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EDITED ORAL HISTORY TRANSCRIPT

CHARLES LINDQUIST
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is July 29, 2015. This oral history session is being conducted with Charles Lundquist in Houston, Texas, as part of the International Space Station Program [ISS] Oral History Project. Interviewer is Rebecca Wright, assisted by Sandra Johnson. We thank you again for sharing this time with us.

I know that you joined NASA in 1993 and have served in a number of capacities for the agency, but if you would start today by describing how you first became involved with the International Space Station [ISS] Program and what were some of the duties that you were responsible for while you were part of that program.

LUNDQUIST: I had started my career as an engineer, working [Department of Defense] programs that was back when the Soviet Union was the "evil empire;" I had a secret clearance and I was designing systems to blow them up. Then Perestroika hit; defense contracts were shrinking; and I started looking around for a more secure job and [thought], "Oh, Space Station Freedom, that looks like a lot of fun," and got a job there. I started my career working NASA projects at McDonnell Douglas [Corporation], back on the Freedom program. Since I started on [Space Station] Freedom, I'll have to include that on the road to ISS.

I worked there for several years, working flight experiments that flew on the Space Shuttle, that were designed to validate assembly of space station by EVA [extravehicular

activity]. You may recall that we had what we called a "wall of EVA," where we were naïve enough to think we were actually going to go up in spacesuits and manually build this large space station. It turns out in practice it was going to be extremely challenging, and it was one of the reasons why, I think, the Freedom concept was eventually scrapped and we moved to the International Space Station.

Then when we were in the transition, I was on the team that was involved in determining what the new station configuration would look like. I was supporting Crystal City [NASA's Space Station office]. Every day we'd evaluate a new configuration, and then one day a fax came in and it had a picture of a Russian element in it. At the time, we were still cutting and pasting [information], then using copy machines [to create a new page]. We were putting these different configurations together—building blocks of Russian elements and our elements—trying to forge a combined U.S.-Russian space station. After that, we disbanded the Freedom office here at [Johnson Space Center], and all of us Space Station Freedom folks got new jobs.

The Freedom team had spread to the four winds at the center and the new ISS program was in formulation. Seems like a short time later, I was just getting settled in my new office when I got a phone call, "Hey, we're standing up the new ISS program office," and they asked me to come over and work in the Russian integration office, which was responsible for integrating the Russian half and the U.S. half of the Space Station. So that's how I got to ISS.

WRIGHT: Seems like a small job description for a very large job.

LUNDQUIST: When I was on ISS, I started out in the Russian integration office, and I worked there in several capacities, eventually was the leader of that office, and then also supported the

U.S. segment in the hardware integration office, working on several U.S. elements, such as the truss segments, the node, airlock, etc. I left Space Station after about 10 years, so it was a great ride. Anyway, that was my Space Station career.

WRIGHT: Let's go back and talk about how you tackled that first job as being in charge of the Russian integration office, and how you built that office. It certainly was new ground to plow.

LUNDQUIST: It was. Some of my most memorable experiences here at NASA were in that job, because here we were, thrust together, two former cold war adversaries, and we're looking at each other, [thinking]: "I don't know you and you don't know me and we don't speak the same language and we're coming at this from very different angles." So we had to forge a combined team that worked together, and over several years it became a very efficient working team. To this day, I marvel at how well everything's working. But in the early days, there was tremendous cultural & language barriers that we had to overcome when we first embarked on the joint Space Station.

WRIGHT: Can you tell us about some of those first meetings and what they were like, and how you managed to move forward with your new counterparts?

LUNDQUIST: You know, the first meeting we ever had, there was a large contingent of Russians that came here to Houston, and I think we were having the meeting in Building 9, there were some temporary cubes [cubicles] set up. We brought in a bunch of translators, because obviously we had to bridge the language barrier, and our translators could speak English and

Russian, but they couldn't speak NASA and Russian space agency, or [NPO] Energia. So it was very rocky going at first. At first we had to do some major organizational work to set up the organization, so I remember sitting down on day one with our respective leads, and we start talking.

Team 1 is going to be the requirements team, because we knew we had to develop joint requirements. Team 2 is going to be propulsion. Team 3 is going to be guidance, navigation, and control. We went through all the various technical disciplines, and I've got a counterpart, you've got a counterpart, we were matching up these technical disciplines. And we'd gotten to like 14 or 15 and we realized, wait a minute, when these teams run into problems, where do they bring the problems to? So we need a management team, but we'd kind of run out numbers, so we picked Team 0, and that has stuck to this day. Even today, whenever they have these meetings, Team 0 is the management team. Of course, there have been the endless jokes about Team 0 being the management team, because that was appropriate description of maybe the intelligence of the management team.

