NASA Headquarters Oral History Project
Edited Oral History Transcript

Charles F. Bolden, Jr.
Interviewed by Sandra Johnson
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Johnson: Today is March 6th, 2015. This oral history with the NASA Administrator, Charlie Bolden, is being conducted at NASA Headquarters in Washington, DC, for the NASA Headquarters Oral History Project. Interviewer is Sandra Johnson, assisted by Rebecca Wright, and we're also joined today by Allyson Thomas and Shakib Ghassemieh.

We wanted to talk about Hubble [Space Telescope, HST], and next month is going to be the twenty-fifth anniversary of STS-31, and the release of Hubble, which you were a big part of that mission.

Bolden: I was a little part.

Johnson: Well, you were the pilot on that mission.

Bolden: Yes.

Johnson: We have talked about it before in an oral history, but I just wanted to go back and talk about when and how you first learned that you were going to be on that flight, and then just for a few minutes, talk about the training for that mission, since that Shuttle was going to fly further, or higher, than any other Shuttle before that. You were going to release the Hubble, and how that Hubble training impacted the actual release, because there were some problems.

BOLDEN: Yes. Big problems. I first learned I was going to be on the mission—it was an unusual crew assignment, because I was training at the time, for my first flight, STS-61C. As a matter of fact, I was actually training for a [STS-]51L. We were the original 51L crew. Then, kind of late in our flow, because the NASA Administrator had invited members of Congress to fly, we flew Senator Jake Garn in ’85 [STS-51D]. Then Congressman Bill Nelson, because he was the Chairman of the House [of Representatives] Subcommittee on Science, Space and Technology, said he would go ahead and fly to represent the House. So, he came down and was added to our crew, and Dick [Francis R.] Scobee took the Teacher in Space flight [STS-51L, Space Shuttle *Challenger*].

Our training went forever; the flight just kept slipping, slipping, slipping. But they wanted to get the crew named for Hubble. I was named to fly as John [W.] Young’s pilot for Hubble, for STS-31 which, for me, was just like a dream come true, because John was a legend. Before I flew my first flight, I actually had an opportunity to get in a simulator with John a couple of times, because he had actually started putting the mission together before I flew my first flight.

Then, I flew in January of ’86, and then 10 days after we got back, we lost *Challenger*. Everything just got put on hold for a while. When we got back to talking about when we were going to fly again, the debate was what should be the first flight? Ordinarily, Hubble would have been pretty close to being the first flight after the *Challenger* recovery, but decisions went through a lot of stuff, and it was decided, no, we’re not going to do that. We’re not going to put Hubble on the very first flight of Shuttle return. We’ve got confidence in the system, but don’t think we have that much confidence in the system.

The other thing that happened was, they reconstituted the crew, and all of us stayed on it, except John. John decided that he wasn't going to fly again. That was what brought Loren [J.] Shriver on as the commander of the crew. About midway through our recovery efforts, our crew came together, and we started training. We probably trained two years or more for Hubble, in earnest. Two of the crew members, Kathy [Kathryn D.] Sullivan and Bruce McCandless, had been with Hubble almost from the beginning. In fact, there were three people in the astronaut office; Story Musgrave, Bruce McCandless, Kathy Sullivan, who had actually been with Hubble for ages; Bruce McCandless and Story from its very inception. The three of them probably knew more about Hubble in the astronaut office than any other living human beings. That's how I got assigned to the crew, and that's how we started training.

JOHNSON: The training that you did, how did that affect the actual release? I know there was a problem, of course, with the solar array.

BOLDEN: Yes.

JOHNSON: How did you train for that possible event?

BOLDEN: That's a great story. I love this story. Training for every flight, no matter what it is, is disaster training. That's just what we call it. You see two nominal scenarios back in the Shuttle days. Just before you went down to the Cape [Canaveral, Florida], the last ascent exercise you did in the Shuttle Mission Simulator would be a nominal ascent. Nothing would go wrong, they'd let you get to orbit, so you could see what it's supposed to look like, what it's expected to look like.

That was the only nominal ascent you had in however many years you trained. Then, you did a nominal entry from what we call entry interface, when you first get back to the atmosphere. You went through the last half hour of your entry and landing. Those were the only two nominal things you saw.

With the Hubble deploy, we never saw a nominal deploy. There was no need to, because everything was going to go right, and it would be easy. Because we always do disaster training, both Steve [Steven A.] Hawley and I were the RMS operators, the Remote Manipulator System operators. Steve was prime, and I was the backup. We always had off-nominal things occur; you'd have a joint stick, or a joint failure, or something else. You had to figure out how to manually, as opposed to just operating the hand controllers, you were trained to manipulate one joint at a time, or whatever you needed to do to get the telescope out. It turned out to be fortuitous because that's exactly the way Steve had to deploy it. When he initially began to lift the telescope with the RMS—25,000 pounds—and it's a 25,000 mass—the HST began to twist instead of coming straight up as designed. Although it was "weightless," that's still 25,000 mass on this arm. Because it was so heavy, the joints didn't act exactly the way that everybody thought they were going to work. It started twisting and tilting, and I was relegated to reading attitude and position numbers off for Steve, to make sure we kept everything zero-zero-zero-zero-zero-zero. We decided to move the arm one joint at a time and that's what Steve did; he did it, joint by joint, just maneuvering the telescope until we got it up and clear, and out of the payload bay. Then we could go back to normal, automatic operations.

