evolved in the IT world, various pieces of the ground system became expensive and cumbersome to maintain, so those needed to be changed out. So the big challenge to the Operations and Ground Systems Project was to keep the observatory operating at peak efficiency, doing the maximum number of observations and satisfying as many users as possible. Keeping it highly productive, while at the same time introducing the changes required by servicing and doing these servicing missions and doing it in a way that minimized the amount of down time and disruption to the overall observing program. So that was, I think, the major challenge that we faced.

But just on a more humorous note, it was around that time that (this was the early 90s) there was a series of movies that Leslie Nielson did—you know what's coming [laughing]. "The Blue Note Café."

GAINOR: Yes. "The Blue Note Café."

BURCH: The bar for losers where you see above the bar, the picture of the Edsel [Ford Motor Company, discontinued division and brand of automobiles produced 1958 to 1960], a picture of the [RMS] Titanic sinking, the picture of the Hindenburg [German passenger airship] blowing up, and then of course, there's the Hubble Space Telescope. And people would ask him, "What did you think of that movie?" And I'd say, "You know? We laughed our butts off. We thought that was funny as all get-out." And I don't think anybody ever got insulted by that, you know. We were the butt of late-night jokes with David Letterman and what-not. He had this top-ten—have you seen his [top ten list]?

GAINOR: Oh yeah.

BURCH: Top ten reasons why the Hubble mirror got messed up, and we—all of us—I mean, if you don't have a sense of humor in this business, you're at a real disadvantage. But we thought it was kind of cool. We were getting a lot of publicity, or attention I should say. It wasn't all positive at that time, but we were really confident that we were on the right track.

GAINOR: So, by the time you got there, they were pretty well on the way with COSTAR [Corrective Optics Space Telescope Axial Replacement] and all that.

BURCH: Well, when I arrived, it was a year after launch and we were in preliminary design reviews and that sort of thing. The hardware hadn't been built yet, but we were going pretty much full tilt.

GAINOR: But you had the idea.

BURCH: Right, right.

GAINOR: Yes, because I spoke to Charlie Pellerin, and I think this is probably before you got there, but he said it was really tough for a while. That it was really hard on some people when all that happened, but that had all sort of dissipated by then.

BURCH: By the time I got there a year after launch, I think a lot of that had dissipated. Of course, the ones who bore the brunt of this were people at the more senior levels in the NASA organization. There was no doubt it was an enormous embarrassment that no one expected, and people like Ed Weiler were really hugely affected by this, and understandably. I'd known Ed a little bit, because he had worked on the Orbiting Astronomical Observatory. He was part of the Princeton Experiment Package. That was OAO-C, which I became one of the test directors on. I didn't have a whole lot of contact with him in those days, but that was something we had in common.

But, in any event, just a (I don't know) snapshot of my career progression: came in in '91 as the deputy project manager, then in '98 my boss, Ann Merwarth, retired after becoming the project manager of the Operations and Ground Systems Project, and then somewhere along the line, the name morphed to just Hubble Operations Project, and Cepi's project became the Hubble Development Project, and then in I think it was January or February of 2001, I got called into John Campbell's office. By then he'd become the director of flight projects at Goddard, and the acting program manager of Hubble was a fellow by the name of Dave [David] Scheve, and so Dave had been the deputy program manager, I think to John Campbell, after Joe Rothenberg left. Anyhow, Dave was in an active role as program manager, and he used to call me down to his office once in a while. He'd say, "Oh Preston, I don't think I can keep doing this job much longer. My back's bothering me," and this and that.

I'd tell him, "Dave, I think you're doing a great job, and I'll support you any way I can," blah, blah, blah.

And so one day Campbell calls me and he says, "Okay," he says, "I want you to take over as the program manager." I thought he was totally out of his mind.

And I said, "You've got to be kidding!"

He says, "No. I'm serious."

I said, "Well, there's got to be better people than me, qualified to lead the Hubble program."

And he goes, "Well, name some of them." I only came up with one or two names, and it was immediately obvious as names rolled off my lips that that wasn't going to work. There was really a shortage of people to potentially do it. And I thought I would last about a month. I figured, inside of a month they'll figure out that this guy is totally unsuited to the job, and I'll be out the door. I was really uncomfortable with the thought, but I have to say that there was a well-worn path by that time.

We had had three servicing missions, I guess. We'd had Servicing Missions 1, 2, and 3A, and although the last two servicing missions that I was responsible for, 3B and Servicing Mission 4, with each servicing mission we continued to raise the bar on our demands and what we expected to get out of it, and the degree of the technical challenges that we faced. We—the team that we had on Hubble—was just absolutely the A+ team at NASA. I mean these were people that can do just about anything asked of them. So I know it made our friends down at NASA Headquarters very nervous. They felt, especially in Servicing Mission 4, that we were putting 10 pounds of you know what in a five-pound bag.

