HUBBLE SPACE TELESCOPE OPERATIONAL ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY CHRISTOPHER GAINOR
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The questions in this transcript were asked during an oral history session with Joseph H. Rothenberg. The text has been amended for clarification and for publication on this website.

GAINOR: Okay, it is September 27th, 2016, and it's Chris Gainor, and I'm in Mountain View, California with Joe Rothenberg. Okay. Maybe you could just tell me about, just quickly, some of the things you did before you got involved with Hubble [Space Telescope, HST]. I'm particularly interested in hearing about your work with the Orbiting Astronomical Observatory [OAO].

ROTHENBERG: I was fortunate, right out of college, to go to work for Grumman Aerospace, and it was a time when there was a lot more work than there were people. Within three months of my joining Grumman as an instrumentation engineer, I was recruited to work on the Orbiting Astronomical Observatory project, a Grumman Contract with NASA Goddard Space Flight Center [Greenbelt, Maryland] because of my instrumentation, electronics background of three months. [chuckles] Within three months of joining the project, I was heading up a group that built all the test equipment for testing the satellite, launching it, taking care of the satellite on orbit.

The Grumman Orbiting Astronomical Observatory contract included four flight satellites and a prototype, in then-year dollars, about $50 million each. They were not trivial satellites. They were the first space-based, three-axis stabilized, with precision-pointing optical telescopes conceived by Lyman Spitzer in the late 1940s. The idea was reduced to practice at Goddard in the 1960s; there was a prototype of four satellites. When I joined the project, they were just building the prototype, so I got involved in all of the development of all the ground support equipment and simulators to support the thermal vacuum testing. I grew from that into leading all test and launch support operations.

The first Orbiting Astronomical Observatory [OAO 1] failed after three days in orbit and we had a year-long redesign effort with a lot of NASA Goddard engineers working with us at the Grumman [Bethpage] New York facility. At the same time the satellite final integration and test work was moved from Grumman's Bethpage Long Island, New York facility to Goddard Spaceflight Center, I was asked to support the planning and conduct of the test program at Goddard that would help ensure that the second OAO satellite would work on orbit. As a result I spent a lot of time down at Goddard and Greenbelt in 1966. That's where I met Frank [J. "Cepi"] Cepollina, incidentally.

Frank is the father, as far as I'm concerned, of satellite servicing. Had a lot of creative ideas, was tenacious, and followed through in spite of other people not believing it could be done. Nothing can't be done in Cepi's vision. If he conceives an idea and he believes it can be done, he does not stop pursuing his ideas until he hits the absolute brick wall, and even then, he will try different tacks until he gets diverted to a new idea.

Cepi, I, and a lot of other folks, spent a fair amount of time developing a test article called Test Article 2, a prototype of the OAO 2 to be subjected to extensive testing to demonstrate that all the problems we learned from the OAO 1 failure on orbit—and it was in the phase of the US space program where we were still learning about things that happened in space—that you couldn't or did not understand enough about to simulate and test for on the ground. There were extensive systems design changes from OAO 1 to OAO 2 that were incorporated in the test article.

The NASA/Grumman team designed an extensive test program that included a new hifidelity test environment that simulated what the satellite saw in space, in terms of power coming out of the solar arrays in guide star simulators, to test tracking, thermal temperature stimulators that were more sophisticated than used to test OAO 1.

So I spent a lot of time at Goddard between 1966 and 1968 to support the OAO 2 test program and at Cape Canaveral [Florida] to support the launch. After OAO 2 was launched, I was asked to lead the field support group at Grumman's Bethpage facility that provided the design and test engineering support to the Grumman test at Goddard, where the remaining satellites were integrated and tested. OAO 3 and 4 were designed and subsystems were built and put together at Grumman's Bethpage Facility, and then they shipped it down to Goddard where the final integration and test was conducted by the Grumman team. As the lead to the field support engineering team, I was responsible for the design upgrade and maintenance of the test equipment at Goddard and the launch support equipment. This included the responsibility to ensure that the team at Goddard had the Bethpage based engineering support they needed for testing, launch, and to resolve problems that they found during test and orbital operations. I was also responsible for the flight instrumentation that went onboard the satellite to measure pressure, temperature, currents, and all of the information operators needed.

So I did that for almost eight years, after completion of the launch and initial orbital operations of the last OAO [4]. During that time, relating to Hubble, (if you want me to continue down the path), Frank Cepollina had this idea about servicing the satellite on orbit, and Cepi was the kind of guy [that said] contract, no contract, let's go work on this interesting thing. And of course I was always looking for an interesting engineering problem to work on, and satellite servicing sounded interesting to me. Cepi had us working on tasks to look at how would you normally replace a component on the ground and how you would do that on-orbit. As one example of the challenges, the technology at the time for mounting a typical electronic component on a satellite required a very flat machine surface and thermal grease to ensure conductivity. How do you do that in the zero g [weightless] environment in-space? The second piece of it is how do you mate electrical connectors when you can't quite see what you're looking at if serviced by humans or remotely if servicing were to be done robotically. And so, we looked at the various techniques at the very low-level technology level to understand what changes in design approaches were needed to allow for on-orbit servicing.

Fast-forward, we finished the OAO program integration, test, and launch. Frank Cepollina was now off on a path of developing what was called a Multi-mission Modular Spacecraft [MMS]. It was the first spacecraft specifically designed to be serviced on-orbit, and the Grumman team helped him design of one of the modules, the power module, for an MMS prototype. As a reminder, we had at this time all four OAO satellites, but we still had a set of spare OAO components on the ground. He took a lot of that spare equipment, and by hook and crook is the best way to describe it, he created, pretty much, a fully functional MMS prototype satellite that demonstrated how one could autonomously service a satellite on orbit. Specifically he developed a design that had three modules that looked like saddlebags that were easily replaceable with a single large screw-like actuator for each module, and that became the servicing concept he proposed for a long time. And on the SolarMax [Maximum Mission satellite] repair, he demonstrated it worked.

I headed up the operations team for the SolarMax satellite. In my role at Grumman, which by the mid 1970's included the responsibility for all Grumman Goddard contracts and we were awarded a contract to develop the on-orbit operations for SolarMax. I was looking to recruit a project manager to lead the SolarMax operations team, but after thinking about it, I decided it was time for my family and I to get off of Long Island for a couple of years. We did. We went down to Greenbelt, and I put together the operations team that developed and conducted the on-orbit operations for SolarMax.

About six months after launch, SolarMax began to experience fuse failures that disabled the reaction wheels and thus curtailed the mission. As an MMS design-based satellite, it was designed to be serviced on-orbit, and Cepi convinced NASA and the Congress to fund SolarMax. My Grumman flight operations and Bethpage engineering team began working closely with Cepi to plan and ultimately conduct the on-orbit servicing.

At that same time, I also had an opportunity to join the government. I did, but to work on Hubble. Hubble needed help in the operations development area, and NASA recruited me to join the government to lead the mission operations development for Hubble, and that was in 1983. Once the SolarMax servicing was successfully completed several key members of the team joined the Hubble operations development team, which later turned out to be fortuitous.

GAINOR: So OAO was in no way serviceable. Was Cepi just kind of looking over your shoulder while you're doing that?

ROTHENBERG: What, on OAO?

GAINOR: Yeah.

ROTHENBERG: No, no. He had the responsibility to develop the test article to be used to demonstrate that all the problems that we had on OAO 1 were actually fixed on OAO 2, so he led the development of a prototype of OAO 2. A test article that duplicated the design of OAO 2 was subjected to a large number of qualification tests—electrical, avionics, power, thermal, and battery testing—to ensure we adequately addressed all of the on-orbit design problems we found on OAO 1. So, he ran that program. But Cepi was always working on three things. He never worked one thing. I could tell you Cepi stories all night. I worked with and consider myself a friend of Cepi's for over 50 years.

GAINOR: Was this work with SolarMax a factor in you getting the job at Hubble then?

ROTHENBERG: Many of the NASA people I worked with on OAO, worked on SolarMax after OAO. Immediately after SolarMax was launched, and well before the need to service SolarMax occurred, most of the NASA Goddard people I worked with on OAO moved on to Hubble. When the need came up on Hubble for a new mission operations manager, they recommended me for the job.

The background leading to me being asked to join NASA really started during the OAO 2 test program development work I did with NASA/Goddard. During the OAO 2 test program development, I became part of the Goddard team *versus* part of the Grumman team. I became a good liaison between NASA Goddard and Grumman. The relationship between the whole Goddard/Grumman became one team pretty quickly. But initially, it was arm's length, and the Goddard people, when they came up to Grumman, they talked to everybody and they asked me to come down and work with them. And I was probably one of the first ones to start with, and then a few more joined. NASA Goddard decided in their plan for going forward, and they would need about 200 Grumman people down at Goddard. As the Grumman team grew at Goddard I transitioned back to Bethpage, and as lead for the field support team, I in essence became their person on the other end.

However, in leading the team that developed the operations for the SolarMax, it demonstrated to NASA that I also knew something about operations, which I did but was not an expert. I had a good team. I learned a lot about operations on SolarMax. I knew satellites, I knew satellite subsystems, but to think like an operator and understand that was a big learning curve for me and my team. I only had a few people that actually worked on a satellite operations team before my team, but we got a couple of graybeards to educate us and work with us and give us advice, and that turned out to be very successful.