The other thing that we had trained for was the potential that the solar arrays might not go out all the way or not at all. We actually went all the way to Bristol, England for this training. The solar arrays were built by British Aerospace, in their facility at Bristol, England. The whole crew flew over to Bristol, and we got a brief from them, got an opportunity to look at our solar arrays, the ones we were going to fly. What they had in Bristol was a water table. It was actually a long trough that was as long as the solar arrays were when they were deployed. On that water table, we were allowed to actually manually go in and crank each solar array out, in the event of a solar array automatic operation failure. All of us got a chance to do it, but as the two EVA [extravehicular activity] crewmen, it was really focused on Bruce McCandless and Kathy Sullivan.

We were well-trained on how you manually deploy the solar arrays. We knew that that would be a bad day. If you had to do that, because it screwed with a lot of the automatic mechanisms of the solar arrays that would allow them to work forever and ever and ever. Once you did it manually, then it really messed with the automatic system. You understand that stuff because this is all software.

Then we came back, and we continued to train our very last integrated simulation. An integrated simulation, or an integrated sim, as we call it, is one where you tie in the entire team. You have the flight control team in Mission Control [Center] in Houston [Texas, Johnson Space Center (JSC)]—if you're going to go from launch through something, which we did. We actually started at launch, got on orbit and then skipped to the second day, which was supposed to be deploy day. So, then you brought in the Orbit Flight Control Team, and people at the Space Telescope Science Institute in Baltimore and the Hubble team at Goddard [Space Flight Center, Greenbelt, Maryland]. All of them were tied in electronically in a giant computer simulation.

We went through the nominal deploy, that didn't have any problem at all; didn't have the problem we had on deploy day. Then we started deploying the solar arrays. First one went out, no problem at all. Started deploying the second one, and it got out about sixteen inches, and—[makes noise]—just stopped. We went, whoa! So, the team, mostly in Houston and Goddard, put their heads together and tried to figure out what we needed to do. They came to a relatively quick decision that we need to do an EVA [extravehicular activity], that Bruce and Kathy needed to get out and undo it, because we had real critical time constraints, because the batteries needed to have the solar arrays out in order to not die. The vehicle was in a—flight control-wise, we called it "free drift," so it meant we had no power on the vehicle to keep it in a position that you wanted to be. We put it in the desired deployed position, and then turned all the jets off, for all intents and purposes, so it was now just going to go around Earth, and if it decided to drift, it would drift. We didn't want to drift too far out of attitude, so there was a pretty constrained timeline for getting the solar arrays deployed, getting the antenna deployed and getting it (HST) off the end of the arm.

The decision was made, let's go ahead and put Bruce and Kathy in the water. They left the simulator, went over to another building at JSC and donned their suits. I went with them, because I was the IV crew member, the intravehicular crew member. Got them in their suits, got them in the airlock, got them outside, then I came back to the simulator, and we simulated having Bruce and Kathy out actually deploying the solar arrays manually. We tied everybody into doing this. You know, at the end of the exercise, the solar arrays were deployed, and that was the end of our integrated sim. That was our last integrated simulation. It occurred two days before we left to go to the Cape.

We went down to the Cape, it took us a couple of days to get off, because the first time didn't work. It was my habit. I was with Steve Hawley, again. We were always trying to figure out whether it was me or Steve, because STS-61C was five attempts before we finally got off.

We finally got off. Everything went great on the first day and into day 2, right up until when we started to deploy HST. There, the training came in, because the remote manipulator system (RMS – robot arm) didn't perform as in our training. Steve Hawley had to downgrade to single joint ops - manually lifting Hubble out of the payload bay moving one joint at a time. Once we got it into the deploy position, we went to free drift on the shuttle, and we put the high gain antennas out, no problem. First solar array went out, no problem. Second solar array started going out, and [makes noise]. About 16 inches out, just, [makes noise]. Stopped! We said, "This is not happening. This can't be. It's not supposed to happen like this." The ground did what they did in our final integrated sim, and they started talking about it.

The irony was, Bruce McCandless, when motion on the solar array first stopped, he said, "Oh, you know, it's probably the tension monitoring module."

We said, "What the hell is the tension monitoring module?"

And Bruce said, "Oh, it's just a software module that was put in to protect the solar arrays from ripping themselves to shreds if they had some mechanical jam, or something like that, so that we could figure it out and get it all straightened out so we wouldn't ruin the solar arrays."

We went, "Yeah, right." We, on board, just kind of twiddled our thumbs because there was nothing we could do. For hours, the ground control team and the guys at Goddard and the Space Telescope Science Institute tried all kinds of things; resending commands, trying to retract it, trying to do stuff, and nothing worked. After several hours, the vehicle had drifted quite a bit and it was way out of attitude. There was no sun going on the solar panels, so the battery was starting to drain. All of a sudden, after a number of hours, they called up and said, "Hey, we got a young engineer here"—I think he was at Goddard—"that says he thinks it's the tension monitoring module."

We all went, "Oh, shit!" Bruce was right. Because Bruce was always right.

"He says he thinks if we allow him to no-op the tension—just turn a one into a zero, just take it out of the sequence, then everything will work. We're going to try that." They said, "Just stand by, we'll let you know when you can do something.

Sure enough, they kind of said, "Three, two, one," and [makes noise], the solar arrays started going out when they did that. He just made a software change from the ground. The solar array deployed. They took a look, and everything was good, except the shuttle's attitude. The attitude was horrible—we were well out of the deploy attitude. They said, "Okay, we need for you to maneuver it to the deploy attitude."