So those early discussions were quite interesting. Even NASA people oftentimes have trouble communicating just across divisions, much less when you're talking about the whole culture. When we went to Russia for the first time, it was a real culture shock for me, because here I was standing in Red Square, and just a few years before, I mean, this was evil territory, I was trying to figure out how to blow them up. I never thought I'd be in Red Square as a free man. I thought if I ever was there, I'd be a prisoner of war. So it was pretty cool.

And once you got to know the Russians as individuals, they were good people. But we had to overcome those key cultural differences, and that, I think, was the biggest challenge. Technically you can say International Space Station was a tremendous challenge, but looking

back on it, I think it was the soft skills—the people, culture, language, organizational—that were the biggest hurdles to overcome.

WRIGHT: How open were they to show you their facilities and provide that information during those first meetings?

LUNDQUIST: Well, that was a huge challenge, the openness. That was one of the key cultural clashes that we had. Americans are very information rich; we have documents everywhere, and we are quite free, at least here at NASA, passing information back and forth. Whereas in Russia, under the old Soviet system, knowledge was power. You could be replaceable; if you wrote out all of what you knew, they could replace you and you could wind up somewhere you didn't want to be. United States—people move around a lot more; we tend to focus a lot more on documenting processes. The Russians had a lot of it in their heads, whereas we had most of it written down, so we were constantly asking them, time and time again, "Let me see your drawings. Let's see your documents." And we kept getting kind of the runaround. They would never say *nyet* directly to us, but, you know, later there was always some obfuscation that pushed it out.

After, it must have been a couple of years of doing this, I remember being in Moscow and finally, after continually nagging them, "We want to see your drawings of the service module," they walked us down these labyrinthine hallways and finally to this room, it was hardly bigger than a broom closet, and we walk in there and there's this wall of drawings rolled up, like old parchment, papyrus paper. They rolled it out, and it was all well-worn, kind of like your favorite book. It was covered in pen-and-ink changes, where in contrast, our drawings were all

in an electronic system. You'd never have this broom closet with old worn-out drawings; it's all computer CAD operated and everything. So they rolled it out, and there it is. There were like two of us in the room and we got to see it. They rolled it up and put it back in the wall, and we left. That was how they finally shared their data.

We tried to work around that a lot. We had a contract, remember [ISS] Phase 1? We were working with the Russians on the Mir Space Station that existed, and Phase 2 was working with us on the International Space Station. We had some money set aside for this partnership; we were paying them for delivered documentation. So money did talk to the Russians, and that helped facilitate a lot of the data transfer that we did get.

WRIGHT: And were you able to set up a good team on this end that would work well with the Russians? As you mentioned, so many people for years had thought of the Russians as our enemies. Did you find folks that were ready and willing to go work with the Russians and help build this relationship from this side as well? Did you have any hesitations?

LUNDQUIST: Sure. We had a great team. We had a dedicated cadre —you know, NASA people are excellent at solving problems, and this was a really difficult problem to solve. It was a strenuous time—you would go to Moscow for two or three weeks and you were totally dedicated to that, but there was a lot of time spent away from home. There was also a time difference; you had a nine-hour time difference. Our normal mode was, we'd come in early and the Russians would stay late, and that's how we kind of overlapped our respective times.

I will never forget walking into Building 4 South in the wee hours of the morning, still dark outside, and you're going up to the fourth floor and you come out the elevator and you hear

all this Russian talking. It's kind of weird at four in the morning. And you go by these different cubicles, and we had the GNC [guidance and navigation control] meeting, and the propulsion meeting, and we had a sign-up sheet. We had over a dozen different technical teams and they would sign up, and we only a few translators, so you'd have a 4:00 to 5:00, 5:00 to 6:00 a.m., 6:00 to 7:00. You'd want to sign up for that 7:00 a.m. to 8:00 a.m. time slot if you could get it, because you didn't have to come in that early. So if you got to the sign-up sheet late, you got the 4:00 a.m. slot.

Anyway, there was that hardship, but there was also a lot with the team that we assembled They learned from their Russian counterparts, they became friends and co-workers, and there was also the satisfaction of bridging the cultural differences and forming those partnerships that ultimately, history showed, was very successful.

WRIGHT: Hopefully history will help people understand that it wasn't immediate, because it sounds like it was one step at a time that you built that trust and built that exchange of information.