GAINOR: And you started on Hubble at Goddard around?

ROTHENBERG: 1983. August 20-something. I can't remember the date. It was important that on-orbit satellite servicing was one of the attractions to me about Hubble. In there was a (National Academy of Sciences I believe) summer study that looked at the alternatives for maximizing the orbital operating uptime of the Large Space Telescope [later named Hubble]. You may be familiar with the summer study. It was conducted at Woods Hole [Massachusetts], I believe.

One of the goals of that study was to look at alternatives to maximizing uptimes in terms of the investment in satellite systems redundancy, having multiple satellites and on-orbit servicing. I don't remember all areas the study covered, but the one thing I remember that came out of it was that on-orbit servicing was the most cost-effective alternative for maximizing reliability. Cepi has a curve that probably still sits on his desk that Grumman produced from the study results that shows the cost of reliability versus uptime achieved by servicing. And I guess at that time, with the space shuttle being touted by the agency at $5 million a flight, it's going to fly every two weeks, it was very attractive to have servicing as the way of maintaining the uptime on the telescope, which is another way of expressing reliability.

GAINOR: There was a lot of talk at the time of just grabbing a telescope and bringing it down.

ROTHENBERG: Yeah, in fact that was still in the program when I joined as the operations manager. The way they had planned it was every five years they were going to bring it back. They looked at a number of options in that study, but the baseline plan when they issued the contract out of Marshall [Space Flight Center, Huntsville, Alabama, MSFC] to Lockheed, was every five years they would want to bring it back. I think they were going to have a servicing mission, and really it wasn't a servicing mission in those days.

It was geared to be an opportunity to revisit, to upgrade it, to change out the instruments, and incidentally, if something was broken, we could fix it. Historically, the benefits of being able to upgrade the instruments was the key selling point for science community support of a serviceable satellite, and it was not emphasized that it was also a repair mission. That terminology changed and the first servicing mission was more commonly called a repair mission for obvious reasons – spherical aberration. Although the more common name for the first servicing used by the media was the repair mission. I always liked to refer to it as the first servicing mission.

But back to your question, in'83, '84, there was a pretty big cost overrun projected for space telescope. If I remember right, there were $300 million—the program was at the $500 million range in that time—and I think there was a $300 million infusion of money at that particular time. It was pre-[Space Shuttle] *Challenger* [accident, STS-51L]. They replaced a number of the management team down at Marshall, and some at Goddard, and that's sort of how I got hired. That's what created the opening. The agency was not hiring externally at the time. The job was originally advertised for only a civil servant, but I was told that there wasn't a qualified Goddard civil servant interested in the job, so I applied for it. (I was advised to.) And after they went through the round with the civil service applicants, they opened it up to external applicants, and I was brought onboard.

So early they really thought about returning to Earth and they dropped that from the program. They dropped returning to Earth and they targeted every three years for servicing. Every three to three and a half, if I remember exactly, *versus* returning to Earth. And you can think about it. One of the features of the Hubble is it's extremely clean, extremely particulate-free, no dust to scatter the light. You bring this thing back to Earth, you have a huge vacuum cleaner, right? Because as it re-pressurizes, now it creates a problem.

The second thing is to get that the satellite off the ground took a lot of people, a lot of money, and a lot of political support. The astronomy community has many mission demands. Hubble is just one of them. And even a large fraction of the science community looks at Hubble or looks at JWST [James Webb Space Telescope] as a big money sink and taking resources away from their research areas. They'd rather have twenty smaller programs. So I did not, and I don't believe that anybody else believes, that if they brought it back to upgrade it'd ever get Hubble back off the ground again.

GAINOR: Yes, I remember both of those ideas.

ROTHENBERG: Also I believe, frankly, if they had a program that said every five years, we're going to put a new Hubble up there, we're going to build on the other one, and we're just going to launch it, it would have been cheaper than the original plan; however, it wouldn't have been a sustainable program. Would we ever get to build that second one? Or would the latest priority in the scientific community divert to a higher question of the dollars that were being earmarked for UV astronomy.

GAINOR: So you were the program manager at Goddard at the time?

ROTHENBERG: At which time?

GAINOR: Say, the late 80s.

ROTHENBERG: Late 80s? No, I was brought on as the mission operations manager in 1983, left the program in 1987 and was asked to come back and head up the repair mission shortly after spherical was discovered in June 1990. As mission operations manager, my responsibility was to develop from scratch how we are going to operate the satellite. First from a flight systems safety viewpoint, and second getting the imagery to ground and processing it for use by the scientists.

GAINOR: And Marshall was busy building the thing.

ROTHENBERG: Marshall had the responsibility overall for the program. They were the lead center for the overall program; they had the responsibility for building the spacecraft and the optical telescope assembly. Goddard had the responsibility for building the instruments and all the electronics required to take the instrument data and get it into the communications system to the ground. So they had the instrument package and all of the electronics behind it, and the electronics had a name, but I don't remember. There were five instruments: four telephone booths and one piece of pie. And the other three pieces of pie were the Fine Guidance Sensors [FGS]. The second responsibility that Goddard had was the ground system and operations. And I was brought in to be the one who led the team to develop the operations, and it was a Lockheed team located at Goddard that was the lead operations contractor.

Bendix at the time [later Allied Signal then Honeywell] also was part of the Lockheed team, and there were two challenges. One was to develop the operations, second was to integrate all the pieces of the ground system needed to conduct the operations. The Space Telescope Science Institute [STScI] was responsible the ground system operations for all of the science operations. The STScI puts the plans together on an annual basis to optimize the observing time of the telescope that includes scheduling observations to minimize blockage of the Earth and lost time slewing from target to target over the astronomical year. They developed a Guide Star Catalog access system, allowing them to rapidly select guide stars as deep as the 15th or the 14th magnitude so that Hubble could maximize the flexibility to observe scientifically interesting targets.

They were responsible for all of the processing of the imagery, laying out the schedule of the collections of the targets, and sending that down to Goddard, and Goddard did what we called a constraint check on that to make sure that it wasn't violating any limits, such as bright object down the telescope, or bright object in the Fine Guidance Sensors. They had a system that did that also, and now they're integrated, but at that time there were two separate systems. Just because of the heritage or culture, for a short period of time before I joined Goddard, I was actually a consultant at the Science Institute. That's how I met Riccardo Giacconi.

When I was consulting, the Aura team was selected to operate the institute and Riccardo had just been named as the first director. I met him, and then later on he tried to hire me, but that was right before I went with Goddard. He and I remained pretty good friends but I haven't seen him in about 6 years. In fact he wrote about me in his book, which was surprising because at that time I hadn't seen him in almost 10 years. I go into a book signing and found out I was invited because of a few mentions in his book.

Anyway, the point I'm going to make is I was responsible for taking what the science institute did, along with the pieces that were built by a number of different contractors in Goddard, that weren't in the same organizational units within Goddard, and integrating all the plans, systems, and demonstrating via tests that we could operate the spacecraft and all the instruments prior to launch. We started testing by sending one command, and by the time we finished, we ran a whole day in the life of Hubble while the assembled satellite was at Lockheed in Sunnyvale, California, remotely from Goddard. "First light" on the ground for Hubble was part of the test and was achieved by shining a bright light down the telescope and seeing with the Wide Field Planetary Camera [WFPC]. So that's what I did.

Challenger happened before that and the Hubble launch date was uncertain. We finished our ground systems and operations testing, and I got selected to head the Mission Operations Division at Goddard, responsible for the operations for all NASA Goddard projects: building the ground systems, flight operations, and all activities associated with on-orbit satellite operation. I did that for couple of years, and then I got promoted to the Deputy Director of then Goddard Mission Operations and Data Systems Directorate, where my responsibilities included not only ground systems and operation, but space communications flight dynamic and data science processing.

The following year, in 1990, Hubble launched and shortly after that there was the discovery of spherical aberration. Between Charlie [Charles] Pellerin, Head of NASA Astrophysics Division, and Ed [Edward J.] Weiler, Hubble program scientist, and Jack [John W.] Townsend, I somehow got asked to lead the Hubble project. I thought about it for few minutes, actually probably less than a minute, and said yes. I really wanted to help and I believed that it could be fixed. I also believed from a management viewpoint, I needed to fix the team first, because they were totally demoralized and peeling the Hubble bumper stickers off their cars.

GAINOR: Right. The book I'm doing basically starts off with the launch of Hubble, but I am interested in the work you did to get it ready for operations. And the question that comes up all the time is what would have happened if *Challenger* hadn't have happened, and you had launched in '86. A lot of people say it would have been a lot worse than it was.

ROTHENBERG: Well, the spherical aberration was there. There was no question about that. Was the ground station ready to operate the satellite efficiently? I can personally say, from a health and safety viewpoint, we were ready. There was no problem. To execute science operations cleanly, including getting the proposals into the system in a user-friendly way from astronomers around the world, that capability was far from ready. And in fact, there were a number of ingredients. One was the science ground system was immature. Second was the operation concept and procedures to conduct operations were immature. The science community didn't have confidence in the system that Goddard was building.