You know NASA's become a very risk-averse agency. It's gotten worse with time, and that's their job. It's always trying to quantify or assess what the risk is on any of the missions that we do at NASA. We have five-by-five matrices that try to quantify this stuff. But a lot of this is judgmental; it's subjective and it's difficult for people who aren't close to the day-to-day work that's going on to make those assessments and get comfortable, so that's sort of how we earn our money is trying to convince the people above us that we know what we're doing, and that we have a reasonable prospect of pulling this off successfully.

GAINOR: Could we step back a little bit to the first servicing mission?

BURCH: Sure.

GAINOR: Why don't you just give me your impressions of that? How tough was it and what were the big problems around it?

BURCH: Well, I tell you. Joe Rothenberg and I had been friends for many years. He was the program manager, but we both used to work at Grumman back in the '60s, so we knew each other well. And so even though I was very drawn to come to work for the government on Hubble, I did have a couple of reservations, and one of them I won't talk about (involved a particular individual) but the other one was in terms of resources. And I asked Joe, "Do you think you've got what you need in order to be able to do this?" And what he told me, unequivocally was, he said, "Headquarters will not let us fail. They are giving us everything we need." And he was right. We had enough money, enough people, enough resources at the Center, so that wasn't going to be an acceptable excuse that we failed because we didn't have enough of everything that we needed.

I tell you, I look back at what we did in the years that I was there, from '91 up to the servicing mission, which was December of '93, and I'm kind of amazed at all we accomplished. Just the sheer number of reviews that we had, the amount of work that had to be done, it was prodigious. We had a large team, and we were well organized, but the amount of work was just incredible and unrelenting. Sometimes I'm amazed that we were able to get it all done. So that's one thing that really stands out in my mind.

GAINOR: Were there any particular technical problems?

BURCH: Well, there's always technical issues. Speaking from the Operations and Ground Systems side, one of the problems we had, of course, were the darn gyroscopes kept pooping out on Hubble, and so for a while there we were wondering whether we were going to be able to continue to do science.

GAINOR: That kind of drove the next couple of servicing missions, too, didn't it?

BURCH: Right, but what it did do is drive us toward developing some software, some flight software. We weren't able to do this with the original DF-224 [space-qualified computer]. Ultimately when we gave Hubble a brain transplant in Servicing Mission 3A, we put a more modern computer in it. It was a 386 [coprocessor], and people were like, "What are you using a 386 for? Everybody's gone to the 486." But the thing needs to be rad-hardened [radiation-hardened] and space qualified, and that takes a lot of time. But with the advent of a more modern computer, we could then implement some very advanced algorithms that would enable Hubble to operate very efficiently and effectively using less than the nominal three gyroscopes. We could do it on two gyros; we were even at a one gyro operating mode, so we were able to make some amazing advances that way.

But the major challenge, I think, was one of organization and coordination, which I think the program and the projects did a remarkable job of. One of the complaints you'd hear from time to time was about professional meeting goers. You'd have a meeting, and an army of people would show up, and whoever organized the meeting would always feel a little miffed, like, well don't these people have something better to do? But the internet was still somewhat in its infancy as was desktop computing. It was in its early, early stages, and it was an effective means of keeping everybody on the same page with where we were, what we were doing, whatever problems we were having. A really effective communication mechanism that was put in place.

First time I'd ever seen it was on Hubble, was the top ten. So we had a Hubble top ten, and sometimes it would only be half a dozen problems, or it could be more than ten problems. It was a very effective means for communicating not only up and out about what the program was facing or the projects were facing in terms of problems, but down on them as well. So I think communication was one of the things that really enabled us to be so successful. Because to keep that many people organized and focused and moving forward, and we had a hard deadline to meet.

GAINOR: Do you want to talk about the next couple of servicing missions? They kind of get forgotten in the whole story, except perhaps for the Y2K [year 2000] bug.

BURCH: Yes, well the Y2K turned out to be a non-issue. That was Servicing Mission 3A, but Servicing Mission 2, you know—we continued to grow a list of things that were degrading and failing on Hubble. And at one point it caused people to start to ask, "Is Hubble just an old piece of junk, that maybe we're, we're not spending our money wisely by continuing to perform these servicing missions? Maybe we ought to cut our losses at some point and say enough is enough and embark on a new program?" And I think Frank Cepollina, again was very helpful in this, showing that you normally go through an infant mortality phase on any vehicle. Things break when they're relatively new, but at some point, if there's been some reasonable level of quality, things will level off, and then you're looking at the far end of the bathtub where you have aging effects, and things poop out, due to wear out mechanisms.

But when it came time for Servicing Mission 2, by then we had two new instruments to install. The STIS [Space Telescope Imaging Spectrograph], and the NICMOS [Near Infrared Camera and Multi-Object Spectrometer]. The Fine Guidance Sensors [FGSs] had an issue with the bearings in them. The star selector servos had ball bearing–type bearings in them, and the balls were separated by Teflon spacers, and the bearings were later determined to have been under-lubricated. So what happened was the Teflon toroids [doughnut-shaped rings made from or coated with Polytetrafluoroethylene], would wind up getting chewed up and left debris in the recess of the bearings. So this caused the FGSs to not perform properly. And so it became apparent after a while. We tried coming up with mechanisms to help ameliorate the effects of that, what we call clearing slews, where we would roll the bearings back and forth at certain prescribed intervals to clear out the debris and keep the lubricant moved up. What would happen was you'd get a bow wave of debris mixed with lubricant that made it difficult for the star selectors to move.