LUNDQUIST: You can't overemphasize the importance of those personal relationships in being successful. By the governments deciding at the top, "Hey, we're going to have this partnership," the people are thrown together, and it was only when we began to work together and understand each other, know each other, that those barriers begin to fall. I think that most of us became what you could call friends with our Russian counterparts over time.

WRIGHT: Was there a significant time or an event or a tipping point that you remember that you realized or learned that hey, we can move forward now? That some of those barriers were broken down and you were working together as a joint team to get this module ready for the Station?

LUNDQUIST: Well, there was never an "aha" moment like that, but when you look back over time, you go, "Well, things are going smoother now." I mean, we hit some rocky roads. The Russians had what they thought was a perfectly good space station that was already up there, the Mir Space Station, and it was pretty early on that they got the idea that said, "You know what? We have a perfectly good space station up there. Why don't you guys just attach your new half onto our old half?" That was obviously not well received on our side.

I led the team that assessed that proposal and was basically told from the beginning this is not a good idea; you need to come up with the appropriate response. So I led the team that came up with many, many, many reasons why that was not [the answer]. You know, you don't want to expend many billions of dollars on the world-class orbiting laboratory and attach it to something that was not designed for it and had a very limited remaining lifetime. It would've been a tremendous bust for us; [but] made sense to the Russians, because they were really cash strapped. The Russian economy at the time was really abysmal.

I'll digress a little bit at this point, because funding actually was a big deal. My Russian counterparts were making less than the cigarette vendors on the street corners. When the Soviet Union collapsed and Russia was standing up, there were several years where basically the contract with NASA was what was keeping their space agency afloat. Of course politically, the story was, whether it was in the meetings in the hallowed halls of Congress, that the partnership

was arranged to keep all those Russian scientists and engineers who had been building bombs employed so that they would be working on something jointly with us that had value, as opposed to maybe selling their wares to Iran or other countries of not such grand designs or friends with us.

WRIGHT: I just was visualizing all of the information based on that time period, because it seems so long ago, but it really wasn't, that you were having these discussions and negotiations. So talk to us a little bit about how you actually got it to move forward, where you actually started to see plans develop and the program starting to take shape, where you could actually bring something back and tell management this is moving forward.

LUNDQUIST: Work always expands to fill the available time, and there's nothing like a schedule to bring the team to focus. We had an aggressive schedule to build the FGB [functional cargo block], which was a U.S. paid-for element that Khrunichev [Production Center] built, and then the Russian elements would soon form the backbone of the station. Necessity is the mother of invention, so the schedule was the impetus, the driver that pushed us to forge those relationships and make the progress that we did. There were a lot of bumps in the road along the way. We did not meet—the Russians didn't meet their initial promised date; they were actually two years late on the Service Module. But of course we put that time to really good use; we had used the time to do a lot more ground testing of the U.S. segment and were able to really give us a lot higher confidence in the pedigree of the hardware that the U.S. was sending to Space Station. So that's what I think was the ultimate driver of the progress that we made.

WRIGHT: You mentioned that you were there for 10 years, but along this progression, at what point did you move?

LUNDQUIST: I left Space Station shortly after the node launched.

WRIGHT: So you got to see—

LUNDQUIST: I got to see the first elements launched. I actually had an opportunity to go—I'd spent 10 years working on building Space Station, I wanted to then go use Space Station. I was excited about its prospects as an orbiting research platform. There was an opportunity that came up, at the time it was called the Space and Life Sciences Directorate, working different payloads, because it was exciting, the prospects of the microgravity research. So I spent several years doing that before I was pulled back into the flight programs when Constellation kicked off.

WRIGHT: What were your thoughts when you saw the door opened? There's got to be some feeling of satisfaction or reward when you got to see the two modules unite, then astronauts taking full-time residence. Can you share some of the—

LUNDQUIST: Oh, sure. That's what really motivates us NASA engineers, you know, is seeing the fruits of our labor finally realized by flying, which is why it's so tough for us nowadays when we don't have a human spaceflight capability. These are years we have to weather the storm, and it's harder to come to work. Which is motivating us, like on Orion or a commercial crew, that we feel that the United States needs to have a place as a world leader in technology and

human spaceflight, we should have a preeminent role in that. We're hard believers in our country's leadership role in technology and want to play a role in that.

WRIGHT: You said you spent some time in the human and life sciences area. Were you working on elements to go as far as what they were doing to go to Station?

LUNDQUIST: The place where I went to was responsible for the crew health, and all the experiments that are done on the human subjects in Space Station were run out of the place that I went to. It's really a gem, it's a building here, Building 37 at JSC; it's where the astronauts came back from Apollo [missions]; that's the same building where we quarantined them briefly because we were worried about the microbes they might be bringing back from the Moon.