Goddard contracted with TRW [now part of Northrop Grumman] to build a ground system call the Science Operations and Ground System called SOGS, and that was a major enabling piece of the science operations. The Science Institute had outstanding scientists and engineers but there was always a friction between them and Goddard. The scientist culture prevailed at the institute, "this is what I want, this is what I need; I don't understand why you have to go to this lengthy procurement process." And they did not have the patience for all the things that you do in a bureaucracy, so there was always this friction. So basically, "Give it to us, and we'll get it done."

But they also were used to developing software that would work well but didn't have a lot of documentation, and long-term system sustainability would be difficult. And we needed to have something around for 15-20 years. We needed to have some system and documentation robustness, so as things evolve, the new requirements of technology change, we can build on it, and I don't have to go find the guy who wrote the code and hope he remembers what he did. There were a million and a half lines of code that were just integration code for the system. Not the basic ground system itself.

So it was a huge system, and they had five different contracts, five different contractors, five different approaches to developing things. We spent one year or two years trying to resolve the question on a particular equation, which was the best way? So at the end of the meeting we would always talk about it, debate which way, and then we keep our agenda. We went about two years before we said, "Time! Pick one!"

I agree with you that we were not ready in 1987 and would have operated very inefficiently if we launched. We would have operated safely. We would have gotten images, but there would have been a lot of questions about the quality of the image, itself. For example, it would have been very inefficient to distinguish problems with the flight instruments/software from a problem in the ground processing, because we hadn't had enough run time, confidence, or scientific community confidence in the ground system. So that would have been part of the equation of trying to understand and resolve problems while the whole world was watching. I think they would have got there pretty quick but suffered a lot of criticism in the process.

One thing about NASA—Goddard in particular, NASA in general—when a problem arises, they all of a sudden shed bureaucracy, remove organizational barriers, and start working the problem. So I think they would have gotten there eventually, but it would not have been pretty at the front end, and it would have been a lot more confusion in understanding that we had spherical. What we would have had to do if we would have launched in 1987 is set expectations for success in term of a phased bring up of observational capability, collection efficiency, and Hubble Image/Spectral products. Setting expectations, if done right, can bring everybody along as a partner.

But the point is, it's creating expectations consistent with what you can deliver, and that works. There was no way to predict the spherical, and as you have probably heard from a number of people, and I learned that lesson in spades. We predicted success with Hubble in '83 and '84 that we were going to get up there and measure the Hubble constant, we're going to know the size of the universe, we're going to return these spectacular [images], and it's all we ever talked about. We never talked about the risks of space. We never talked about the risks in the technologies. In fact, we didn't even have the maturity when we were talking about what they were going to do. And that's not unusual for people selling the program, and then the designers in the front end, because they were very optimistic that we were going to succeed. And somebody needs to talk about the hurdles they have to cross and the technology. If you talk about it too much, Congress will cancel the program. So, you've got to balance.

You've got to depend on skill, good luck, and bad luck, and you can't predict the worst case. You don't want to predict that because you'll never get off the ground. And they tend to lean toward the best case.

GAINOR: Right. Was it nice to have that extra time to work things out? Like some of those tests you were talking about that took place after *Challenger*.

ROTHENBERG: Absolutely, yes. Absolutely. *Challenger* was in January of '86.

GAINOR: That's right.

ROTHENBERG: That particular test—one that did a day in the operational life of Hubble—was in March of '87, to give you an idea. We were pretty close to launch. I always had a plan; project managers—and that's Marshall in this particular case—do not like to give the ground system people a lot of time on the spacecraft. They've got such a crammed integration and test schedule that any time a ground system guy or operations guy wants for testing diverts time from building and getting the satellite off the ground. And you can always fix the operations later. So I learned that and was very successful on SolarMax, a very simple example.

The project manager was named Pete [Peter T.] Burr. He's the guy who ultimately made me the deal to come run Hubble. Pete Burr was the project manager on SolarMax, and when I told him I wanted a week's worth of ground system and operations testing in incremental chunks of time, he laughed at me and said "I'll give you two hours. Tell me when you want it." [laughs] And I said, "Okay." So, we ran the first test. We issued one command to the satellites. It was let's see if we can walk before we try to run approach. If you try to do everything at once, you'll fail and you'll never get back to the satellite. So you take and prioritize it. I want to be able to command it; I want to be able to listen to it and understand it. Then I want to be able to load commands and memory, so you sequence things to walk before you can run. So the first was a walk. We sent the first command up, and it didn't work. Of course, Pete's comment was, "You guys are not ready yet." So we looked into it, and it turned out to be a design problem with the satellite command receiver. As soon as they realized that he called me back and asked, "How much time do you want? Tell me what you want to do. Come up with a good plan, and you'll get it." And that's what I did.

So when I took on Hubble, the very first thing I did [was] I met with the project management team and I said, "I want little windows to test." And looked at the Hubble integration and test schedule and said, "Here's where I want one; and here's where I want another one." And the one that we ran the day in the operational life of Hubble, the scheduler inadvertently called it ground system thermal vacuum, and everybody got a kick out of that because it implied we were putting a ground system and thermal vacuum. I never bothered to change the name, because it stayed on the schedule and that's what I needed. No one took it off.

So I had all these test windows reserved from day one. I got on the train before they ever knew I was on the train. That was very helpful because those tests are exactly what we did. We learned what we needed to fix and we went on to the next test. I had built a concept of how to do it with a team of experienced people. That test approach and some members of the original team were part of the project through the last servicing mission. They were there at that point, almost 25 years.

So to answer your question, the launch delay due to *Challenger* did give us much need extra time to be ready for launch. We would have been able—the health and safety of the spacecraft— to probably execute a very inefficient science program that was planned and developed long in advance, with limited flexibility to change it for any reason in a timely fashion.

It would have taken take us months to put that in place, where today they're doing that daily, and so it would have been a lot slower front end. We would have had to market our expectations, and once our capabilities were understood by the team, we could have done that. We would have had images; the public would have said wow! That all could have happened but as we now know, spherical would have prevented that.

GAINOR: Well, let's go to 1990 then, and do you want to tell me what you were up to when Hubble was launched? There's not only the spherical aberration issue, but there were other things like the jitter, and the stuck antenna thing, and the South Atlantic anomaly, I think, was a little worse than people expected, and things like that.

ROTHENBERG: Ah, the last one, I don't know. Having operated OAO—the South Atlantic anomaly has always been a problem for us. It drives how you design certain things and how you can operate.

GAINOR: Do you mind just telling me what got your attention and the order it got your attention in a little bit?

ROTHENBERG: Well from the time I left Hubble, and I was running all operations, becoming deputy director, we still had responsibility for pieces of the ground system. We were supporting the project in that. One of my projects had about twenty different spacecraft we were supporting, but one of them was Hubble. So I always stayed close to it. In fact my wife supported PAO [Public Affairs Office] and as part of the public affairs team, a volunteer (that's not her job, but she worked in a different industry) and so we followed it. I was there in the background on the launch team to ensure my systems were performing.

Unfortunately, I'll say this, the operations team out of Marshall did not have real operations experience. And so during the whole deployment they were struggling. And I saw that frustration. I knew them, but I'm not in a position to give them any advice, and even if I would, it may be the wrong advice because they were in the trenches, knowing all the variables, listening. I'm just watching through the window, watching my people perform and making sure their systems worked.

The stuck antenna? That was one of the things we trained for. By the way, we had thoroughly developed all of the deployment contingency plans and trained for them. A stuck antenna was one of the things we trained for. We trained for solar arrays that wouldn't unfurl; we had a lot of things we trained for. Obviously, my real paying attention to it was when it was released from the Shuttle and then they started to see the—I watched them do the checkout. They were in my building. The team was in my building; we housed them, PerkinElmer was looking at the data. And I kept wondering why they were there late at night near the end of June, and it became obvious that they were huddling over something. No one was talking, and I wasn't in a position that I could have asked. I didn't know exactly what was going on.

As soon as I heard about it, I worried about the team that was operating Hubble and running Hubble not having enough experience with problems, and I was concerned about how they were going to react, and I offered to help. I said, "I will make time in my schedule." My boss was out for about nine months; he had just come back to work. He can run the directorate again. It's his direct work to begin with, and I can help over there. I didn't get any bite on that, so I just let it lie.

But somebody said, "I hear you're coming back to Hubble." And that was two weeks before they asked me. I said, "Not that I know of." I said, "I wouldn't mind coming over there and helping them." And people called me. Everybody knew but me, as it turned out. I was downtown at [NASA] Headquarters [HQ] and Pete Burr called me up and he said, "Hey, how would you like to come over and head up Hubble and head the repair mission?" And I had a program, and at that point the repair mission was kind of—I thought about it maybe 10 seconds, and I was higher in the organization, had enough challenges. I was enjoying myself. I said, "I've got to do it." There isn't a lot of choice. I can help. I believe I can help, and I'll do it.

I said, "But I don't care if you just have me over there. Give me some authority, but I don't need to run the thing. I just want to lead the fix."

He said, "No, no, no. Everybody, the center director, everybody said, you're the guy."

And, I said, "Okay."

I told my boss. [Associate Administrator of Operations] and both of them said, "We knew, we even knew what the phone call was about. We were down there for a monthly meeting." Everybody knew.