We said, "Are you sure you want us to maneuver with the arrays deployed?" The reason we didn't want to maneuver was because they were afraid we'd damage the solar arrays by the loads that would be imparting on them with the jets firing and the vehicle moving.

They said, "No, we need to get in the deploy attitude and get it off the arm as quickly as we can, because we're really running down, we don't have much margin left in the batteries."

So, we maneuvered on—we have two kinds of reaction control system thrusters on the Shuttle; verniers, which are small, 75 pound thrust jets each. The big ones are primary jets, and they're 750 pounds per [boom]—they sound like cannons. They said just use the verniers, and maneuver to the deploy attitude. That was where Loren and I started maneuvering the vehicle. I was up front, and he was back flying it. So, we maneuvered the vehicle into the deploy attitude. They gave us the go-ahead to release it. Steve released it, and Loren flew the vehicle away, and Hubble was gone. That's how we got there.

Then, for us, it was just a matter of following it for the next two days, because we were upside down with the payload bay pointing toward Earth. Because we were on a higher altitude, we were going to go slower, naturally. So, as we stayed up there, we just gradually drifted behind it, and down and under it. You'd end up doing this big circle, if you didn't do anything at all, due to orbital mechanics. We came back here and maneuvered ourselves so that we would stay behind it, position ourselves behind it. They didn't want the orbiter anywhere close to Hubble the next day, when they were going to open the aperture door, which was going to let light come into the telescope. They just didn't want any contaminants from the orbiter getting on the HST mirrors. I forgot what the distance was that we were separated, something like 10 or 20 kilometers, but it was so bright, that you could see it up there brighter than a star.

So, we followed it around a couple of days. They got the aperture door open, Bruce had a set of binoculars, and he could tell that, yes, the aperture door was open. When we left it, it was in pretty good shape, we thought.

JOHNSON: Right.

BOLDEN: The rest of the mission went normally—we had a lot of experiments we did. We had two IMAX cameras on board; one in the cabin and then one out in the payload by that was hard-mounted, that got just incredible images that you see in several IMAX movies. I was the IMAX camera operator.

Oh, I skipped one thing. The most important thing. The reason Kathy Sullivan is angry with me to this day. When the solar array didn't deploy, then the ground control team, after a while, said, "Okay, we need to send Bruce and Kathy out." So they said, we've got to go do this EVA. I scurried down into the airlock with Bruce and Kathy, and we got them suited up and everything, and we started depressurizing the airlock, and got it down to vacuum. We were about five minutes from opening the outer hatch and letting them go out and manually deploy the solar array, and that's when the young man came forward with, "Before we do this extreme thing, how about if we try this?" So, they said we're going to try it.

When we decided to do that, we didn't have enough time to re-pressurize, get Bruce and Kathy out of the airlock, so it meant I had to leave them in the airlock at near-vacuum, and float back up to the flight deck. Now, what was going to be a five-person operation with cameras all over the place, and me helping Steve with the arm, and me helping Loren with the vehicle, it ended up there were three of us. I had to help Steve with the arm, help Loren with the vehicle, and do the cameras that Bruce and Kathy were going to do. I was like a one-armed paper hanger.

The IMAX camera, in-cabin camera, is big. I forget how much it weighed, but it didn't weigh anything on orbit, but it had incredible torque when you started it, so you really had to have a hold of it. When we got ready to do the release, we had also trained extensively on everything we were going to shoot for IMAX. I had the IMAX camera helping Steve read the numbers, helping Loren make sure we were in the right attitude. When they said, "Release and start flying away," I made sure it was gone, and Loren was getting ready to fly away. Then I had to back off and shoot Loren and Steve while they were doing this stuff. So, I'm very proud to say that I did one thing that people said had never been done before, because IMAX is all manual. What they wanted, the IMAX folks wanted, was a close-up of Loren, a close-up of his hands, and everything else, at the moment of release and starting to fly away. But they wanted us to move the lens out so that you got him whole. You had to do that manually, keeping the camera in focus. You weren't looking through any eyepiece, because IMAX didn't have that, so you just had to do it by feel. But the IMAX team had really done a great job of training us, so I did it by feel. It was one of the things that caused them to just go berserk when they looked at the film. They just couldn't believe it, that we had been able to do it. We got all the IMAX imagery and everything else, and the rest of the flight was that.

But about a week later, we got the word that it [the Hubble] wasn't quite what they wanted. You know, the first image, first light, was spectacular, because it turned out they had been imaging a star for decades. But that was what they wanted, because they knew this star so well, they wanted the first light to be that particular star. When they imaged it with Hubble, it turned out it wasn't a single star; it was a binary. It was two stars that were so close together, that they seemed to be one. That was Hubble's first discovery. However, it looked great to people like me, but to the astronomers, they said that's horrible. It's out of focus. We went, "Oh, okay."

Then Steve and I started trying to figure out what could we have done wrong, you know, did we bump it? Did we do something while we were taking it out? It didn't take them very long to determine that what the problem was a mechanical problem called a spherical aberration, where when they ground the mirror, which was perfectly ground, right around the very outside of the mirror itself, it was either over ground or underground by a millimeter. Not even a millimeter, by [2.2] microns. What it did was, it caused the image to not form on the instrument, but to be down here, or on the backside of all the science instruments. You got what was an okay image, but not a perfect image, the way they wanted it.