All the different physiological laboratories and scientists live and work in that building. I ran that division, and we were interested in the physiological decrements associated with spaceflight—extended exposure to microgravity has issues with bone loss, cardiovascular, behavior performance, circadian rhythm, gastrointestinal, all the body's systems are negatively affected by extended spaceflight—and so a lot of brilliant people there studying those effects and trying to develop countermeasures, which are mitigations. How do you preclude these deleterious effects so that the crew can stay healthy longer in space and perform the mission, which obviously is important for us? Restoration of normal activity when they come back from something like a stint on Space Station, but really going forward, is even more important, if you're going to a planetary extended spaceflight to someplace like Mars. You need to be able to have a long exposure to spaceflight and then perform a mission in a gravity environment without any doctors, without any physicians there to help you recover. And then you've got to come

back. That's really the work that people are doing now on Space Station—to use that one-of-a-kind facility to learn what these effects are and how to counteract them.

WRIGHT: So explain what you were doing, or what kind of steps that you set in foundation that are being used now?

LUNDQUIST: Space Station, like I said, is that orbiting platform, and it's a very constrained resource. You have very limited opportunity to get experiments up, and even more limited opportunity to get experiments back down for analysis. Part of the problem and the challenge is just figuring out—out of all the possible science you can do, what's the highest priority with that very limited funnel, that chokepoint that you have to go through, which is up mass and down mass. Crew time is another constraint. Power is another. There are a lot of different things that if you have a laboratory here on Earth you don't even think about, but up there you really have to make a very judicious use of your resources. So there was a lot of planning and effort that took place on prioritizing the research that would be conducted, and then making sure that research was done in a most efficient, mass efficient, time efficient manner possible to glean the most data that you could, so that we could make the most progress possible based on the time and the dollar and the up mass.

WRIGHT: How were you able to configure what you were doing here when the Station wasn't even up and going? Can you give us an idea of the challenges that occurred of taking what you believe as theory and not actually having a laboratory to figure out what was going to work?

LUNDQUIST: Well, you know, Space Station was manned right after I left, pretty much, and we began performing science on Space Station well in advance of its final operational capability. We only had three crew members, and we had limited facilities, like before the lab and then the ESA [European Space Agency] module, so we've incrementally added to the capability of Space Station. We had limited ability to do science, and that has expanded more and more over time after I left, to where there is a much higher capacity and throughput now. So it was even more important back then, when we had such a constrained ability to do science; we were very smart with what we were able to plan and do and perform in space.

WRIGHT: During the time period that you were there, were there policy decisions or organizational changes that might have impacted greatly some of the work that you were trying to do? One you kind of already explained in one way, was that you were working on Freedom and all of a sudden you all were all dispersed to different areas and then they called you back. In the last few years we've changed from the Vision for Space Exploration with Constellation to not having that program. During those 10 years, are there significant events that made a definite impact that caused you to move in a different direction or change the way you were thinking?

LUNDQUIST: Policy direction from on high—it's important to have consistent policy that's sustained over time. Fielding a major manned spaceflight capability takes many, many years. It has to be sustained over many administrations and Congresses, and so a part of what we're doing now is trying to make the most flexible and adaptable architecture that can address various different missions.

I'll go back to Apollo—it was very directed towards getting a man on the moon, a tremendous accomplishment, especially considering the technology of the day. That was its only mission, really. Looking back at Space Shuttle, it was a tremendous asset for low Earth orbit. Now looking forward—we are trying not to make this a one-shot: go to the Moon, or go to Lagrange point or go to asteroid or go to Mars. We're trying to make this a versatile capability that can accommodate a large number of different types of missions, so that NASA and the nation have that flexibility in the future as space policy change and adapts over time, that this system that we're fielding now can deal with it. I would say that from a policy perspective, I see NASA as trying to adapt to that with more and more flexibility.

WRIGHT: Along the way, were you able to make any recommendations or suggestions to management and to the Agency as a whole, as you mentioned, to do things that would become more broad-based? Or were there other times that you were able to make recommendations that says, "Hey, we're doing it this way, but maybe if we do it this way it'll make a difference?"

LUNDQUIST: I was actually quite fortunate. I didn't think I was fortunate at the time, but it was one of those pivotal times when Constellation was cancelled, Orion was cancelled—I was here on Orion at the time, and as you can imagine, a little bit of depression set in amongst the team here. Okay, what do we do? Even though the President cancelled it, Congress hadn't yet, so there was all this uncertainty. I had an opportunity at the time to go to Headquarters in this time of great transition, and I went for about six or seven months. And it was kind of traumatic at the time because there was so much uncertainty.