So then I called my wife, and I said, "We're in for a ride." That was it, and the next morning I was over there. John [M.] Klineberg, who was just coming onboard as the new center director, flew in from [NASA's] Glenn [Research Center, Cleveland, Ohio], where he was the center director. He flew in to meet me and basically approve it. He had certainly a right to say no. We talked, we chatted for an hour, and that was that. I was moved into the office of the current project manager, and the only demand I made is that I don't want to have to operate through a remote program office; I want the whole program to come to Goddard. I don't want to have to deal with Marshall. I want to have the full authority to do what needs to be done. I need to be in charge of all pieces of it.

So I called the project manager at Marshall, who I knew, and he and I used to go at it. I told him what I wanted, and he said, "I'll support you." He said, "The only thing I ask is don't move it until October so it doesn't look like it was taken away from us."

"That works for me."

And he says, "In the meantime, you're in charge, and just keep me informed so we called Headquarters and told them the plan."

I said, "Okay." A guy named Doug [Douglas] Broome. Doug was the program manager, he talked to Doug, and Doug bought into that, and—

GAINOR: He was the guy at Marshall?

ROTHENBERG: No, Doug was at Headquarters and worked for Charlie Pellerin. Ed Weiler was the program scientist. Funny story. When I took over SolarMax operations, I didn't know anything about operations, so I went and looked for some people. And Ed was Lyman Spitzer's post-doc at this time, operating his experiment on OAO, and we were talking, and I said, "Why don't you come over and help us on SolarMax." He said, "Okay." At that time Nancy [Grace] Roman contacted him and asked if he would come down and talk about joining NASA as the program scientist. He may have not started out as program scientist, but I think he did, joining NASA to work on Hubble at Headquarters. And obviously that was a better choice than operations for SolarMax. Ed and I go back, you know I've known him since he was in graduate school.

So anyway, fast forward. That night the first thing I did that was kind of important—having to decide—I sat with Al [Albert R.] Boggess and Al was the project scientist at Goddard. I got his view of the world and the scientific community, and I laid out a two-page plan. The first page, it was real simple. It was three bullets. The first thing you want to do is understand what's wrong with Hubble, not only optically, including what's going on with the solar arrays [jitter]. The second thing we want to do is take whatever steps are necessary to do what we can do to fix the problems, and the third thing we're going to do is want to ensure that the development of next generation of instruments continues.

Now the importance of that last point is that historically programs always rob from the future to deal with their current problems. Whether it's the technology programs at NASA, or in this case it would have been our next generation of instruments, to pay for today's problem. I looked at the budget. I looked at everything and I said, "I believe we have enough money the way it's laid out. [Senator] Barbara Mikulski threw in another $25 million and took a lot of credit for that, like that was all the money we needed. It wasn't quite true, but we certainly needed her support, and $25 million was no chump change. There was a couple of things that were important. Having that, then the next page was what does that mean? And so the one thing that I still remember from that is that we listed the particular instruments that were going to be on the future servicing missions. We laid out the road map and said that we were going to hold onto that. What that bought me is continued support, but skepticism from the scientific community that owned those instruments. And they helped spread the message.

The second thing is I picked at that time—December [2, 1993] was the launch—so I picked a date, and I said that's the date of the first servicing mission. No. Excuse me. The very first thing we did is we picked a date, we made it three years, so it was going to be the first of June. That was the target when we were going to work because I believe that if you don't have a schedule and a real date that everybody believes in, then everybody's going to march to their own drummer getting their pieces together to their schedule. That doesn't work. Everybody has to be working to the same schedule so you know when you need to make decisions here, to meet the overall schedule *versus* delaying decisions downstream, hoping the guy next to you is going slip when that date comes. So I made a firm schedule commitment, so that was important.

Then I said that any encroachment on any budgets such as the Science Institute budget or any of the future instruments that we might need to do, I would make the science community a full partner in that decision. That was the background, I went to the American Astronomical Society [AAS]; I went to everybody who would listen to me with the messages on those two pages and used it to get their buy in to the plan, make them a partner in the success. Al Boggess gave me a great input and helped guide me. But that became the strategic mission. Then along came the science community who went out at that point. Wide Field was identified as the first opportunity to put a corrective lens in there to fix spherical.

Meanwhile, General [Lew] Allen and the team were out trying to understand the root cause of the spherical aberration. We still didn't understand the cause. We knew the symptom, but until you find a root cause, a symptom could be just a symptom and not really evidence of the real problem until you find out the root cause and then you connect the two. Then we ran a lot of on orbit tests, brought in independent consultants to look at the data and convince themselves that indeed the mirror polishing was what had gone wrong, and the quantification of that error, and then the on-orbit measurements validating the quantifications around the error with a very small error band. And it took about a year to do that, in parallel with moving forward.

At the same time the science community went off Labor Day weekend—now the Science Institute led by Riccardo [Giaconni]—and they go off to Paris to go study what else we can do to fix Hubble. And that bothered me a little. Everybody's in Paris. Why did it have to be Paris? Why can't it be right here in Greenbelt, or Pittsburgh? So to their credit they came back. Well, they involved the Europeans as a partner and it was good. The Europeans had an interface with the solar arrays. That's another story. But they came back with COSTAR [Corrective Optics Space Telescope Axial Replacement], and you're now familiar with COSTAR?

GAINOR: Oh yes.

ROTHENBERG: So, they came back with the notion of COSTAR. I looked at it, and Riccardo called me up and he said, "Hey, can you come on up to the Science Institute? The guys have come back with this concept." And they had worked it through—you probably heard of Murk Bottema—and came up with the practical design. So they came up and they presented this thing and they said, "We believe that this will fix all the other three instruments. We've got an agreement from Bob [Robert C.] Bless and the high-speed photometer, for all his research on the high priority on the first three years. They made the presentation to me, and I said, "We can't not do this." That was my conclusion. I said, "I don't know how I'm going to pay for it, but we can't not do it."

So I then went and presented it to Charlie Pellerin. I think I went down there alone. Maybe myself and Weiler. And Charlie said, "You didn't hear this from me, but we've got to do it, but I'm not giving you any more money. I don't have any more money. And I don't want to give you money towards it, but you've got to go do it."

I said, "Okay, let me go work it." I said, "I can understand that." I had enough money; I could do some things. So Ball [Aerospace] had a price of $25 million, so I immediately doubled it because Ball hadn't built something quite like the COSTAR. There were some tricky mirrors and a lot of new mechanisms. And I said I want to double it. I went back to the science community and I went around and I said, "Here's what we want to do. Here's my sources of money." It turned out we didn't have to take anything away from them. But I made them a partner on COSTAR.

Well, they didn't quite trust me, so they put together another review committee, and they had first review with the institute, and then the Hubble Science Working Group, to understand what the fix was, and then about every two months held another meeting to review the design. We kicked off COSTAR. Along the way, here's a story, we gave Ball a sole source contract for COSTAR. To get a sole source contract of $25 to $50 million takes a year, and all sorts of things. If you happen to have the agency's number one priority, you suddenly get treated a little differently. So I went in at my normal monthly meeting with my center director and laid it out. I said, "we've got a fix for the rest of the instruments. No choice, we have to do it. It will fix all the instruments at once." Then I said to do it we'd have this concept, this COSTAR, and Ball has all the technology, they actually have a structure built already, the right ones, the only ones that will ever do it on the schedule we want. I said, "I want to issue a $50 million sole source contract." And everybody on the director's staff is looking around. They know this guy's nuts (meaning me).

Then the head of procurement said to me, "Where's the paperwork?"

And I said, "We have the whole package prepared, and I can have it on your desk this afternoon."

He said, "Give me your wristwatch."

"Okay."

He says, "When the papers get to my desk, you get your wristwatch back."

GAINOR: [laughs]

ROTHENBERG: Everything was on his desk that afternoon. That Friday we had a contract issued to Ball.

GAINOR: So, you got your watch back.

ROTHENBERG: I had my watch back too. I can even remember what time it was. But the point is, when you have the organizations number one priority project and there's a problem, people rally around it and help solve it. I don't know what he did. You know he was the procurement officer.

So one other anecdotal story at the start. The science community—I said, "Any new things I'm spending money on, I'm going to get you involved in the decision." Because they do risk not having enough reserves to do something downstream that pops up. Cepi came up with this notion of building a VEST [Vehicle Electrical Systems Test], that's building a replica of Hubble on the ground in the clean room. He came to me and said, "I've got to do it. One, it gives the engineers something to rally around, so they get to understand Hubble since we didn't build it at Goddard." The second thing he said was, "It will also give us something where we can test everything before it goes up." Well, he convinced me. We talked about it a little while. It was $25 million.

So, I went back to the science community to sell them on the need for the VEST, they went nuts. "This is a play pen your Engineers want. You guys screwed it up to begin with."

And I said, "Well, you know, I hear you, but this is one area where I honestly believe that it's going to pay off in spades." I said, "For an awful lot of reasons. The documentation for Hubble was for a one-off satellite and is redlined, and this is the only thing that's going to get us to capture what we have up there for long term servicing, number one; and number two, we got to get the servicing mission right, and the more we do on the ground to do that the better chance we have of success."

Now, fast forward, the gyros on Hubble began to fail and the replacement of the failed units was added to the first servicing mission. We now had a couple of gyros, and also we had the solar array to replace along with the science capability restoration. We worked with Bendix, the gyro manufacturer, and developed a plan and schedule to replace the gyros and also to test them on the VEST before the mission. In comes the first set of gyros. When, we plugged them into the VEST, they blew a fuse. I was a technician at one time in my life, and I thought, "I put the wrong voltage on, connect this, or we'll use breakout boxes in here to make new boxes, and put 18 volts on the 10-volt line." I figured somebody made the same kind of mistake. So, they replaced the fuse and it doesn't work again. So, Cepi and his team dug into it.