So, then started a three-year project to build a set of eyeglasses for Hubble. That was called the COSTAR [Corrective Optics Space Telescope Axial Replacement]. It had mirrors and lenses in it that was put into the optical train of Hubble, inside the body of the telescope. When images came into the telescope, it went through COSTAR, and then was sent out to the instruments corrected, so that it formed a perfect image on the various instruments. That was the beginning of the repairs to Hubble. Then, we did four more. I think we did five, total, that left us with an instrument that today is better than it was ever designed to be. It's not a telescope, it's an observatory. It ended up being an observatory with six incredible instruments on it, after the fifth and final [repair mission]. STS-125 was the final one, which was great.

JOHNSON: Hubble was built to be serviced.

BOLDEN: Exactly. Yes, Hubble was built to be serviced, and it was a dream for Bruce McCandless and Story Musgrave, because they're both EVA people. Story is one who believes that there is not a problem anywhere in the world that you can't fix with a spacewalk. It doesn't make any difference what it is, you could fix it with a spacewalk. So, he and Bruce, mainly—Bruce McCandless, more than anybody, designed all of the Hubble tools. Hubble had very unique tools for every aspect of any repair that was going to be needed to be done to it. I don't remember, I think when we flew, we didn't have a planned EVA. We probably had 120-some-odd Hubble EVA tools that Bruce had designed. They all were the Mc-some—you know, because his name, McCandless, we had the McTool, the McThis, the McThat—they all had been given a name. He did them with the guys over here at Goddard. It was Bruce's baby. Each subsequent mission, we went back in, and they designed unique tools for whatever the task was they were going to do.

JOHNSON: Yes, that's quite an accomplishment. As you said, they started those repair missions in '93, and then the fifth one was scheduled for 2005, but then [NASA Administrator] Sean O'Keefe decided after the *Columbia* [STS-107] accident that there was going to be no more servicing. Then, of course, Congress got involved, and Senator [Barbara A.] Mikulski—

BOLDEN: Senator Mikulski to be precise.

JOHNSON: —got involved, and the public, there was a large outcry, and from scientists saying that that wasn't the right thing to do.

BOLDEN: Huge outcry. Yes.

JOHNSON: So, they decided to have the National Academy of Sciences National Research Council [NRC] Committee formed, and you were asked to be on that committee.

BOLDEN: I was.

JOHNSON: If you can talk about how you were chosen to be on that committee?

BOLDEN: I have no idea. I think, to be quite honest, they wanted someone from the astronaut office. I had already served on a couple of NRC study groups before, for things based on my military background. They were comfortable with me, I think, so I was asked to be on the committee.

JOHNSON: Did you have any reservations, or what were your feelings when you were asked? Since you had been on the deploy mission, did you feel like you would have a good perspective being an astronaut?

BOLDEN: I thought I could be objective. To be quite honest, I think if you talk to most of the people on the committee—when we came in, I think the affectionate title of the committee was Saving Hubble. We were not asked to determine if we should do a human mission, a servicing mission. We were asked to determine how we could best save the Hubble Space Telescope. How could you do this last servicing mission most effectively, and most safely? Because everybody was leery about flying anywhere where the [International] Space Station was not a safe haven. Because Hubble was in a different orbit than the International Space Station, it would mean the crew would not have the safe haven of the International Space Station to go to, if we had some trouble with the vehicle. Safety was the original reason that Sean gave for not approving the mission.

I think all of us on the committee went in with an open mind, and most of us felt that a robotic servicing mission was probably the most reasonable thing to do. It would get the telescope fixed, and it would satisfy those who were concerned about safety. I was not a person who was concerned about safety, to be quite honest, because I thought, both out of *Challenger* and *Columbia*, we had come back with a vehicle that was as safe as we could possibly make it. I wasn't worried about putting the crew at risk, any more than we would by going to space. I didn't think going to Hubble without having a safe haven with the International Space Station would make a difference.

But we all started out trying to find an acceptable way to do it robotically. We talked to all the experts we could find all over the world; we spent a lot of time with the guys from Draper Labs [Charles Stark Draper Laboratory, Inc.], a lot of folks from Carnegie Institution [for Science], because they were noted for their computer science [expertise], and robotics. We went to industry, and everything. We went to DARPA [Defense Advanced Research Projects Agency]. We looked at classified programs, we looked at everything. There were a couple of robotic tests that DARPA was getting ready to do that were classified, so we said, okay, we'll see how they come out.

In the end, we said there is no robotic method, the technology is just not there yet. So, we would probably end up destroying the telescope, as opposed to saving it or repairing it, if we tried a robotic servicing mission, because we just don't have that capability. The nation doesn't have it. We said, okay, can we safely do a crew servicing mission? That was relatively easy, to be quite honest, because we looked at what the risks to the crew were. The risk to the crew was no more extensive doing a Hubble servicing mission than it was one going to the International Space Station. The only difference was, we did not have a safe haven.

So, we came up with the concept of an on-call mission. This was the first time that we said what we're going to do is, we will train a second crew to do nothing but go rescue the Hubble servicing crew, if necessary. When the Hubble servicing mission launches, we're going to have a crew on standby. We're going to have a second vehicle on the launch pad, and we can launch within days, if we need to. How do you get a crew from a crippled vehicle back into a good vehicle? That involved how many extra suits do you need? Do you use the arm? I think the final—and we didn't do this, the committee didn't, but what the folks at JSC did was come up with a pretty ingenious way of using the arm, the Remote Manipulator System, to literally grapple the other Shuttle. That would be the way that we would connect them. Then, we would send an EVA crew member down from the good vehicle to the damaged vehicle—we were worried about holes caused by tile coming off, or by debris coming off the tank; the kind of stuff that happened to *Columbia* on its fatal mission.