So we only had one start up. These are very complex electro-mechanical devices built by Perkin Elmer. But knock on wood, they were extremely reliable in terms of their electronics and the photo-multiplier tubes and whatnot. But we only had one spare that had ever been built. And building another one, we thought about building one using more modern technology, using CCD [Charge Coupled Device]-type detectors rather than photo-multiplier tubes, but it was prohibitively expensive. So the only thing we could do was replace them one at a time and bring the one back and overhaul it and repair it. And that's what we did. So we did that on Servicing Missions 2, and Servicing Missions 3A and 3B, I guess it was. I hate to say it, I think I need a cheat sheet on when we did all these things.

On Service Mission 2 [SM-2], this was the first time that we changed out one of the fine guidance sensors. We installed the STIS and the NICMOS science instruments. I'm sure we must have installed gyros. I think it was also—let's see, did we change out one of the tape recorders then?

GAINOR: I think you might have. The only reason I can remember that is because I talked to Joe [Joseph R.] Tanner about a month ago. He was on that mission.

BURCH: We did a lot of them, it's like four. I know we did some stuff that doesn't appear on here. But SM-2 is mainly about the fine guidance sensor, the near infrared camera and the STIS.

GAINOR: But I think Joe did say they changed out a recorder, or something like that.

BURCH: On SM-2?

GAINOR: On SM-2, yes.

BURCH: Okay. And then for SM-3A we did the advanced computer and the fine guidance sensor again, and gyros. And that was a truncated mission. That was three days long. What happened was Servicing Mission 3 got to be so big we had to break it into two pieces, and then the other thing that happened was that the gyros were failing so rapidly at that point that we needed to do this.

GAINOR: Wasn't it in safe mode by the time you got it up there?

BURCH: Yes, that's right. But the planning for these missions starts years in advance, like for SM-3, we anticipated that we were going to be in a bad situation by the time we got up there. We were hoping that we'd still be doing science, but you're right, we had stopped doing science by that time.

I'm just trying to remember—of the three engineering and science tape recorders, two of them were changed out, and I think one was on SM-2 and the other was on SM-3A. I don't think we did the recorders, the other recorder on 3B, but I could be wrong. I'll have to look back and check the manifests on these.

GAINOR: And so by the time of 3B, you're the project manager.

BURCH: Yes, the overall program manager.

GAINOR: Program manager, yes. One thing I'm a little curious about 3B is that set of solar arrays that you put in. And I was under the impression, you had an awful problem with the first set of solar arrays, the jitter and all that.

BURCH: Yeah, the bi-stems.

GAINOR: And then, the next set was better, but still perhaps not quite what people hoped.

BURCH: Right. Right.

GAINOR: And I'd just like to sort of ask about what your impressions were of those things. The third set that went up on 3B was quite different from the first two.

BURCH: That's right. The arrays that we built for Servicing Mission 3B were procured from a production line that was producing solar arrays for the Iridium satellites. So those were—and we designed and built here at Goddard—a structure to mount those on that was based on an aluminum/lithium metal technology. And so they were rigid arrays, unlike the flexible Rollup Solar Arrays [ROSAs] that were used for servicing missions. Well, that was on at launch and installed on Servicing Mission 1. So there were a couple of problems with the flexible solar arrays. There was the effect of the bi-stems, and then, I don't know if you want me to go through that. You've probably already familiar with the problem.

GAINOR: I'm kind of up on the first set, and I was just wondering a little bit about the second set.

BURCH: So the second set was very similar to the first set. The design was almost identical. One of the things that was done was to protect the bi-stems from the thermal transients that happened every orbit, the effects going into the Earth's shadow, or coming back into the Sun. So there was thermal insulation that was put on the bi-stems that was on there before launch. And it was folded up like an accordion, so when the arrays were extended and the bi-stems were extended out of their cassettes, the tubes that formed the thermal insulation moved right along with it.

There was a multi-layer insulation blanket that protected the bi-stems from the flexing mode that was going on. The banana-ing (if you will) of the bi-stems and going from light to dark and dark to light. So that helped enormously in terms of reducing the twitching and jitter that was introduced by the solar arrays. But they still were not perfect. There was still a—I believe it was a stick-slip phenomenon that was going on. The array blankets themselves were rolled up on a drum, and that drum allowed for some movement of the arrays, and I'm trying to remember exactly what the phenomenon was there with the second arrays, but I know that even though it was a huge improvement over what we had with the arrays that were on at launch, there was still some movement going on that compromised the integrity of the observatory. It was not sufficient to really mess up the science. We got enormously good science out of the observatory from SM-1 and onward.