I don't know whether you know the fuse story. They discovered that the VEST fuses, which replicated the fuses onboard Hubble, were undersized . They discovered that as a result of changes in the Hubble design and servicing concepts made in the early 1980's, the designers did not go back and resize the fuses based on what additional equipment, such as gyros, they might now change on orbit, with their startup current impact on fuse sizes, and all that stuff. So we had a bunch of undersized fuses onboard Hubble. Had we not found that on the VEST, you could imagine what would happen and the public reaction when we went in and plugged in the gyro and blew a fuse. Spherical aberration would have been an acceptable mistake compared to blowing fuses. And you know, all 1,800 of us would have been cleaning up the national parks.

GAINOR: You did talk about the fuses in that [oral history] interview you did with Johnson [Space Center, Houston, Texas], but I'm surprised as hell that the VEST wasn't there from day one.

ROTHENBERG: That was the thing that caught it. We had that VEST; the VEST probably took the better part of a year to put in place. We couldn't do it right. We had to struggle. We had mechanical and electrical simulations. Plus we had the ground system to operate. We learned a lot. We got a PerkinElmer; we got a fine guidance sensor simulation. So had we not had that VEST, we would have never found out that the fuse. Again, Cepi was pretty thorough. We had replicas of the Hubble, we had the flight spares, the spare fuse modules, that's what we had in the VEST, so we knew we had exactly what was up on orbit. Then when we check the prints, of course, we realized what was wrong. So the first thing we did on the servicing mission was change the fuses.

GAINOR: I'm just surprised that they didn't build the VEST say back in the 80s or something. And like I'm not sure how they were going to work these issues.

ROTHENBERG: Hindsight is great. I could say a lot that should have been in the 80s.

GAINOR: I know that money was really tight, and that was an element in the spherical aberration business.

ROTHENBERG: I can give you a couple of anecdotal stories that, because of monetary constraints, could have led to even more serious on-orbit Hubble problems and prevented Hubble from operating at all on-orbit that were caught and fixed before launch. Spherical of course in the end was a very serious problem because it happened, and in-part because of money during the development, and Marshall's trying to stop the bleeding money, as they were continuously getting beat up for overrunning. They finally just put blinders on and pressed forward.

An anecdotal but true example of one that was caught and fixed that I mentioned above—

nowadays technology is different. They operate different. But up through the 90s, the flight computer had memory onboard, and an operating CPU [central processing unit] like any ground computer. But one of the most important things with the technology at that time was that when you uplinked, uplinked anything to on-board computer memory—stored commands, flight software updates, etc.—you dumped a computer memory readout down to the ground and verified it against what you uplinked and made sure you uplinked all of the bits correctly. For one thing, the communications links were not as reliable as they are today. There were a lot of problems. So it was really important that you could dump it.

Well, there are two ways to dump a flight computer. Turn it on and have the software generate a hardware dump, where the only thing you have to have is power to the computer. It does not require flight software to run, and after that you could command the hardware dump. I really didn't know a lot about operations when I signed up to do SolarMax. I learned from my experience from SolarMax that a hardware dump was very important because as a flight computer shut down, you had no other way of diagnosing [except] to get that data down there. So the very first day on the job at NASA as the Hubble operations manager, I was out at Lockheed, and in fact it was a joke. The project manager at Goddard, Frank [A.] Carr reported at the weekly management Telcom, "I finally got an operations guy in place, and the first day he doesn't show up at work!"

I was out at Lockheed to attend my first Mission Operations team meeting, and after hearing the day's presentations, I asked, "Do you have a hardware dump capability?"

"No."

"What do you mean no hardware dump?"

The team repeated, "The computer design doesn't have one."

I said, "Well, how are you ever going to operate it or maintain it?"

And they said, “We load it, and turn it on and it runs .”

And I said, “After a flight software load, what if the flight software does not run? How do you know the load got into the computer.”

They said, “We have to get attitude control and use this high gain antenna and point it at TDRSS [Tracking and Data Relay Satellite System] to get the data down.”

And I said, “Really?” I said, “What if you don’t get the load up and you can’t get attitude control? How do you know what went wrong?”

And they said, “We don’t. That’s what we got. There is no money to make additional changes” And I realized that I had a bigger challenge then I thought ahead of me to get Hubble operations ready. That’s why I carried this top ten risk to operations. This problem was right at the top. I created this top ten list, and we had this quarterly review down at Marshall where I would show and discuss this top ten, and once I said, “We must have a way to do a hardware type of flight computer memory dump or you will not even be successful in ground test.” One of the Lockheed flight software engineers Norm [Norman R.] Bennett, in fact he is still around out here, said to me, “We actually have what we call a boot strap program, where you load it into memory, you validate it, and it always works. Then what you have to do is get the power on, this very simple program runs and will load memory that will bring memory down at 500 kilobits/second to the wide-band antenna, the low gain antenna. We don’t need TDRSS, don’t need pointing, don’t need anything, just need to dump it down.” He said, “That’s exactly what we need.” He says, “We’ve known this a long time, but Marshall refuses to let us put it in because it’s going to cost money, and they don’t know how much because whatever we tell them, it always costs more.”

For two or three years, Norm told me they were asking for this capability. So each quarter I show my top ten to the MSFC center director and HQ/MSFC program manager, I forget his name.

Everybody. They let met me go through my spiel but never reacted I even said, "You know, even in integration tests on the ground, we ought to be able to load that flight computer and get it working." And they ignored me, and I said, "It's not going to happen." So for the first load of the flight computer during the testing at Lockheed Sunnyvale, we were back in the control center at Goddard—I and the Lockheed people at Goddard were watching, and it was right before a quarterly. The test team at Sunnyvale tried to load and turn on the flight computer but was not successful. They had no idea, not a clue why. Nor did they have the ability to troubleshoot it because they did not have the hardware dump capability. So at the quarterly, they reported, "Well, we loaded the flight computer," (I forget the name of the computer right now) and then they said, "But we did not get it up and running. There's work to be done."

Okay. Next quarterly, they still don't have it running. So the center director looks at my chart, and I made this spiel, I said, "You know, I believe I have the solution for both." And the center director looked at me, and then he looked at the project manager, and he points to me and he said, "I suspect, if you solve his (meaning my) problem, you will solve your problem."

They were red in the face. They called me to the back of the room. I said, "Just talk to Norm Bennett." I said, "He's got this program. Just put it in there! It isn't going to cost you anything!" And they did, and it worked. That was number one on the top ten. Number two was that it required ten commands from the ground to initially, after launch, turn on the Hubble communications transmitter to the ground, while sitting in the shuttle bay. My standard joke was, I got all those ten commands programmed in every possible permutation you can issue them in. And then I had another command; it prints out 1,800 résumés.

GAINOR: [Laughs]

ROTHENBERG: I now had this now as number one on my list and I was now starting to get be taken seriously, and they fixed it. The design team's original concern leading to the complex turn sequence design was that the transmitter would inadvertently turn on the during launch. After looking at it again, they realized that the power they put out was not a risk to the shuttle. So they didn't have to have ten commands. In fact they could actually launch powered up if they wanted to. And so they went and fixed that one.

But they were the two biggies. The mentality and the money were such pressure on Marshall, and the project managers guidance came from above . The center director was very dramatic, very, "Yeah, this is the way we're doing it."

GAINOR: [William R.] Lucas.

ROTHENBERG: And then he didn't understand that in an R&D [research and development] program for a satellite, it was as complex as a rocket. I'd say he was never comfortable with that. Anyway, we sent those things out.

The other thing is the solar arrays. So, a couple things about that is, number one, when the solar array as the cause of the jitter was determined, the Goddard engineers looked at their design and immediately said, "The root cause of the jitter was the lack of adequate friction to keep the boom material coils locked. The rollout booms should have been dimpled." What was happening was that in the cold part of orbit the booms would contract, and when they came back into the sunlight each orbit, the heat expanded the boom material and they popped into a new position and the resulting solar array motion disturbed the telescope pointing until the solar array motion damped out. Thus for the first fifteen minutes or so of entry in the sunlight each orbit, we were unable to point the telescope at a target and do good science. You had to wait until it damped down. So we finally developed some control laws that would help. It would start right away putting counter forces into damp out. We got it down to maybe four minutes. Our attitude control engineers said, "Oh, they could have amateurs designing it." Everybody's beating up the Europeans, but the truth of the matter is the mechanism came from Lockheed. They bought it from Lockheed at the direction of Marshall. But they got beat up for it anyway.

The second point was that the attitude control engineers at Goddard said, "We're going to write all the software that will totally damp out everything." And meanwhile, the project manager at Marshall called me up and says, "Hey, my attitude control guys are really bummed out about that. They want to write that software." He says, "I know your Goddard guys and my guy don't work together very well, but I'll tell you what. We're going to build the software in the back room." He says, "We'll develop it, we'll let you know when it's ready. You get who you want to come down and look at what we've done, and the testing, and if you want to use it at that time, you can. And if you don't, don't worry about it. I'll take care of it." But he said, "Our guys want to go through that."