So, we figured that with, I think, two extra space suits, which was reasonable, you could go down, and one by one bring the crew out of the damaged vehicle and into the good vehicle, and then you'd bring the whole crew back. We had a way to leave the seats down. The crew for the rescue mission was going to be a minimal crew, I think a crew of three, or a crew of four. So, the mid-deck would be bare, it wouldn't have any seats, because you'd have everybody just lay on the floor strapped down to the floor for re-entry. That was the process that NASA came up with.

Our National Academy study team came in and briefed Administrator Sean O'Keefe on what our findings were and briefed him on what we had learned from the folks at Houston about how you could actually carry out a rescue mission, if you needed to. So, the recommendation out of our committee was that you go ahead and commit to a human servicing mission.

He did not like that. He was not happy at all. In fact, John [M.] Grunsfeld was the Chief Scientist at the time; Ed [Edward J.] Weiler was the head of [Space Science Enterprise], Bill [William F.] Readdy was the head of Human Space Flight. Fred [Frederick D.] Gregory was here as the Deputy [Administrator]. Bryan [D.] O'Connor was the chief safety guy here [Safety and Mission Assurance], and I remember we briefed him. No one had a question except Bryan. But Bryan O'Connor is Bryan O'Connor, if you've ever met Bryan.

Bryan just—I mean, he was incessant. He had this long list of questions that he wanted answered, as the head of safety, if he were going to go along with this thing, he wanted to make sure we had covered all the bases. I think we satisfied Bryan that we had done our homework, and that you could effectively do a human servicing mission. After Bryan finished all of his questions, we said, "Any more questions?" Sean looked at us, he didn't say a thing the whole briefing. Just had a scowl on his face. There is a difference of opinion about which of the four people, Bill Readdy, Sean O'Keefe, John Grunsfeld or Ed Weiler said, "You have just signed Hubble's death warrant." I thought it was Sean, but somebody said no, it wasn't Sean, it was somebody else. But

I think he looked at us and he said, "You all have just signed Hubble's death warrant, because this will never work."

So, we said, thanks. We were asked to do a job, and we did it. Then Sean left, as a matter of fact, as the NASA Administrator, and Mike [Michael D.] Griffin was brought in. So, the team came back in and briefed Mike Griffin and let him know that we were confident that you could do a human servicing mission, and you would put the crew under no undue risk, especially if you had what we call a LON, a Launch On Need mission. Mike said go for it. He didn't have any problem with it.

So, we launched STS-125 which, I didn't get out of it, because then I got assigned to be the chairman of the independent review board for 125, for the servicing mission. I stayed with Hubble even—I was gone from NASA. Remember, I had left NASA in 1994. That was how I got involved in all this. I was available, for one thing. That was great, serving as chairman of the review board.

JOHNSON: Talk about that for a minute, and exactly what that entailed.

BOLDEN: Well, our job was to act as an outside entity, an outside board, that followed along the training, the mission concept development and everything, and made sure that in the end, we were going to be able to carry out a mission that had a pretty good chance of success, and that would be safe for the crew, and would, in fact, do what it was supposed to do, which would be to leave Hubble in perfect shape, or as good a shape as possible. Very interesting, because as the mission concept developed, it was way too much stuff. The team wanted to do five back-to-back-to-back-to-back-to-back EVAs. That had never been done before. Without a break. We were going to do five EVAs, five days in a row. In order to do that, they actually had two EVA crews, and they could mix and match so that nobody would have to fly two days in a row. John Grunsfeld was one of them, Mike [Michael J.] Massimino, [Scott D. Altman, Gregory C. Johnson, Michael T. Good, K. Megan McArthur, Andrew J. Feustel]. An incredible crew.

We followed them through. We had very serious concerns about the aggressive schedule that was set up for them. I think everybody on the team did; nobody believed that we would have every single EVA come off right. So, among the things that we did, that our oversight board did, was work with the folk in the communications arena. A point we made was, how do we get ready to inform the public that we have had a successful mission, when one of the EVAs fails, or we don't get everything fixed, it's still an incredibly successful mission. But it's hard to tell the media that. We spent a lot of time working with them so that we would have a story to tell, a story of success, if we got most of the tasks done.

As it turned out, they did the impossible. They did five back-to-back EVAs; they got everything done. In spite of the fact that they had trouble, a lot. The very first EVA, they couldn't get a bolt loose. I think they ended up having to break the bolt, or something. But that was not a good omen, but after that, they went through every EVA. They still had minor glitches, but nothing major. But it was, for me, the next best thing to having been the commander of the first servicing mission, though. It was pretty neat.

JOHNSON: Yes, and you mentioned in one of your oral histories that you really wanted to go on that first servicing mission.

BOLDEN: I did. I really did. Yes. I just felt that I wanted to close out my career as an astronaut having left Hubble the way it was intended to be left. It was selfish, to be quite honest, but I wanted to close out my career associated with the space program being able to say I contributed to seeing Hubble be the instrument that it was intended to be. Had no clue that I would close out—well, I didn't close out—but at the time, that I would leave the agency having been an integral part of making Hubble whole.

JOHNSON: Yes, that final mission.

BOLDEN: Yes.

JOHNSON: Part of the committee's report, the first committee, stated that Hubble has been one of NASA's most noticed science projects garnering sustained public attention over its entire lifetime.