The other thing was that the technology of the cells was such that they were subject to radiation damage, and there was a question about whether they would be providing sufficient power at the end of Hubble's useful life. We used an existing design in terms of the amount of area and the number of cells. With all the additional equipment, or the changes in equipment that we put on the observatory, most notably with the science instruments, these things became real power hogs. And so you coupled the additional power requirements of the instruments that were put on there, including the NICMOS cooling system, which consumed a fair bit of power. Then you project the loss of solar efficiency as a function of time, and it was pretty obvious toward the end of the mission that we were going to be on power deficit and we were going to have to be cycling instruments on and off, which is something you don't want to be doing.

I think that was the thing that really drove them. What we were able to do with Servicing Mission 3B with the rigid solar arrays, we were able to increase the amount of electrical output from them by roughly 30 percent, and at the same time, we reduced the cross-sectional area, or I should say the total array area of the arrays by at least a third, and that had a beneficial aerodynamic effect. It reduced what they call the ballistic co-efficient of Hubble to the point that it was equivalent to getting a free orbital boost out of the space shuttle that we normally got with each servicing mission. So we were able to stay in orbit longer and have more electrical power. And that was the principal factor in deciding to go forward with the rigid arrays.

GAINOR: I suppose on 3B, the NICMOS thing was probably a bit of a challenge.

BURCH: Oh, it was incredible. You know, the NICMOS cooling system had these little micro-turbines in it. The diameter of them is about the diameter of a pencil. And these things were moving at—what was it? I forget. It was either 5,000 or 7,000 revolutions per second, pumping neon gas through the system. And the system required several hundred watts of electrical power, and the benefit was that it removed just a few watts of heat out of the cryostat, the empty cryostat that NICMOS used, that housed the three infrared cameras. What was really amazing was that we took a technology that was basically a laboratory experiment that the U.S. Air Force was conducting, and we operationalized it. We built an operating system out of it, and then installed it on Hubble, and it worked beautifully. An amazing accomplishment. But quite a team of people to put that together and make it all work.

GAINOR: And then there's SM-4. Even without the actual mission and all the technical challenges, that's quite a saga.

BURCH: But before we go up to that, let's go back one more time to Servicing Mission 3B.

GAINOR: Sure.

BURCH: Servicing Mission 3B was amazing; besides the NICMOS cooling system, the most amazing thing we did was changing out the power control unit. On Servicing Mission 3A we gave Hubble a brain transplant, with the advanced computer. We gave Hubble a new heart on Servicing Mission 3B, because the power control unit [PCU] was really the heart, electrically speaking, of Hubble. It was responsible for taking the power from the solar arrays and distributing it to the various power distribution units, which then fed the various components within Hubble. In order to change out the PCU, we had to do something that we had never done to Hubble before, and that was shutting it down in orbit—turning it off. And there were a number of fears with that.

The big fears were: number one is when you turn the power off, now the observatory is going to start getting cold, and so we had a very limited amount of time in which to do this. But the power control unit also had quite a few cables, these Deutsch connectors. I forget the exact number, it was like 32 or 34 or 36 connectors—something like that. People were concerned. They were difficult to get at. Very, very difficult to get at. And the PCU was never designed to be changed out in orbit. Some astronauts and engineers had worked on trying to simulate doing this in some earlier experience at a much earlier time in the program, and they had walked away very frustrated. They didn't think that this was something that could be done practically. But when we developed an electrical problem with it, it became obvious—you know that we had relays that were failing inside this box. We were going to have to change it out.

So the big concern was not only about how to keep the observatory warm while all the electrical power is shut off to it, but what happens if you get some of most of the cables disconnected, but then there's a couple that you can't disconnect? The concern was a phenomenon called cold welding in space where two metal parts become attached to each other and you can't break them apart. And so, what do we do then? And the concern was that if we used up a good portion of the day trying to wrestle with this problem, we had to be able to preserve Hubble overnight, while the crew was there inside the orbiter resting and whatnot. We had to be able to keep Hubble alive somehow.

So we developed a thing. Some of us referred to it as a heart-lung device. It was basically a harness that we would connect to some of the solar array output and to some of the critical power distribution units that we could use to keep Hubble alive. Because fundamentally, the power control unit was a big box filled with relays and wires. If we could somehow short-wire around that box, temporarily at least, we could keep Hubble alive for another day until we had a chance to figure this out overnight.

I give all the credit to John [M.] Grunsfeld for making this happen, because what we did was build a PCU simulator. What this was, was the electrical bay in which the PCU resided on Hubble. We built a mockup of that. A very precise mockup and a replica of the PCU with all the connectors and whatnot. And we had the tools and so forth. John Grunsfeld worked relentlessly to refine the tools and the procedures to do this. And it got to the point where every day before he would go home to his family, he would stop at the simulator and go through the whole change-out sequence. It was just amazing.