Meanwhile, the Goddard attitude control guys are coming out beating on their chests. They didn't do a thing for three months. And the end of three or four months, Fred called me up, maybe a couple times, he says, "The guys think they've got it solved." So they sent the simulation data up.

My project had two control guys look at it and said, "Looks like it'll work. We've got nothing to lose by trying it." So now the center [Goddard] guidance and navigation engineers, of course, they're trying to learn how to spell Hubble guidance system. They didn't develop the guidance systems. They "wouldn't have done it that way," of course. The Goddard Hubble project team with Lockheed and Marshall tested the new software and loaded on the spacecraft. It worked and it solved the problem.

GAINOR: This is the Marshall—

ROTHENBERG: Marshall guy, the guy from Marshall. They wrote it on their own initiative.

GAINOR: Okay.

ROTHENBERG: Another anecdotal thing. Some kid named Chris Starkey came up right at the end of the thing, Chris says, "Mr. Rothenberg,"

I said, "Call me Joe." I said, "Yeah Chris, what is it?"

He said, "I'm looking forward to meeting you and I would like you to come and speak at a controls conference and talk about Hubble."

"That's the least I can do for you guys. Sure."

He says, "I'm looking forward to seeing you again." Again? He said, "You don't know who I am."

I said, "No."

He said, "I dated your daughter."

GAINOR: Oh! [laughs]

ROTHENBERG: In Maryland. He said, "Dolly from St Rose. I am one of Dolly's sons."

"The one who used to date Joyce? Joyce's friend?"

He said, "Yeah." And it was him. In fact Joyce didn't know where he went after finishing college.

GAINOR: There you go.

ROTHENBERG: She didn't know where he went. He'd graduated college and went down to Alabama with NASA and Marshall. Anyway, he knew her all along, and his mother knew he was working on Hubble as I was. But I hadn't seen her, I was so tied up in work. But I had not remembered meeting him. I only knew his family from the church.

So the second thing that I had to do was I had to go over and convince the Europeans that they needed to provide us with another solar array. And of course I got in the middle of a room full of ESA [European Space Agency] scientists, and they beat me up about the spherical mirror. I said, "I didn't break the mirror." I took my abuse for about two hours. After that, they all quieted down, and a fellow named Roger[-Maurice] Bonnet, who was the head of the ESA science program, Roger pulls me inside and says, "You got it. We'll get you the array. Don't worry about it." He says, "Thanks. If you didn't take that heat, I would have had to take it."

Then I said, "A little bit more than that." Cepi insisted that he wanted engineers onsite in the European factory where they are building the arrays. He insisted. And that was totally against ESA's policy. This became a big issue and I had to have a meeting with Charlie Pellerin and ESA's David [C.] Dale (I think he was Roger Bonnet's boss at the time but I may have that reversed) to argue our case for why we wanted our engineers in there, and I won. I don't think in the end it made a difference having NASA engineers at the ESA contractors' facilities, but it made everybody feel more comfortable.

GAINOR: Right.

ROTHENBERG: So, I don't know where you want to head. I could talk for days on Hubble. It was so many things along the way. We had, I think it was seventeen independent reviews (I don't remember the number). Dan [Daniel S.] Goldin came onboard. He comes out to Goddard, and I get to meet him. Apparently, whatever I said to him, or whatever I did, immediately I was his guy. You know what I mean? He trusted me. And in fact, everybody else standing there in a post-visit meeting, and I'm standing there, and he looks at me and says, "If any one of these guys give you a problem, here's my phone number. My cell, my home, and my phone numbers. You just call me.

You know, I never did use that. They gave me all the support I needed. And that's what I told him. I said, "No. This is the team." I said, "I'm the point man, but this is the team." As the servicing mission development got underway, two things became apparent we were going to need. More than one EVA [extravehicular activity] day from the shuttle crew to service Hubble—typically there was only one EVA day on any mission. No mission had more than one EVA, as I recall. And Cepi started to go over the line. We need two. We need three. Not Cepi, but the amount of work, and Cepi was right. So that became a problem.

The second thing is we got an astronaut, Greg [Gregory J.] Harbaugh, who was a development astronaut for EVA activities working with us. And he says, "I probably am not going to be one of the ones selected to fly on the servicing mission. You want to get the mission crew selected on this as soon as you can. This is a bigger, more complex job than we've ever done before, and nobody at Johnson is paying attention to it, or recognizes this. . Even though it's the agency's number one priority, it's not their number one priority." Their number one priority at that time was the [International] Space Station and flying the shuttle.

I get on the airplane go down to see the center director. "Yeah, we're going to name somebody shortly." Their routine was to name them one year before launch, and there are a lot of reasons for that. Later on in my NASA career I lead that part of the agency. I learned why it's probably a good idea to delay naming a mission crew as long as possible. But the point is they weren't going to name the crew anytime soon, and we were just two and a half years away from launch. We're trying to develop techniques and approaches and tools, and we don't have the crew who's actually going to do it. Their physical attributes have something to do with how you develop operations, and the way they can fit, and the way the hand holds fit, and stuff like that. So we now used the reviews, and it became clear to us that if we [explained] to the reviewers a pattern of why we needed the crew named now, "Well we have this, but we really can't solve this until a crew is named." And there's all these tasks, and that's worrying us. One of the guys was General [Thomas P. Stafford (the guy that did Apollo Soyuz). And in fact, he'll take credit for getting me named the center director at Goddard.

GAINOR: Hah!

ROTHENBERG: And then, later on, he supported me when I was responsible for the space station, at NASA Headquarters, so I got to know him quite well. But the point I want to make is that after the meeting, he gets Cepi and I in Cepi's office, and he says, "I got a feeling that it's important that you name the crew now."

I said, "Yeah."

He says, "I thoroughly agree." And he called up Dan Goldin, right from Cepi's office and said, "The crew needs to named ASAP."

Apparently, George [W.S.] Abbey was in the room with him. George Abbey left the room to make a phone call, comes back in, and said, "You'll have a crew named in a week." That was Tom Stafford's doing, but we learned how to use these reviews. We did the same thing with the EVAs. We talked about how this isn't getting' done in one day, it'll probably be two, we're probably going to need three. We ended up needing five. And each one was painful.

Cepi, of course, his style would be get down to Johnson and throw the request for whatever he needed out on the table and set everybody in turmoil, and then the JSC management would call me up. My task was to get the toothpaste back in the tube, but also get the EVA or whatever Cepi and the team needed. The team down at Johnson wanted to do the right thing, but Cepi's method of getting it out in the open and on the table was viewed as a demand, and at first blush they were inclined to push back. But on the other hand, it got what we needed in the end.

Let me go back. One of the significant things about getting the crew named was—along the way we had been training and training and training. Everybody training in the tank. And one of the experienced EVA astronauts, Jerry [L.] Ross (the EVA office now was watching what the servicing EVA crew did) looked around the room at a post EVA training debrief and said, "You guys don't have a valid contingency plan."

"Well, what do you mean?"

He said, "You've got all of your spare parts and tools stored inside the shuttle."

"Yeah, we need the temperature control."

And he says, "You know, what controls the number of EVAs is how many times we can pressurize the airlock" And he says, "So, you have a problem. And if you have to go back and get something to deal with a problem, that's a pressurization of the airlock." And he says, "That takes an EVA day out of the equation." So, we immediately started thinking about that, and we ended up putting the tools on the outside in the shuttle bay, and that was like eight months before launch. We went through a major uproar having that whole thing redesigned. We wouldn't have picked it up had we not had the crew and JSC EVA office onboard.

GAINOR: There are all these kinds of carriers and things that were put in the payload bay.

ROTHENBERG: Yeah, though the carriers for the equipment were really always there, in the payload bay. What was not there were the tools and little spare parts. You know, bolts and things like that. And it would just take, "Oh, we needed a come-along in order to close the doors on the telescope." And that was something we trained for, and that would have been inside. So the danger was we would have left Hubble exposed and unsafe for release.

We were also trained, as a team, to leave the Hubble in a way that it could be released any night, and we could come back and fix it should the shuttle have an emergency return requirement. And that was why we jettisoned the solar array, the one solar array that tangled up. I said, "Get rid of it. We don't want to leave overnight with a solar array hanging out there broken. Let's just get rid of it, and let's go to plan B." They wanted to bring it back; they were trying to roll it in and bring it back. And I said, "If we leave it there and try to roll it in in the morning, that exposes Hubble. Jettison it; get the new one on and let's get on with it." That was the only real-time decision I had to make during the mission.

GAINOR: So, later on you were in charge of the human space program. How important was that servicing mission to station?

ROTHENBERG: Greg Harbaugh, who I mentioned, he later became the head of all the EVA planning for space station, and the servicing mission helped that planning. (There were other things, of course that helped.) It was able to put some quantification that was tested in space on tasks that they could use as building blocks. So now they had a bunch of big things, this small change of solar array, this complexity, and they could use that as a way of estimating what it might take for a similar task and scale it to the size to fit. So it provided a database for them on EVA; it provided a database on astronaut stamina. So it provided a lot of information that Greg was able to factor into the space station EVA plan.