BOLDEN: Without a doubt.

JOHNSON: It has also had worldwide attention; I think over 4,000 astronomers from around the world have used the Hubble and the images. How much did that, I guess, weigh into those recommendations? Was there a lot of pressure because this was so noticeable?

BOLDEN: No, I never felt any pressure involved in any of the evolutions with Hubble in which I was involved. You're always wanting to make sure everything goes right, but that's normal. I didn't feel any pressure to do the servicing missions, nor not to do them, nor the way we did it.

Like I said, I think all of us on the National Academy Committee came in with an open mind, saying we'll do whatever is necessary. But we think a robotic mission is probably the wise thing to do. We kind of agreed with Sean, at the outset, until we found out that the technology wasn't there. But then, for the oversight committee, or the review committee that I chaired, we just wanted to make sure that—they had a lot of stuff on their plate. We were all worried because—I mean, just weeks away from launch date, the paperwork. That's always what gets you. There's a NASA form – called a RID [Review Item Disposition]. It's a discrepancy report. But when you find something wrong, then you write a RID.

The problem was, for Hubble, for the final servicing mission, they had literally thousands of people who had the authority to write RIDs. When you give somebody that opportunity, human nature is, if I am to demonstrate that I was of any value at all, then I've got to write something. They had RIDs that were absolutely ridiculous. I mean, some of them were just simple. All somebody had to do was go over and say, "Hey, can we just fix this," or "Can you put a piece of tape over that?" It wasn't something that needed to be documented. But literally, thousands, just reams of paper of discrepancies that had to be worked off, because you couldn't fly until they had worked everything off. They literally worked up until launch day to close out all the RIDs.

That was the first thing that we didn't think could be done. We didn't think they'd ever close out all the RIDs, and they did. They were legitimate close-outs, to be quite honest. That made us feel good. Then, the crew was just superb. Ground and flight team. Just a great exercise, to be quite honest.

JOHNSON: I know at Goddard, the folks at Goddard, they worked a year and a half trying to put a plan together to do it robotically.

BOLDEN: Yes, they sure did. They did everything.

JOHNSON: I know they did a lot of work, but it just wasn't quite there, yet.

BOLDEN: It would have taken longer, and we would have had to develop technologies that were non-existent. The first thing you had to do, you had to figure out how were you going to go up and take control of Hubble? Whatever the robotic vehicle was had to be able to go grab it and stabilize it and put it in an attitude that you needed to do. Then, you're either going to need a second vehicle, or that vehicle was going to have appendages that were going to have to—because they actually had to open doors, go inside, change out boxes, and do all kinds of stuff. It just turned out that, I don't think anybody ever imagined the complexity of that final servicing mission, when they started thinking about doing it robotically.

Then, there were a couple of DARPA missions. There were three or four missions that were robotic, sort of robotic servicing missions. One of them was just a dismal failure. Another one ran out of fuel, because as it approached whatever it was supposed to do, it didn't exactly get there, and it started trying to maneuver to get in place, and it just exhausted itself of fuel. I don't know what happened—but none of them were successful. We were holding out hope until the very last minute that someone would demonstrate an ability to do a robotic capture of something, so that we could say, okay, it's worth trying this. It didn't happen.

JOHNSON: It just wasn't there. Like you mentioned with the bolt breaking, I mean, all the things that happened that as a human being there, you can go get the next tool.

BOLDEN: Yes, it would have been a dismal failure, robotically. Even if we had the technologies, at the time.

JOHNSON: You were there on that first mission, and you helped make sure that that last servicing mission was a success. Are there, that you're aware of, any lessons learned from Hubble that are being applied to the James Webb Space Telescope [JWST]?

BOLDEN: Well, because James Webb's not serviceable, I think we're done with that. But there are still entities out there that would love to be able to put a grapple fixture on James Webb, just in case.

JOHNSON: Is the distance too far?

BOLDEN: Yes, well, it's not the distance, as much as it is the technology of JWST makes it an incredibly fragile instrument, and observatory. A lot of people believe that if you went up, so much as touched it, you would damage it beyond repair. It's a cryogenic—it's unlike Hubble, James Webb is at [seven] degrees kelvin, so it's almost at absolute zero. People were concerned that, okay, if we go up and try and service it, are we going to disturb the thermal condition of the telescope? If we do that, you'll wipe it out. There are so many things, so many bad things that can happen. So, they have resisted the temptation to put a grapple fixture on it, although there are people who still haven't given up on it.

But you say, "lessons learned." Testing was the biggest lesson learned. They never tested the integrated Hubble. Not the lens, itself, so, it was never tested to make sure that the image was going to focus on the instruments themselves; they just did it through analysis. With JWST, they are testing every single segment of the mirror, and I think it's got eighteen segments. They're doing a full-scale test of everything. Then it's going to go into the chamber at the Johnson Space Center in 2017, or late 2016. It will be tested as a unit there, also. I think complete, thorough testing is one of the things that came out of it.

JOHNSON: It's been a long process, since it began planning in '96, and then construction in 2004.

BOLDEN: Yes. It is so different from Hubble. It's not a normal telescope. First of all, it's got a segmented mirror that is all outside, so there is no shielding around the mirror, like with Hubble. We were very particular not to even open the aperture door, because you were afraid that you'd get debris on the mirror, or something like that. I'm not sure how they protect the segments on JWST, other than the fact that it's going to be in what they call a Lagrange point, a place of no gravity. Maybe they feel that there's nothing in this particular zone that could contaminate the mirror.