So when the day came to do it, it was actually probably the worst day that we ever had on orbit on any of the servicing missions, because that was the day when he had his suit on and he went into the airlock and his suit started to fill with water. And we had to stop the thing, and he had to come back out and we had to get him out of his suit. We had to take the suit apart. They had to make up another suit out of pieces of other ones, dry out what he had, put this new suit, which was all kludged together. At that point I figured, well this day is a write off. We've got a real problem here. But the astronauts and the team at Johnson [Space Center, Houston, Texas], the shuttle team, decided that we can still go forward, and they salvaged the day and they got the whole thing done. It was just an incredible miracle. An incredible act of human perseverance. I'm still amazed to this day that he was able to pull that off.

So those were the big things in my mind on Servicing Mission 3B. We did put the solar arrays on the advanced camera, which was phenomenal, and a bunch of other stuff. But that was very exciting.

Servicing Mission 4: that was the 10 pounds in a five-pound bag. We had two new instruments to put on board. One was the Cosmic Origins Spectrograph and the other was the Wide Field Camera 3 [WFPC3]. We were going to change out the batteries—again, something we had never done on orbit. This was a first, a whole new suite of gyroscopes. And then we did something that has never been done before. That was the *in situ* repair of two other instruments that had suffered electrical failures. One was the Advanced Camera for Surveys, and the other was the STIS instrument. There were some big challenges on Servicing Mission 4. The thing that we took for granted and thought would be the easiest was changing out the WFPC2 to install the Wide Field Camera 3, and if I recall, the A-latch bolt didn't want to turn. And we took a big risk there in proceeding with turning that bolt.

When I looked around, the servicing mission manager was Bruce [G.] Kamen and he looked at me and he said, "Okay boss, what do you want to do?" And I looked around. Cepi was nowhere to be seen; Dave [David S.] Leckrone was nowhere to be seen; and I thought to myself, we really don't have a choice here. There's no way we can put a blowtorch on this thing to heat it up. There's no way we can put liquid wrench on it to put some penetrating oil on it. The only thing we can do is just proceed as gingerly as we can to increase the torque until it either releases or it breaks, because this bolt is nested so deeply in the instrument, there was no other way to get at it. And Drew [Andrew J.] Feustel, who is the astronaut with the delicate hands, his hobby is restoring old cars and building hot rods. He has magic hands and when the torque-limiter got to the ultimate setting, we needed more torque. We were just a direct drive, and they made it happen. There was a huge sigh of relief when that happened. So that was pretty dramatic.

The other dramatic thing, of course, was the STIS repair, when Mike [Michael J.] Massimino was the lead astronaut on the repair. Here's a guy with a degree in mechanical engineering, and he was trying to take out these hex-head bolts, and you've got to get the drive squarely on the bolt. If it's at an angle, you're going to strip it and round off the corners, and there had been repeated problems in the training on that.

But [there was a problem with] a couple of the bolts and we couldn't get the handle off on one end. The one end he got the bolts out. The other end they were so badly damaged that you couldn't turn the bolts, and so a decision had to be made about what to do on that. Here I credit the team back at Goddard. On all these servicing missions, there's a huge army of people that are watching everything that's going on, on orbit, and it's important that our operations team on the ground remain in synch with what's going on so we don't injure an astronaut. We don't want a Three Stooges kind of thing to happen where somebody gets hit in the head with a solar array, or somebody gets zapped with a piece of electrical equipment that's still on when it should be off. So, in order for our team to stay synchronized, we have these helmet-mounted cameras on the astronauts.

In the control center, all the engineers feel like you're sort of perched on the shoulder of the astronauts as they're doing their tasks. The communication from the engineers on the ground to the astronauts in orbit is necessarily a very circuitous payout, because of the huge number of people that are involved with the mission. But it's important that we anticipate problems, see problems quickly and come up with solutions to them as fast as we can, and communicate those up the chain so they get to the astronaut in a timely way. And in this instance, when we saw what was happening immediately, some engineers at Goddard sprang into action and put together a mockup of the handle.

Big question was what was the amount of force needed to break the handle off? It was only held on by two of the four remaining bolts on one side, and did Massimino have the strength to do that? Was it feasible to break it off, and what kind of a hazard did that pose to him? And so we were able to very quickly (and I'm talking minutes) mock this up on the ground. Apply a force to it and break it off. And so we determined that it was feasible.

Some of the folks at Goddard said, "Don't send this to Burch and the guys at Johnson Space Center." Because what happened was—they made a video of this—when the thing broke, it snapped very suddenly and went flying across the laboratory floor, and you know, tumbling. And so they were afraid that we would look at this as a hazardous operation and something that was undesirable. But when I saw the feasibility of it, I knew that Mike was a very big and strong individual. I felt that this is what we've got to do.