I can remember every day, when I first took over station—we hadn't launched it, and nothing was happening, and the Russians were still dragging their feet, or certain parts of the Russians were dragging their feet. All I would hear from Greg every time I went to the reviews down there, it was about the EVA wall, and the number of them was daunting. And if you look at how they were executed, the space station integration went so well, it didn't have a right to go that well. So many different countries, so many different engineering styles, and everything played together. A lot was done on the ground to help insure that, but the EVAs all went well. A couple of things, but nothing major. There was a lot of good input to it from the Hubble servicing missions, but it wasn't the only input. There was a lot of hard work by a lot of skilled people who had done EVAs, doing analysis and tank training in the work facility.

GAINOR: I got the impression that going into this Servicing Mission 1 [SM1], people really hadn't wrapped their minds around how hard it was going to be until the work actually started.

ROTHENBERG: Oh, absolutely. They weren't even close.

GAINOR: Let's say everything on Hubble had been wonderful, and they went merrily along, and then we went to—

ROTHENBERG: I would tell you that Cepi probably had a better feel than the astronaut corps because of SolarMax, his experience on that. You knew this isn't going to be easy. If you remember there was a—I forget the name of the communications satellite where it was released and had a problem; they wanted to capture it. It was about two missions before Hubble.

GAINOR: Yeah, they had to get three people out there. Yeah. Intelsat [VI], I think.

ROTHENBERG: They had this device to capture it. Well, the device depended on two clamps at the end of a 14 foot or so arm, and they had to line them up and get them up there. And that's almost physically impossible in one g [weightlessness], with everything, to do it right consistently. And they were going to do it with this spinning satellite. And they did. They captured it another way, but the point was that that led again to some inputs to the success of Hubble, because they came back down, it became clear—a couple things happened. Number one, the astronauts developed this tool on their own with some engineering help. Did not want any external review. "They believed there was no one other than the mission EVA crew who understood better how to do what was needed [to be done.] So no second set of eyes, very arrogant, independent. And of course, the result was a disaster.

And I was invited to—because of the lessons we could learn for Hubble—the review of that whole thing, and it became clear that what we did need was external eyes looking at our plans and preparations. In fact it was Jerry Ross' comment shortly after the review of this incident that actually got us into the looking at where the tools were located. That's the incident that actually led to taking another deep-dive look from the EVA office and the crew as to where the tools were located, and the orchestration of that scenario. If something didn't go right, or was needed, it became clear that we would need the airlock before we—

GAINOR: Yeah. So, I think, after that servicing mission, you went on to other things, but you were the center director.

ROTHENBERG: I actually left the agency after the servicing mission for about a year and a half. I didn't bother to mention, between the time I left Grumman in 1981 till I joined NASA in 1983, about a year and a half, I helped develop a small start-up company CTA [Space Systems]. I built up and ran about a third of the business, and I really had fun. It was at this company that we developed the SolarMax servicing and Hubble ground systems integration and test approach I mentioned earlier. I never had worked for a small company, and helping build a business was fun. I'd come out of a big bureaucracy at Grumman and now that was really fun.

In early 1993, CTA bought a satellite company called DSS [Defense Surveillance Systems, I think] they built small satellites for the Government and commercial applications and they did it all in-house. Everything was built in-house. Except the solar arrays were bought. And after CTA bought that company, the CEO of the company called me, and I was about two and a half years into the servicing mission. It was less than a year before the mission, and he said, "Hey, we bought DSS. I'd like you to go and have dinner with the CEO of DSS." And when we finished, the CEO said, "I'd like to retire one day, and I'd like you to come in and take over the company."

I said, "I can't leave NASA, not in the middle of a servicing. Let me think about it. Once the mission is complete, I might consider it." I'm thinking I'll never hear from him again. So Dan, during the mission, said to me he'd like me to be the center director of Goddard when John Klineberg retires. I said, "Really? That's a big jump from manager to the center right then. And very few center directors go up in the agency. Most of them come from outside. So I said, "Gee, that would be a great opportunity, but—"

And he said, "Well, we'll see if John will take a different job."

And I said, "No. He just supported me. I don't want to be part of that. I just can't be part of that. When he decides to retire, if you still want me, I'd be interested at that point."

And he said, "Okay. I'm going to put you in this other job. I'm going to make you the chief engineer."

I said, "I don't want to be parked in some place waiting for somebody to retire. I want to go do something." As it turned out, I got a call for CTA right after completion of the servicing mission.

"Hey, we still want to talk to you about taking over DSS." So it turned out that when Dan Goldin was at TRW, his company owned 20 percent of DSS. I went to Dan and I said, "Dan, I got this neat opportunity, and I'd like to go try it. It's hands on again, it's running something, not being an advisor." Which was what he had in mind as a parking position.

I'd told him about the DSS, and he said, "That'd be good experience for you." He said, "But I reserve the right to call you up when John Kleinberg retires." And that's what happened. I worked there for a year and half, I doubled the size of the company, I put then in the high-tech field, and I had whole bunches of successes. Just circumstances, you know, that happened, I was able to do. I took them into the green; they were in the red. Anybody could have done it, and I just happened to be there for all these opportunities to help make them happen.

GAINOR: When you think back to NASA, were you involved in Hubble really? Or were you just kind of too high up—

ROTHENBERG: First of all, I believe I was in the middle of Hubble every day and made technical, as well as management, decisions that contributed to the success. I am a very hands-on manager, and because the importance of getting the repair mission, I got involved pretty deep in every aspect of the mission development and execution. I had two projects with my office, Cepi's Hubble systems development and the science and operations project went as well as the system integration issues to deal with on a daily basis. I formally met with the project managers and lead systems engineers every Tuesday and Thursday morning to deal with issues and priorities between the projects that included making decisions on technical risk levels, schedule risk, and financial.

I went to Ball and JPL [NASA's Jet Propulsion Laboratory, Pasadena, California] each month to review the status of the COSTAR and WFPC 2. I went to the ESA contractor's bi-monthly to do the same for the solar array. I also had a monthly review of the status of the next generation instruments being built for installation during SM2. I went through the full training program for the mission both at Goddard and at JSC. Finally during the first servicing mission, I was in the same room as the engineering team and sat in on all the daily meetings to review results, plans for the next day and any troubleshooting. My role was to be the final decision maker for anything that deviated from what we planned and trained to do. As I mentioned earlier, I only had to make really one decision and that was to jettison the stuck solar array.

What was left for me at Goddard after the first mission was getting ready for the second servicing, building instruments, etc. Of course, my heart was always with Hubble, so I watched it closely as I do today. My deputy became the project manager, John Campbell, during the first servicing mission. John was one of these amazing people that I call "national resources." An outstanding engineer and manager with depth and breadth in all areas. John became the project manager when I left. It meant that was important, that it was somebody of that caliber. And they do get ready, I watched that close in, and I went down there and I sat in the—even when there was no logical reason why—but I sat in the backroom where the Goddard guys sat through the whole first mission and reviewed the days accomplishments and the next day's plan with the team every day.

Things went well, so I do not have to make any decisions except for the jettisoning of the solar array On the second servicing mission, I think that I was with George Abbey in his viewing box, you know. I just stayed engaged in it because my heart was there. Also, of course, as the center director I needed to be there in the event of a major problems as John Kleinberg was for the first mission. But what I did also is, working with Ed Weiler, the Associate Administrator for Space Science, Ed and I go way back, and at that time JWST—I don't remember what it was called at the time.

GAINOR: NGST [Next Generation Space Telescope] at the time.

ROTHENBERG: NGST at the time was being studied at JPL, and Ed Weiler—Ed's a very temperamental guy, explosive at times—he wasn't happy whatever JPL was doing. He called and said, "If I give Goddard $100 thousand, would you do a small study NGST for me?" Apparently, JPL wanted more money for the same study. He said, "I'll give it to you if your director of space science is on-board with Goddard doing the study."

And I said, "Let me get Steve [Stephen S.] Holt (who was the director of space sciences at Goddard). I said, "Let me get Steve and you and I sitting here and understand what you want. You know, I can commit to it, but I really need to make sure the Steve's team, who will do the job, will understand what you're looking for" And I said, "Don't worry, we'll live under the budget. I'll make sure of that. I've got ways to deal with that."

So Steve got all excited about this. He says, "That's a problem I'd like to really study."

And Ed called me, within a week. We hadn't even got the money transferred, and he said, "I've decided. I've never seen Steve Holt—who is an x-ray astronomer—I've never seen Steve Holt so excited about a program in my life. I'm going to move JWST out of JPL and put it at Goddard."

Then I responded, "If you agree, I will put it into John Campbell's Hubble project office, and he has Bernie [Bernard D.] Seery to assign as the project manager to get us started." And now we got this huge new program at Goddard. And there were times when the program center directors probably regretted that, especially about three – four years ago, when they were getting beat up for the overrun on JWST. As a data point at that time Ed moved NGST to Goddard in 1995, it was estimated as a $500 million program, and now it is $8.3 billion?

GAINOR: Yes.

ROTHENBERG: I, up until the spring of this year, have been a member of the James Webb Science Telescope users committee, which looks at strategic allocation of observation time to the JWST science team and broader research community. I was the "token" manager/engineer. Everybody else was a scientist.

NGST coming to Goddard happened on my watch as center director, but I also had to throw some cold water on the Goddard team culture at the time. The team at Goddard was still in the entitlement world, when the cold war era and expected that the country looked to NASA and Goddard in particular for space and Earth sciences leadership as well as satellite engineering. We restructured Goddard and put a new mission to it and gave the whole center a retransformation. Got into building satellites in a year instead of three years and five years, and set a whole bunch of metrics, and then figured out what to re-engineer, figured out ways to do things differently.