The Agency didn't know what direction it was heading, but by being at Headquarters at the time, I was able to help—I'm not trying to overstate it, but I was able to bring the Orion perspective, which is the crew spaceship aspect into the equation of all the different options that were being considered at the time. You may recall, at the time that Constellation was cancelled, one of the possibilities at that time was, we were not going to have a human exploration spaceflight development effort at all. Rather, we were going to invest all of NASA's dollars into research and technology, game-changing technology that had major uncertainties associated with realizing any kind of fielded system in the near term. Said another way, this policy had significant potential, but very low probability of success. That had the potential to pay off, but it also had the potential too that you could not get anywhere. Like placing a bet on very long odds, which I felt wasn't the right approach for something as important as the United States future in manned spaceflight and exploration.

NASA really needed to have a mixture of a portfolio that encompasses both directed missions (such as SLS [Space Launch System] and Orion, for the beyond low-Earth orbit) and Research and Development [R&D] for the far out things. Even though we do advance the state-of-the-art with technology on directed missions, it's not like we are inventing things all over the place. We are using a lot of heritage designs from previous programs, in particular Space Shuttle, and that keeps the costs down, but it also is more of a sure thing. You're just taking incremental steps in capability as opposed to orders of magnitude. But NASA still needs an R&D effort that is looking at breakthroughs in technology. If you put all your money in one and none in the other, you have an unbalanced program, so today, of course, NASA has a balanced portfolio that realizes the potential in both of those, and we need both those types of capabilities.

Back to the ability to influence question. We had a team called HAT, Human Architecture Team, that was formed to address the question "Okay, Constellation is cancelled, so what type of manned spaceflight architecture can we develop within the resources and timescale to advance our capabilities for exploration?" One of the great things about HAT was that resources were taken into consideration. You can kind of guess what Congress is willing to pay each year, and you build your program around that expected funding stream, because you should not embark on something which has no chance of being financially achievable —or as my father used to say, "Don't go to a restaurant and have your eyes bigger than your stomach." You have to live within your means, and so the HAT team evaluated many, many different potential architectures and ultimately cost, schedule, technical feasibility were all weighed into that and factored into the one that kind of emerged from the ashes of Constellation, which is the one we're working on today.

WRIGHT: So you were able to be a part of that.

LUNDQUIST: Right. I was the crewed vehicle lead on the HAT team, and I was able to help influence and shape the direction that the Agency went when coming up with a configuration of the architecture going forward. So that was satisfying, to get to play a role in that, and of course when I was done, I wanted to come back to Orion and help build it, so I came back.

WRIGHT: Any lessons learned that you pulled from working on the early days of the Station that you were able to apply to working when you were working on the HAT?

LUNDQUIST: Oh, sure. Every job you have, you learn things and take that away into your next assignment. That's actually one of the wonderful things about working at NASA—you get opportunities to have different jobs in your career, and a lot of wonderful mentors along the way. No regrets. Actually, the Space Station experience with international partners, which is kind of where we started this discussion, is helping a lot of us now with Orion, because we have an international partner now. The Europeans are now building part of the service module, and a lot of the lessons learned, scar tissue from working with international partners on Space Station, we are factoring into the working relationship with the Europeans. We're running into a lot of the same issues, and we are employing a lot of the same types of solutions working with them.

Of course, there are pros and cons associated with bringing in an international partner. Obviously the interfaces are made much more complicated, right? You've got somebody on the other side of the planet that you're having to make sure that your hardware meets up with their hardware and it all works together, and that adds a lot of organizational complexity and technical complexity. But there's also a significant political advantage. You have a partnership with other countries, and that bodes well for long-term sustainment of your congressional and administrative support for your program, because if they cancel—you know, they've got commitments with other countries, and that goes a long way in helping to secure your continued support.

So it's a mixed blessing, but on the positive side we are bringing that sustainment. Also, we are bringing bright people from all over the world to help solve our problems. Orion has contracts in 47 of the 50 states, and now I think 17 different member countries. We have a lot of brain power across the planet who are all trying to figure out how to field a beyond low-Earth orbit system for space exploration.

WRIGHT: It's nice that you're able to tie all the bits and pieces together and keep moving space exploration forward.

LUNDQUIST: It all kind of ties together here, and that's what keeps us coming to work. It makes it fun.

WRIGHT: I know that you've made some notes on your pages. I want to make sure that we cover everything. Would you like to take a second and take a look at where we are?

LUNDQUIST: Included in the questions you had was about lessons learned based on experiences, and we touched on some of them, but there are a few that we didn't cover, so I'll go ahead and talk about those.