So once again, Bruce Kamen turned around to me and said, "Okay boss, what do you want to do?" I was kind of hemming and hawing, and the guy who was one of the system engineers had it, on his laptop. He said, "See, here's what they did at the lab down at Goddard." And I saw them break the thing off, and I said, "We've got to go for it." And once again, there wasn't anybody else around to consult with and we weren't inclined to start going into a research project and re-planning. So we gave the go-ahead for it, and it worked out great. The funny part was listening to Massimino. As he's putting his hand on the handle, he said, "Tell me again about that stored energy thing?" You know, the concern was you pull and you pull and you pull and it releases, he'd smack his helmet with the handle. But those were two of the biggest challenges and surprises on that mission. It was pretty exciting.

The other thing was, we had a lot of extra work we wanted the astronauts to do involving putting on the new outer blanket layers, and these were things that were important for Hubble's long-term viability to control the degradation of the external coatings on some of the bays, and the growing heat that was occurring in some of these bays. And we had carried these things to orbit, I think twice previously, some of them, so we were getting kind of anxious about getting them installed. Toward the end of the mission, it looked like we were running out of time, but John and Scooter (Scott Altman, the mission commander) they put their heads together on this and figured, "Well, we're going to get up extra early and we're going to make it happen." And that's basically what they did. So it was a heck of a team effort, as all of these servicing missions are, you know, between the flight and the ground.

GAINOR: And the other thing about that mission that interests me is, of course, all the to-ing and fro-ing about whether it was even going to happen.

BURCH: Ah yes!

GAINOR: Do you have any tales to tell me about that?

BURCH: Well, hopefully none that'll wind up in a lawsuit. I'm tongue tied here. One of the big challenges that I was concerned about when I took over as the program manager in 2002, or 2001—Servicing Mission 3B happened in March of 2002. We were well along on the development for that mission. There were a couple of interesting things that happened to me, personally. One was, I don't think I was in the job more than a few weeks when I got notice that somebody had been talking to Dan [Daniel S.] Goldin, the [NASA] Administrator, who was a tough individual to deal with. And he heard that we were planning on changing out the power control unit, and somebody had been talking to him, saying that this was a risky thing to do and they didn't think it was prudent. So he asked for program to come down and give him a special briefing to explain to him why this was the right thing to do.

I'd only met Dan Goldin once, when he was touring the control center, back before the first servicing mission. And he had quite a reputation. So they said, "Well, you've got to put this briefing together, Burch. Go down there; convince him." And I'm [thinking] this guy's going to make mincemeat out of me. So we put together this pitch. I had a lot of help from Dave Scheve. Dave was really great. I remember I went down there. We went to his conference room, and there was this long table, and I thought well, I'll just sit down here in the middle part of the table. Ed Weiler came up (he was the associate administrator for science at the time). He grabbed me by the arm. He says, "No no no no no. You're not sitting here. You're going to sit down here, right next to Mr. Goldin, because you're going to explain to him why we need this."

So Dan Goldin comes in, and I'm like, "Oh boy. Not sure how this is going to turn out."

So he sat down, and we exchanged names and a few brief pleasantries, and he said, "I want you to tell me why you need to change out the PCU." He said, "I'm not going to make a decision on this." He says, "That's not my job. That's your job. But I'm going to be looking you square in the eye to see if you have a conviction of what you are telling me." So I guess I must have done a good job of convincing him, because at the end, he didn't have any qualms.

So we got through that, but the big thing that I was worried about, and I brought this up with John Campbell at the time, when he was telling me that, "You're going to run the Hubble program." I said, "You know, we've got a real problem with this SLIC [Super Lightweight Interchangeable Carrier] that we're developing." This was a carrier that was being built from scratch, unlike the other carriers that we had, which were pallets left over from the shuttle Spacelab program, and those were made out of predominantly aluminum. This was made of a lot of advanced composite materials, never been done before for the Shuttle Program, and as part of wheeling and dealing, a small contractor in Bridgeport, West Virginia, FMW [Composite Systems], was selected. And their primary experience was they made rubber fuel bladders for the Marine Corps, and stuff like that. They had no experience in these materials. They had no experience with space flight hardware, and they were way behind schedule and things were floundering. So I felt like, I'm really getting stuck with a pig in a poke here. So I kind of talked with John about that, and I didn't get much traction.

So, boy, I'm going to be sweating bullets trying to figure out how to make this work. And when the [Space Shuttle] *Columbia* [STS-107] accident happened, after thinking about what a horrible tragedy it was, it then dawned on me that suddenly the SLIC schedule wasn't going to be a problem anymore. But little did I know that it was going to be even less of a problem, because for the next year or so we continued to make progress on getting ready for Servicing Mission 4, but finally the administrator, Sean O'Keefe, made a determination that it was too risky to go back to Hubble and that he was unwilling to subject the astronauts to that risk.

My boss at that time was Dolly Perkins. She had then become the head of the flight projects directorate, succeeding John Campbell. She was holding a management retreat down at the Wye River Plantation. I had to drive from my home out there, which I live in Columbia, so it was over an hour drive. Anyhow, I got out there early in the morning, and she ran up to me, and I said, "Hey Dolly! How's it going?"