JOHNSON: From what I've read, they're hoping for at least another five years out of Hubble.

BOLDEN: They'll probably get more than that. If we say five years, then it'll probably get ten. That's just the way they do stuff. The instruments themselves, as far as I know, and I haven't asked anybody of late, but I think everything continues to work very well. There's no problem with the batteries, no problem with gyros. Those were the things that they expect to go first. The batteries, the gyros that maintain its attitude. So far, so good. Solar arrays, it's got the newest generation of solar arrays on it. That will eventually be a limiting factor, but I don't think it's something that will cause it to not be able to go beyond five years.

I'm not a scientist, but scientists gauge the success of something on publications. When you look at scientific publications pre-Hubble, and then you look at scientific publications post-Hubble, there was just this incredible—it was almost an asymptotic rise in the number of technical papers and books published after Hubble that contained Hubble data, or results from Hubble investigations, and the like, a couple of Nobel Prize winners. And it's because it is an instrument that is available to anybody in the world. So, you don't have to be on the Hubble investigating team, because all you need to do is go to the Space Telescope Science Institute's database, and everything that Hubble gathers is eventually available on a database. Anybody can use Hubble data. A couple of the Nobel laureates from Hubble, they weren't on the Hubble team, but they had access to the data. They used Hubble data to write their papers that brought them the Nobel Prize.

JOHNSON: It is one of the most visual things that NASA has, to get the public's interest. It's still on the news, the discoveries.

BOLDEN: Yes. Another thing people don't know, every once in a while, you can see Hubble. Not very often. Nobody follows Hubble like they do Space Station, but every once in a while, Hubble finds itself in the right place, such that at dawn or dusk, the sun reflecting off of it allows you to see Hubble. I can remember when, for the final servicing mission, we were watching from the ground as the Orbiter closed in on Hubble. You could actually see these things that were two little dots, you know, lights.

JOHNSON: Closing in on each other?

BOLDEN: Closing in on each other, yes.

JOHNSON: That's amazing. Was there anything else about Hubble that you were involved in, in between the first and the last, or anything else that you did during that time?

BOLDEN: Not really, because I didn't do anything with any of the other servicing missions, other than the fact that I was on the ASAP, on the Aerospace Safety Advisory Panel. For the intermediate servicing missions, the ASAP had lots of questions, but we didn't get intimately involved, or anything. It was just a matter of staying informed of what the mission was going to be, and what its challenges were from a safety perspective. But other than that, no. That was it.

JOHNSON: I was going to ask Rebecca if she had any questions.

WRIGHT: Well, I've got one for you and the crew, when you were deploying the Hubble. That was the first time that the Shuttle was going to go as far.

BOLDEN: Oh, yeah.

WRIGHT: Bill [William D.] Reeves has talked about the risk one of the fuel systems had.

BOLDEN: Yes. I can talk about that, as a matter of fact. It was interesting to train. I'll talk about how we trained. We trained really hard, and Bill Reeves was our—I want to say he was our ascent flight director, I think. He knew it intimately, because when you plan a mission, you make sure you have enough propellant in the Orbital Maneuvering System engines, the OMS engines, the big engines on the back, above the main engines. They have two purposes in life; one is to circularize your orbit to get you where you want to be, big moves, and get you home. In the case of Hubble, since we were going to 600 kilometers, which was 400 nautical miles higher than anything had ever been before—short of going to the Moon—we pretty much strained the OMS system of Shuttle. We fully loaded, we had enough propellant to get us to orbit, and get us back home, and no reserve. It meant when we got into our circular 600-kilometer orbit, we were going to have just enough OMS propellant left to do a de-orbit burn, and not one drop more.

And, if we developed a leak on orbit, which was a contingency for which you planned all the time, we were probably not going to get back home, because we were not going to have enough propellant—even with using the reaction control system jets, which you could use that supplement—it would be dicey trying to get home if you developed a leak in the Orbital Maneuvering System engine's propellant system. But we practiced a lot, we practiced a lot of leaks, and a lot of ways to get the Orbiter back down to Earth.

I was the pilot, which is the co-pilot. I was not the guy in charge. It gets to the point I don't explain that to people anymore, they know what a pilot is, and they assume the pilot's in charge. Loren was in charge. But as a pilot, I was responsible for all the propellant systems. I knew that I wasn't going to have to say anything to Loren about propellant state, because if we had a successful de-orbit burn, we were going to start getting alarms just before the burn was complete. The alarms were going to be no more propellant. They were going to be low fuel. That was our signal that our de-orbit burn was complete, because we got, "do-do, do-do, do-do, do-do, do—" Lights, and whistles and all kinds of alarms, which for us, was good, because we knew that it had lasted until the very end, and we were on our way home. That was the dicey part of that, and that's probably what Bill Reeves was talking about. It was interesting training for that.

WRIGHT: And the back of your mind, you know your mission is to get the Hubble deployed.

BOLDEN: Yes, and you know, we never worried. I never talked to anybody about whether they were worried about it, but I know Loren and I, we were confident that the vehicle—and the thing was, we had, I don't know, 30 or 20-some-odd Shuttle missions before us, and other than the two that we lost, you didn't have problems with the Orbiter that much. You really didn't have that many in-flight failures, or that many in-flight anomalies on the Orbiter that didn't end up being instrumentation. It's a fly-by-wire vehicle, so you're not looking at positions of things; you're actually looking at electronic data that are telling you, okay, this surface is at that position, but that's not what the surface was saying. That's what all the data was saying. You'd get a lot of alarms frequently in-flight that would not be real. They'd be false alarms, and it would be a transducer failed, or a transducer got a little piece of dirt on it, or something like that. I don't think Loren or I were worried about propellant problems.