We put in place a catalogue that took advantage of all the existing busses and tailored them to the mission, and now, each time to save time, money, and put more money into the science and less money into the development, repackage it with technology, in many cases new technology. And focused on new technology, we were advancing the science, we were advancing the measuring capability, with downlink, not just upgrading it because the next generation was there. That wasn't the differentiator in that particular mission. We had a fun two and a half or three years. Then Dan Goldin called me up and asked me would I come to Headquarters and take over as Human Space Flight. That was kind of a heady thing, but it wasn't the best job I had at NASA. There were a few years it was a great part of my career. I got to go to the White House, meet the President. But the last two years it got old. It was arguing with Congress, getting beat on, you know.

GAINOR: Yeah.

ROTHENBERG: Having to account for everybody else's mistakes. That's what a Headquarters job is. You're the liaison between the administration and the legislature and the program. Your job is to advocate the program, and then your job is to tend the budget, and then your job is to take the beating when the budget is overrun.

GAINOR: You mentioned that there was a reason why they didn't name the crews until a year before.

ROTHENBERG: Oh, the reason is that once they name a crew, they then have a set of obligations, training is extensive and generic, mission specific, and finally astronaut task specific training. The longer before a mission you name them, the more time you have for things to come up that will cause you to need to replace one of that crew. So of course they don't want to increase the probability that they will have to replace people midway through the mission preparations. So they shorten the time to the minimum time they think they need for training, they name the crew there, and then 24/7 that's all they do. They train for it.

There's a whole bunch of things they can't do during that period of time. They're not supposed to do aerobatic flying; they're not supposed to do motorcycle riding; they're not supposed to—there's a whole list. The list is never published, and the reason the list is really never published is because there's probably things on that list that some of them had never thought of before, and as soon as they see the list, they would try that.

GAINOR: [laughs] Okay.

ROTHENBERG: So, the reason was really to minimize the imposition on the crew, the constrictions on them. Also the possibility of one dropping out for whatever reason, and then having to replace them. If you took two, three years in advance to train, the chance of family issues of other things, like they have flown before and now get a unique opportunity back in the military. Somebody says there's a command open leading to a general or admiral rank they can go to, you could lose them. So they minimize that time.

Also the minute they get named, then you use every inch of runway you have in front of you. You start training in every way you can make it. They live at the payload contractor for a while, look at every inch of the payload, the standard and expand the work to fill the time. Overtraining is as bad as not training enough.

GAINOR: Right. Do you think there's anything that you'd like to say? We could probably go on all day here.

ROTHENBERG: Well, the final thing was when COSTAR came in, the only concession I asked for was I needed six months more of schedule in order to make sure we want to get—and we used every bit of schedule we had. I think we had a little reserve on it, but we needed six months more schedule. We then set the date, and this was now probably February or March of 1991 when we set the date for launch in December 1993. No, two, two stories—when we set, or picked a new date, the end of '90 or early '91, we understood enough about COSTAR to pick the date. And now I got to go back to the science community. And before I did anything, I—here's why—but we'll correct the other three, and so, we did that and we picked a launch readiness date, I want to say the 1st of December, and we held schedule to ready by that date independent of what was happening with shuttle manifest.

There were people on the team who wanted more time, and everybody noted the shuttle manifest is moving around, but I kept that December 1 as our launch readiness date. I just kept pushing the team to be ready, no matter what the Shuttle manifest projected for launch, on that date. And so when the shuttle manifest moved around, everybody thought, oh, I can use that extra two weeks or month, but we held that December 1st as launch readiness date. And lo and behold, although over the three years the Shuttle manifested date for Hubble moved back and forth, they finally settled on the 30th of November (if I got it right). They picked the 30th of November, and so we get down there, ready to work for the 30th of November, of course, there was a weather problem, if I remember exactly. And it actually moved to the 1st of December. So, I said we picked the date.

We picked the date, we managed within the budget, and I had a lot of people contribute in different ways to that success of staying within the budget. For example I sat down with the Science Institute director, Riccardo Giaconni. The institute had wanted a budget of this much, I wanted 20 percent out of that budget. Well, I didn't think they should get that much, but I also needed to manage the whole program evenly to stay within the overall budget. I sat down with him, and he listened, and he said, "Okay." He said, "We'll pick a number. We'll let our guys negotiate the content of the work. This way, they own it."

And he said, "You and I will stay out of it. And when they come to us asking for you to talk to each other, we will but we won't. You know, you see we have an agreement that we're going to achieve that number." And it worked.

At Lockheed, they moved all of their work from their corporate division that built the telescope to their services division. The same people, no less support, in fact probably more, but it took a million dollars out of their quarterly rates just because they wanted to contribute. A lot of people around put a lot of effort into trying to help make it successful. And then some funny things happened. Remember I said we had all of these independent reviews. Well, we had the Inspector General come in—I think it was the Inspector General. I'm trying to think who sealed the big investigation, congressionally mandated.

GAINOR: The General Accounting Office [GAO]? That's the big congressional thing, I think.

ROTHENBERG: It may have been GAO. The GAO came in and they were investigating us, wanting to make sure that we were using the money right and we follow all the rules and all that. Well, we made them such a partner when they came out, they advocated we get more money.

GAINOR: Hah!

ROTHENBERG: Then they came to the launch, came down to watch the ending, and I'm pretty sure it was the GAO, and the head guy for the GAO came to meet the NASA administrator, and they invited me up when they put out the report. And he says, "By the way, my team has never put out a report this glowing about any management team in the history of the agency." So they fully supported our plan and fiscal management.

There was one other anecdote that illustrates the kind of support we had for Hubble not only from within NASA but the GAO and other government oversight groups. One of the concerns about Hubble was we had gyro failures, and if we lost one more gyro, we'd have to go into a software hold mode. And I forget the name. But zero gyro mode, I think it was called. And that is a standard practice in operations. You don't go test contingency modes because if you ever test one, and you can't get back out of it, what do you say at the trial? So you don't turn off redundant equipment because if you turn the switch to it, and you can't switch back, you've now lost it, whether you like it or not. So, it's a standard practice in satellite operations.

The zero-gyro mode was important because what happens if the shuttle takes off, and the spacecraft, the Hubble, loses the last gyro with the shuttle now on its way there, how do you control it so the shuttle can actually get to it? And the only mechanism was the zero-gyro mode. So after a lot of gnashing and multiple meetings going through all the pluses and minuses, we convinced ourselves that it was important to test this. Then my learned out of school, you always get every stakeholder and make them partners. They make critical decisions like that because there are plenty of people who will be standing around second guessing you. So you make as many stakeholders as possible in the plan. There are many people with a stake in it, so I get everybody, including the GAO/IG in the room, and we go through all of it. Does anybody have any problem with what we're doing? No. Okay, I'd like everybody to raise their hand, and we'll record who's here and if all approve, we will record unanimous approval . And I think the GAO was the first one to raise their hand. [chuckles] Yay!

We get to do it. It was easy, with everybody in the room. Then one of them came up to me. "My guys can't endorse the decision, it's not their job." You know it was just the right thing, and then people got so enthused about the mission people went above and beyond. How can I help? What can I do?

The other funny story is up until early 1991, there was always a little quip about Hubble in the newspaper on the front page. In spite of its flawed mirror, it had this wonderful image of a sombrero galaxy that was like a textbook. And in spite of the flawed mirror, we got this thing. Everybody in the world told us what Hubble couldn't do. And that was my, the third thing on that second page, it was we were going to demonstrate what Hubble could do.

Everybody tells you what it couldn't do, but what can it do? And we discovered pretty quickly it could do pretty spectacular astronomy, and with a little ground processing correction in the software and a little integration time, it could be almost to the original spec. Of course, we couldn't now stand and say, "Well, the flawed mirror, that was a mistake, but we really could get there." We couldn't do that. We had to go ahead with the plan, but that was getting very credible world-class science out of it. But everything was always opened up with some snide remark about the mirror.

In January 1991, we were up at PerkinElmer, Cepi and I and four other people, including I think Ed Weiler. We were going to fly back out of the airport at Newberg, New York, the air force base, which was the closest airport to PerkinElmer's facility in Danbury. But a snowstorm hit, so we decided to drive back to Maryland in the rental car. We're driving down the Jersey Turnpike, and that was the night they announced Desert Storm. And I said, "We're going to get off the front page of the paper!" And that's what happened. [laughs] That's what happened. We got off the front page of the paper, we were no longer mentioned every day in the paper, and certainly not on the front page for quite a few months. The next time we surfaced on the front page was "the heroic servicing mission is being planned." It was about four or five months later, and the media became much more focused on what we were doing going forward and what got us there.

There's a lot of little anecdotes like that, but I can just remember in the car, everybody heard about that, but it registered to me, "It's going to get me off the front page of the paper. I don't have to talk to a reporter every Thursday afternoon with Ed Weiler." They had a conference every Thursday afternoon to find out what was going wrong.

GAINOR: Right.

ROTHENBERG: Ed Weiler was a great communicator, and he put that weekly telecom together so that the press would get a consistent status and not just inputs from the disgruntled science community and pundits.

GAINOR: Well, thank you very much.

[*End of recording*]