She said, "Did you hear that Servicing Mission 4 has been canceled!"

And I started laughing. I said, "That's a funny joke."

She said, "No no no! I'm serious."

I said, "What are you talking about?"

She said, "It was in the *Washington Post* this morning. O'Keefe has canceled the Servicing Mission."

And I'm still looking at her like, "Okay, where's the punch line here?"

Finally, she convinced me that it was real. And she said, "You need to get back to Goddard and get the troops together, because he's going to be coming out there." So, I immediately tore back to Goddard. And O'Keefe came out, and John Grunsfeld had convinced him that he needed to talk to us face-to-face about his decision. So we pulled together a relatively small group of people. I don't know, there might have been 30 of us or so in the room. You know, we introduced him to everybody, and then he explained his rationale, and there were some good questions that he was challenged on, but it was clear that he had made his decision. So needless to say, we were all stunned.

At that point, some wheels started in motion. Are we really thinking about everything? Has all this really been properly assessed? There was at least one individual who worked on the program under me, who was my deputy program manager, technical, Dr. Mike [Michael L.] Weiss. He was very close to the Shuttle Program. Had a lot of good friends down there. He started talking to some folks down there about the risks and whatnot, and he started getting some information from them that indicated that the risk wasn't really well understood or appreciated.

Then, in the meantime, we were also talking with Steve [Steven V.W.] Beckwith, who is the Director of the Space Telescope Science Institute, and if any one individual, besides [Senator] Barbara Mikulski could be credited with saving Servicing Mission 4, I would have to say it was Steve Beckwith. Steve and I were in discussions and he put us in touch with a *New York Times* reporter who interviewed me and Mike Weiss, and we told him what we thought about the risks and the need for canceling it. And this article was published.

I was pretty nervous about it at the time, seeing as I was really going around our management team, and so we weren't referred to by name in the *New York Times* article. But the article, when it came out, really cast big doubts on the wisdom and the need for curtailing the servicing mission, because they were still planning to go back to the Space Station, and so at that point, that was when Mikulski came out with her "Dear Administrator. I think we need another opinion," letter. And that's when the wheels started to come off. So a month later, Sean O'Keefe came back out to Goddard, for a second meeting with the same group of people and said, "Okay, you know, you guys read what Mikulski has said, etcetera." And so he challenged us to come up with a robotic means of doing Servicing Mission 4; at least the essential elements of it, and so our team is always up for a good technical challenge.

We had already anticipated this, and it's a funny story. Cepi is very forward looking, as you probably are aware.

GAINOR: Yes.

BURCH: He's a real visionary. So right after the *Columbia* accident he realized we're really on thin ice here, and there's a real possibility that this thing may not happen. And if that happens, how are we going to save Hubble? So he immediately started thinking about a robotic servicing mission. This was almost a year before it was canceled. So Cepi got together with a number of his engineers and even some of the astronauts, and they started thinking about all the things it takes to do a servicing mission; how we could translate this into a robotic mission. And at the time Al [Alphonso V.] Diaz was our center director, and he was forever calling me up in the morning. And anyhow, one morning, he called me up, and we started talking about one thing or another, and I guess I was trying to make conversation or something. So anyhow, I said, "And you know, Al? One of the things we're really doing to try to make sure that we try to keep Hubble going is Cep's off looking at a robotic servicing mission and what it would take to do that."

Well, my God! It was like a nuclear bomb went off over building 8. He started screaming and yelling at me, "I don't want somebody to work on a servicing mission!" And I'm holding my phone out here, like this, and my secretary could hear him screaming and yelling.

"Okay, Al. Okay, Al." So I went back to Cep, and I said, "Cep, I made a mistake. I spilled the beans to Al about what we're doing, and he's not happy about it, so we're going to have to fly under the radar on this stuff. So, keep doing what you're doing, but we've really got to keep this hush-hush, because he's not supportive of it." And once in a while, word would leak out.

I remember the guy that was the deputy center director at the time, Bill [William F.] Townsend. I remember him telling me at one of our monthly status reviews, "You guys just don't get it. You know, servicing is probably not going to happen, you know." But we were continuing to push things along. So finally when O'Keefe came out and challenged us to a Hubble robotic mission, we already had in place a lot of the ideas and concepts for doing such a mission, so we sent Jill McGuire and some engineers up to McDonald-Detweiller and Associates up in Canada who built the Dextre [Special Purpose Dexterous Manipulator] robotic capability for the Space Station, and we put together a video that showed how the robotic arm that's used on Dextre would be used on an unmanned mission.

GAINOR: Yeah. I've seen that.

BURCH: Oh, you've seen that, okay. So that became a road show. So myself and Cepi and Jill McGuire went down to Headquarters to brief people. We gave several briefings on this, and it was all very convincing. They looked at it and thought, "Yes. This could really work." We'd figured out ways to open the electrical bays; ways to manipulate the various electrical connectors—all the essential tasks that had to be done. So we put together a concept for a mission, and took it through as far as the preliminary design review, which we passed, but after about a year of working on it, Sean O'Keefe decided to cancel it, and it was shortly after that that he left, and Mike [Michael D.] Griffin came in.