One is the communication and how important it is. You can have communication without comprehension, and we have all these cultural biases—this lens that we filter and process information through. You know, the way we got around that was kind of just brute force working with the Russians and now with the Europeans, it is meticulous detail with our protocols. We spend a lot of time; we have a meeting and then we wordsmith, you know, the document that comes out of the meeting. It can't be, "he said, she said," "I think he said this." The protocols, which are the written agreements, become the basis for work moving forward.

I'm reminded now about how we talked about the data, how the Russians hold on to data. I did want to add another story about that. I talked about how we couldn't get data from them. We would supply a lot of data to them, kind of in one respect hoping that, okay, this is how you

do it. We would go over there to the Russian meetings and I would find our documents sitting upside-down in the paper bin of the copier—they were just using these for the other side; paper was in short supply, so we'd give them documents, they'd take it to the copy machine and just use it for paper. One time, we found a lot of our documents in the bathroom for use as toilet paper, so they obviously had a very different value system. Whereas we value "put that information down, write it down, document it," they didn't value it really as much.

Learning what motivates your counterparts, too. We talk about the cultural differences. With the collapse of the Soviet Union, I told you they were making a lot less money. Prestige in their job was pretty much what was keeping them going, but they were more in a survival mode than us. They would kind of tell us what we wanted to hear just so that we'd kind of keep things going, so you really had to know what their motivations were. With the Russians, you felt like you were playing a chess game and they were always several moves ahead, because they had other motivations. I just wanted it to be business, "Let's build the Space Station," and they had other things that were driving them.

I'll add a little bit to the lessons learned on schedules. We talked about schedule being a driver. On ISS, we went through a couple of years where we had some really poor performance on our schedules. We eventually licked that, but it took some pain and suffering. I remember we called it the GASR, it was the [Center Director] George Abbey Saturday Review, and there was a huge package, I mean it was two inches thick, that we compiled every week. There was a tremendous machine, infrastructure of people and meetings to feed this massive schedule that would then be carried up to George's ninth-floor conference room every Saturday morning, and we'd just go through that massive amount of data with him. He was doing that to force us to get

our act together on the schedule. It was painful medicine, but it was ultimately quite effective because it forced us to really pay attention to the schedule and make the progress that we needed.

We also had some quite adept and proficient leadership like Jay [H.] Greene, who, I don't know how you can talk Space Station without talking Jay Greene, who was a brilliant leader but he was also very demanding leader. We don't have guys like him anymore; we're much more politically correct. Fear was a motivator with him, and it was quite effective, because you did not want to get on Jay's bad side, and there was no surer way to get on Jay's bad side than to be late with schedule. So those were all kind of key things. Of course schedule is still important. We don't use all the same tools that we used back then; fear and intimidation, we try not to use those as much nowadays.

WRIGHT: And what's that been replaced with?

LUNDQUIST: Cooperation and teamwork, "We're all counting on you." There are other lessons learned, like the importance of having margin and reserves for a program. On Orion, we're building a spaceship on a shoe-string budget, and on Orion it really limits management's flexibility to react and respond to problems. I remember on Space Station we had Change Requests [CRs] coming all the time; change requests are generally a response to address a problem. People have a proposed solution and that usually entails expenditure of dollars, so they're asking for money. I remember on Space Station, on Freedom, we had a meeting called SCUD, Screening CRs Under Duress. We had this flood of CRs every week: "People—here's my problem, I need money to fix it." So we'd screen those to prioritize which ones come to the

various boards for disposition. We had the same thing on ISS. We had a lot of CRs that we had to evaluate regularly and kind of pace to get through the board structure.

On Orion, we hardly ever have any people write CRs, because there's no money. You can go to the Orion Program Board and ask for money, and there isn't any to give. A lot of what we figure out to do—we call it affordability initiatives, as we go through the year, every time we turn around we're looking for some way to save money so we can deal with problems as they occur. It forces you to be very, very frugal and constantly—you never can rest on your laurels, because always the new problem's going to come up, right? I mean, that's what our bread and butter is, solving problems. Many times they take resources, so we have to prioritize the resources we have to resolve the new issue.

WRIGHT: That's interesting, thanks for that.

LUNDQUIST: You also asked about memorable moments and we covered some of those, but a couple that I haven't mentioned yet was like that GASR review. You know, personalities. I was lower in the org food chain back then, and I would go to these GASRs and I would see this man [George Abbey] who's rather imposing. I was scared of him. He was sleeping at these Saturday reviews. He's up at the head of the room, we're talking, and he's sleeping, and then all the sudden he'd open his eyes and ask this deep, penetrating question that was right in line with what you were talking about. You're just like, whoa. So he was asleep but he was hearing all this, and he always kept you guessing.