Did we know Hubble was going to be what it turned out to be? No. Did we talk about it all the time? We always talked about it, and I can remember when we went down to the Cape—you go down three days prior to your launch, that's when the crew—you're pretty close anyway, but it's just you all. You bring spouses and kids down, and you don't get to see the kids. But the spouses come in for dinner, or stuff like that, every once in a while. But you have a lot of time to talk, and we sat around talking about what we all thought the significance of Hubble was going to be.

To a person, I mean, Steve was the astronomer, so he had his vision of what it was going to be like. Bruce did, Kathy did, Loren did, I did. The only thing I knew was, because I put things a lot of times in terms of faith, and the big thing then was the Big Bang Theory, and people were talking about, well, maybe Hubble will answer the Big Bang, will finally solve this. We would sit around and we'd say, you know what, the one thing of which we're certain, Hubble is going to leave us with way more questions about life and the universe than we ever dreamed of. We were all certain of that. We figured this instrument is going to be so absolutely incredible that it's going to create more questions than people ever imagined, and that's exactly what happened.

Hubble began to open up the universe, and it caused people to have to rewrite textbooks because some of [Albert] Einstein's theories, and things that we accepted as fact turned out to be not correct at all. There's a lot of questions about whether the universe was expanding or contracting at the time, and I think the prevailing wisdom at the time was that the universe was slowly contracting. Man, Hubble blew that out of the water—it's expanding. The other thing was, there was this thing called the "Hubble Constant." It was some coefficient, or some fraction or something that could tell you how fast the universe was expanding, if it was expanding or contracting. It turned out the Hubble Constant was wrong. But that had stood for decades. But Hubble was able to give scientists the data they needed to do that. It has been an absolutely remarkable observatory.

I was talking about the papers, that's the big thing. You look at anybody's report on technical papers, and it was kind of churning along. Then, when they started writing papers from Hubble, it just skyrocketed. It is still like that. Papers generated by the Hubble Space Telescope in the scientific community way outweigh anything else. To the scientist, that speaks to the greatness of Hubble. People are hoping that James Webb will do that, when we finally launch it.

JOHNSON: Are there plans to celebrate the twenty-fifth anniversary?

BOLDEN: Yes. As a matter of fact, the 24th of April, there is a ceremony at the Smithsonian [National Air and Space Museum]. It's going to be a reception. I think the 23rd at the Space Telescope Science Institute, there's actually going to be a whole day of panels, because I'm supposed to participate in one of them, and give a crew perspective. My guess is there'll be celebrations for a week or more. People from all over the world coming to talk about Hubble and what they did, and how they were responsible for it.

JOHNSON: That's quite a milestone.

BOLDEN: Yes, a quarter of a century.

WRIGHT: I'm going to ask one last question, just to reflect. What do you want people to take away from NASA, or about NASA, with the legacy that NASA has given to the world with Hubble? What did we learn about NASA with Hubble?

BOLDEN: For me, Hubble actually, hopefully, teaches people that we are more than just rockets and people, that we're about discovery and exploration, and not being afraid to go into the unknown and do things that other people say can't be done. Hubble is, for me, the observatory is a perfect example of taking science fiction and turning it into science fact, or an expression I like to use all the time, taking the impossible and making it possible. We thought it was impossible—not impossible, but pretty close to impossible, to carry off STS-125. They did it. To me, that is amazing. I mean, we were all going, "Holy shit!" After the last EVA, we just went, "Who'da thunk it? How great!"

WRIGHT: People with a purpose, or people with a mission.

BOLDEN: I tell people all the time, what makes the International Space Station so great is the fact that it is an incredible source of lessons for humanity, to help people understand that you may hate somebody, but if you have a mission, and a common goal, you forget about that for the time being. It's the Russian-U.S. relationship that is so strong when it comes to space exploration, particularly exemplified by the International Space Station, and the way the crews work and train together, the way they carry out their mission, the way that all of us remain lifelong friends, in spite of what's going on.

I just had a telephonic meeting with my new counterpart, Mr. [Igor] Komarov, the new head of Roscosmos. I was overwhelmed in a positive way with his whole attitude about the relationship. He said the same thing I did. We have got to figure out some way to make sure we don't screw up.

JOHNSON: Get beyond politics. Just keep going.

BOLDEN: I think that's what's so great about NASA. Having spent 34 years in the Marine Corps, I actually believe that—and I've said this to people before. There are two organizations—there are more than two, the Department of State does okay—but I think NASA and the Department of Defense do more to engage other people around the world and keep us as much at peace as we possibly can. There's always conflicts that you just can't avoid. But for the most part, we spend our entire time trying to engage people, finding out ways that we can draw them into the things that we're doing, and make them partners, as opposed to making them enemies. We're not looking for any enemies. I don't need any, to be quite honest. And I don't need a space race; I don't need any of this other kind of stuff that people are always trying to generate. It isn't there, so quit dreaming about it.

JOHNSON: Just ambassadors of science and peace.

BOLDEN: Yes. Yes, exactly.

WRIGHT: Well, thank you.

JOHNSON: Thank you so much for taking the time to talk to us again.

BOLDEN: No, thank you all very much. It was great.

[End of interview]