I'll have to be honest with you. In my own view, I'm a pretty optimistic guy and a daydreamer, too. The cost of this servicing mission, I think we stopped counting when it hit about 1.5 or 1.7 billion dollars. And it had a lot of potential single points of failure in it, and I think it would have been a challenge for this thing to come off successfully. And if it hadn't, it would have been another huge black eye for NASA. So I think Griffin absolutely did the right thing. He bore into the technical details of the shuttle vulnerabilities and risks, and got those beat down to a level that everybody felt comfortable with, including the astronauts.

GAINOR: Right.

BURCH: But it was a pretty exciting time, and I think in retrospect most of us believe the Hubble Robotic Servicing and De-orbiting Mission (the HRSDM, as it became known) served three useful purposes. Number one, it kept the team together, it kept them hopeful and motivated. Number two, it gave us the platform to go off of and continue to evolve the robotic servicing technology, which is what Cepi now does with his satellite service and capabilities office. And number three, it also gave us some important data and a concept for ultimately de-orbiting Hubble. The original idea was that Hubble would come back the way it went up, only on the space shuttle. But with all the changes that we've made to Hubble over the years, with the rigid solar arrays and a lot of the equipment that was installed, that equipment was not designed to survive the re-entry loads that a shuttle return flight would impose. So we would need another mission of several days length and the pallet to take all this stuff off of, and to put it on and then jettison, and then have that come in so that we could bring back an important museum artifact, which now isn't going to happen, at least not any time soon.

GAINOR: During that time, did you have to make special efforts to nurse Hubble along? Because that was a long period of time.

BURCH: It was a long period of time, and that's a very good question. We continued to develop the flight software for enabling Hubble to continue to operate on with a minimal number of gyros. I think we had a one gyro science mode. That was one thing.

GAINOR: And they still have that ready to go?

BURCH: Yup! God forbid! Another thing that we worked on was we had been really concerned leading up to Servicing Mission 3B on the state of the batteries. We were concerned about whether we would get to Servicing Mission 4 with the batteries that we had, because the batteries were starting to deteriorate. So what we found out was the occasional testing that we were doing on them was actually deleterious to them, so we stopped doing that. We came up with more optimal ways to operate these nickel/hydrogen batteries, which helped to preserve their integrity; to slow the rate of decline of their charge capacity until we got to Servicing Mission 4. So that was a big deal, because for us, we thought that the batteries at that time were going to perhaps be the ultimate life-limiting factor on Hubble. So a lot of effort was spent on that.

GAINOR: Okay, and I guess shortly after Servicing Mission 4, you moved on to other things.

BURCH: Yeah, I spent the year after Servicing Mission 4 morphing the Hubble office into an office that is now known as the Astrophysics Projects Division. So the Hubble program office, when I was there was responsible for not only the Hubble Development project and Hubble Operations project, but another project called the SSMO, the Space Science Missions Operations project, which had roughly 18 space science missions that were being operated. A lot of them out of control centers here at Goddard, and they're done on very minimal budgets, and we try to make use of some of the Hubble infrastructure and lessons learned, and that sort of thing to make them more successful, and to maximize the return from those other instruments.

But in addition to that, we started focusing on the future beyond Hubble. So there are two programs: The Cosmic Origins program, and the Physics of the Cosmos program (PCOS), and at the time they had some fascinating missions that were under initial conceptual development, including things like LISA, the Laser Interferometer Space Antenna, which is a mission to detect gravity waves, and use gravity waves as a means of exploring the universe. You know, most of our missions use the electromagnetic spectrum, you know either visual, or infrared, or radio waves, whatever it is. This is a totally different spectrum – gravity waves, and you can potentially do things like look inside a black hole. So, nobody has ever detected a gravity wave. They've been theoretically predicted to exist, and there are laboratories on the ground that are quite enormous and quite expensive that are doing research in this area. So this is a whole new technology endeavor. So that was one of the programs or missions.

We were looking at another one, the Joint Dark Energy Mission (JDEM). So this was to explore dark energy and to better characterize it. Another one was the International X-Ray

Observatory (IXO) which was going to take x-ray astronomy to the next level. So these are all tremendously worthwhile projects, but they also require a tremendous investment, and so those aren't going to be happening any time soon.

But anyhow, I spent a year getting the office oriented toward supporting that windup work, and then likewise the Hubble Development Office morphed over into the Satellite Servicing Capabilities Office. I stuck around for a year to do that, but my boss called me up one day and said, "I think you need something a little more challenging." So I started up the Joint Polar Satellite System program, and we started up from scratch in February with hardly any money and hardly any people and built it up to what it is today.

GAINOR: Good. Well, I think we'll wind it up there.

BURCH: Okay. Alrighty.

[*End of recording*]