WRIGHT: Always on your toes, huh?

LUNDQUIST: Yeah. So that was a memorable occasion to see.

WRIGHT: It's a different type of management style, I guess.

LUNDQUIST: Right, right. We've seen different types of leadership through the years, and it was all very effective. Another memorable experience was getting ready for the first U.S. element to fly the node. There were a lot of processes we were learning at the time, and so we had mountains and mountains of open paper, and I got the lucky job of closing out all the open paper before we fly. We had like 4,000 pieces of open documentation, and we had this burn-down curve and all these individual issues with people responsible for closing them that you had to reach out and touch. Everybody was an owner on this or that, had to sign off on it, so there was tremendous push, meetings all day long. I think back on it, and it was great. I got to talk to hundreds of different people to try to get this mountain of paper closed.

The lessons learned out of that is there is a lot of paper to close before we fly. Getting the hardware built and tested is important, but there is also a lot of certification, verification that has to occur as well. We experienced some of that on Orion before we flew our test flights. I'm sure we'll encounter it again more, even, when we're flying people, but we're trying to bite it off more as we go rather than let it all accumulate until the end and then have this mountain we have to tackle. It's much better if you can bite it off a piece at a time.

WRIGHT: Was there a chance that that mountain of paper would prevent a launch?

LUNDQUIST: Yeah, well, you know, during the COFR [Certification of Flight Readiness] process or flight readiness review process, you basically have to sign up all the verification is complete, all the open discrepancies have been dispositioned acceptably. The list goes on and on of the different things you have to sign off, that all the "i's are dotted, t's are crossed." You don't want to go into a flight readiness review and say, "I've got 3,000 pieces of open work that address the verification, the certification that this thing meets its requirements." And so yeah, it needs to get done. Of course there is a prioritization, there are some key things and some not so key things, and so that obviously plays into it as well.

WRIGHT: Were there some that were more challenging than others to get closed? Some of the priority ones? Are there any that you recall that you could share with us, like maybe your worst nightmare was going to happen because something didn't push through the way it needed to?

LUNDQUIST: What I recall more is some individuals were much more difficult to convince than others. There might be a very low probability event, but it had serious consequences. There are varying levels of risk acceptance across NASA. The safest way to never have anybody hurt in spaceflight is to never fly, and obviously we don't want that, so what is that acceptable level of risk? And there's funding, and schedule. All are parameters that you weigh against risk. You could have something very, very safe, but it's very expensive and takes a long time, or you could—if budget is a constraint and schedule is a constraint, you might have to take more technical risk. As NASA engineers, we work with the crew and we are very, very sensitive to risking the crew's lives. We also recognize that there is a risk to spaceflight, and the real challenge is, and there's no textbook for this, is how do you maximize safety while minimizing

cost. That's really the challenge. Where's the most bang for the buck for risk mitigation? That's a challenge we face every day—where do we put our precious limited resources to try to have the safest spacecraft possible?

And you get different opinions. If you were to be talking to, let's say, the heat shield person who's responsible for the thermal protection system—Orion gets 4,000 degrees when it comes back through the atmosphere and there's one inch of heat shield protection material between the astronaut's rear end and that temperature—we really need to make sure we have a very robust thermal protection system. It all sounds very good, but if you were to put on a lot of margin, you're going to have a lot of mass there and you're going to have to dial back on the structure or the life support system. So the spacecraft is a very integrally linked—it's like a human body in complexity. Like if you ask a cardiologist how to design a human, he might say, "Well, give him three hearts." Orthopedist might say, "Give him an extra hand," which I would love, by the way.

You've got all these very brilliant discipline experts who want to maximize the performance of their system, but you have to potentially suboptimize those so the whole, the integrated system, is optimized. That's really the challenge of spaceflight, because we can only launch so much and there's only so much we can take, so where are we going to put the margin in the structure—the heat protection system, the life support system, the command and control system, the guidance system?

There's all these different competing things, and there's all different probabilities that that particular system might fail, and so how much redundancy do we put in? How much can we afford? If I put in this additional unit, I'm going to have to take something else out. It's not like I can keep adding and adding and adding, because then I won't be able to afford it or I won't be

able to launch it off the ground. That's the systems engineering challenge that we deal with. So we deal with a lot in the program team, both on Station and on Orion. That's the fun part, is trying to figure out what's the best way to do this.

You asked what I believe the legacy of ISS is. I would say I have several things. I have very fond feelings for Space Station. We couldn't build it today. It's kind of like a pyramid; could we build one of those now? But the Station and the Shuttle were inextricably linked. One was designed to be built with the other. I think it'll be the technological pinnacle for generations to come, because I don't see how we could ever build it again. Looking ahead at the architecture we're building, it's good for deep spaceflight exploration, but it's not going to be able to build something like Space Station and low-Earth orbit. So it's a precious resource. We want to keep it up there as long as possible, glean as much information as we can, and we need to be very prudent in how we use that resource.

But probably after all is said and done, as important as the science is, that may not be the lasting legacy; it could be international cooperation, bridging the U.S. and the Russian relations. Even today they're even maybe more icy than they'd been in the past, but the engineers on our side and their side continue to work together, and they are part of the same team, and they are going to make this work. So as long as we are working together, we can get that common understanding, and I think it's going to help our two nations bridge this and ultimately we'll come back together. Administrations change, and so it's a key element, I think, in our world global relationships.

WRIGHT: What are your thoughts about the legacy of the Station science, since you were there at the beginning and knew the importance of making sure that there was science value there? Share

with us what you think about the progression of where that was when it started and where it is now, and where you hope it will be before it no longer is doing its job.

LUNDQUIST: I'm probably not as well prepared to answer that, because I'm so down and in on trying to field the Orion system; I don't get to spend the time that I would like watching what Space Station is actually doing now. Having been a part of designing and building Space Station, I know it was an incredible platform for conducting research, and having worked with some of the best and brightest in the Agency who were worried about the effects of spaceflight on people and seeing the cleverness of the experimental designs to get so much information out of so little up mass or down mass or crew time—being resource constrained really forces you to be clever. I've always been impressed with what we're able to do with so little, but I really can't tell you what the key scientific progress is.

WRIGHT: Well, hopefully the science on Station will be able to help science on Orion, just for crew and from the work that they've done.

LUNDQUIST: Right, yes. On Orion, we're potentially going to destinations like Mars, and so we're going to need the results from Space Station to help us keep the crew healthy to where they can perform that very demanding mission.

WRIGHT: Sandra, do you have any questions?

JOHNSON: Looking at your background, you have a very unique perspective because you are an engineer but you also have the biological science background, so it's just kind of interesting to me, it's more of a statement than anything that you started working on those early programs and designing missiles, but then you moved to Station and then to the science side of Station. That's kind of a unique contrast compared to a lot of engineers that we've talked to.

LUNDQUIST: It's kind of weird that way. It was a real culture clash—talk about culture clash with the Russians, it was a culture clash for me being an engineer to lead a division filled with 43 different PhDs and MDs. They weren't used to me, and I wasn't used to them. I think I did a lot of good things there. Researchers don't feel like—putting a researcher on schedule, with costs—they'll say, "Well, you can't put curing cancer on a schedule." No, but we're supporting research on Space Station, and there are missions and flights and Station increments, and we have to do all the planning to maximize that. I think merging the two, the engineering and the scientific disciplines, produces some very positive results, because we brought the strengths of both.

We need both types of people. I would say—I'll probably get in trouble for this from my friends over there—engineers are much more team oriented. My name is not on that Orion capsule anywhere, and I don't care. I get satisfaction when it flies. Scientists, they want to discover things, publish that paper, have their name first on it. That's important for them with their science, that they are helping to advance the state of their particular discipline. So they would perceive things through that filter.

I look at Space Station in one way, and one of the researchers who was interested in neurovestibular effects of spaceflight might look at, "How would that platform do my research?"

They will view it as that's its main purpose. Someone in exercise physiology might view it as a place to go exercise in space. Well, that's not really the purpose of it. You need to do that so you can stay healthy, but it's not for that.

So we had some interesting dialogue, but I think when I left there we had much more of a project focus to research. We organized all the researchers into projects that were dealing with these effects of spaceflight and mitigations, countermeasures, to address them with certain critical questions and a plan to answer those critical questions that would then form a countermeasure. It was much more, I think, organized to tackle those problems; hopefully it set a good path, and from what I can see, they're doing great stuff now.

WRIGHT: Thanks for adding that, because that really does make a lot of sense in how things are organized and running. Is there anything else that you would like to add? We don't want to leave anything out that—

LUNDQUIST: I think we caught the key things. This was kind of interesting for me, because it forced me to kind of go back in time a little bit. You get so focused in the problems of the day. My life has been Orion for seven or eight years, I guess, and so I haven't thought as much about Space Station as perhaps I should.

WRIGHT: Well, thank you for sharing what you remembered this afternoon.

[End of interview]