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INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is November 27th, 2007. This oral history with Bob Wren is being conducted for the Johnson Space Center Oral History Project in Houston, Texas. The interviewer is Jennifer Ross-Nazzal, assisted by Sandra Johnson. Thanks again for joining us this morning for our fourth session. I wanted to begin today by talking a little bit about your work with Space Station. In 1984 President Ronald Reagan directed NASA to build a Space Station within ten years. What impact did that have on your career? What did you think of his speech at that point?

WREN: I thought it was excellent. We had studied quite a few versions of the Station and Base, and like I said before, the Lunar Base and the Mars mission and so forth. Usually what would happen is we'd do all these studies for a year or two and then they'd go on the shelf. Then we'd come back a few years later and do another study. We had several versions of the Station that had been looked at in various studies. Different approaches and shapes and so forth. We had H-shape, and quite a few. But to actually have the President say, "Hey let's go now, let's have an edict, let's have a goal, let's go," instead of just doing the studies, that means quite a bit. Of course the follow-up to that is for the Congress to appropriate and authorize the funding for it. That's what happened to Apollo, is that it wasn't that NASA decided not to go to the Moon anymore in Apollo, it's that Congress wouldn't appropriate the funds for it, which is another thing I mentioned before that was a little bit in error on the *Mars Rising* series that's currently on TV. So yes we were excited about that.

ROSS-NAZZAL: What impact did that have on your career at that point? Were there any changes as a result of this decision? Or did that take a while to filter down?

WREN: It was probably about the same, because we just continued to do what we were doing in effect. It just gives added impetus to go ahead and study. Of course we had retreats and so forth at Reston [Virginia] and here and there to get more serious with a goal in mind.

ROSS-NAZZAL: Did you do any work with Neil [B.] Hutchinson and his group?

WREN: No.

ROSS-NAZZAL: Tell us about some of the more memorable payloads then that you were working with for the Space Shuttle up until the *Challenger* accident.

WREN: Sure will. One thing I'd like to say, if I could veer off for just a minute before I get into the payloads, because it's a lead-in, and I touched on this throughout the sessions, and that's on aircraft and spacecraft design considerations and approaches. This embodies really aerospace system engineering. As I had mentioned before that, personally I had gone from of course a journeyman and then to technically in-depth and then to project and management in real broad and so forth. As you go in that direction then you come to realize that you've got to know systems engineering so that all the components, the assemblies and subassemblies play together. So I think it's important for young people coming along in aircraft, especially spacecraft, to remember that all these myriad of parts and components have to play together.

It's like the computer discussions we were having. Oftentimes there's a symbiotic relationship between two different subassemblies so one will help the other. On the other hand they have to also be independent on their own, if you like, where necessary. A good balance in design when folks are designing these things -- in other words you got a question, again, of what is it that you want to do and why and perhaps when, and that's for the leadership, and then from then on, why, if you like the engineers and so forth down the organization figure out how to do it, and so then you got to go out and design some hardware and so forth to do that. But a good balance in the design where again the functionality is always playing against the weight, cost, and schedule, and of course playing into that is your mission success and your safety.

I can give a couple of examples that might be helpful. I don't want to waste too much time here, but like controlling functional devices. What do you mean by functional devices? This would apply to all the disciplines. Avionics, thermal, guidance and nav [navigation], structures, ECLSS [Environmental Control and Life Support System], so forth. A functional device, the way we would define that is something that has a capability of changing state. If it's electrical in nature, it would, for example, change the electrical path. Like switches and so forth. If it's structural it could be like latches and so forth. It would change the structural load path. How you design all that with your control logic is very very important. That's a systems engineering function because when those things happen in one subsystem they must be compatible with what's going on in other subsystems.

I think I mentioned before that these functions, usually you can talk in terms of a must-work function or a must-not-work function. If you've got a must-work function then generally what you do is you run parallel strings so that if one string goes down you still have adjacent strings to accomplish the function. If you don't want it to work, then you want them in series, so you stack it up, you've got barriers in series with those inhibits. Also very important is about the timing of when all these things happen. So they play together.

For example in avionics, let's suppose that you're powering the activation of functioning devices and you decide that you want three inhibits. One thing to really watch out for -- and we saw this many, many times -- is that you want your inhibits to be in the power train and not in the control logic train, because you can inhibit the control logic, and maybe one of them is defeated, but the power train is still there. So you’ve got to really be aware of and study your logic diagram and your control diagrams and what is the philosophy that you're trying to take there.

For example, you could have a sneak circuit that comes back around and will get you on the power train. You think you've got all your inhibits, but they're in the control train if you like. All of a sudden kapow, and you've got something activating when you don't want it to activate. So be very watchful of that. Of course the inhibits, to be valid, need to be independent of one another. In other words if one inhibit is lost, you don't want other inhibits then to copy that and do the same thing. That also then would suggest, rightly so, that all of these control devices need to be environmentally sound. In other words, they can function regardless of what the expected environment would be, vibration, whatever it might be, thermal, so forth. I said that the inhibits must be independent.

Another thing is identify common cause failure modes. Be sure that those are satisfactorily controlled. In other words, if there's one characteristic of a particular device that's prone to failure and you're using several of those same devices, why, then you could have several go out instead of just one. It might be because of the design and/or manufacturing of that device, or it could be environmental again like vibration. Sneak circuits, I mentioned that.

We discovered that it's always good to have at least one inhibit in the ground leg of your electrical circuit, again to guard against sneak circuits. There's more than one way to approach the task, and from a systems level, again you've got different levels, system, subsystem, assembly, subassembly and component. But oftentimes you might be prone to overlook the fact that in order to get the redundancy that you're after, you might go back up to the system level and have entirely different approaches to do something. For example, if you're going to lift a payload out of the Orbiter bay using the Orbiter arm, and it loses its capability and dead in the water, well then possibly another way to do it would be using the Station arm and a different approach. In some cases maybe you could eject it or dock it and undock it and take different approaches. So that always should be looked at.

Another example for functional devices in the mechanical area and structural area, we make good use, full use of over-center cams in our latches and so forth. What is an over-center cam? That means that it goes into a position such that if there's vibration or anything else going on it won't inadvertently release it. In other words it will always hold its position. Therefore it holds the structural load path. Anyway I just thought it might be helpful as we lead into talking about some of the payloads to go back and revisit a little bit on the systems engineering.

The payloads, I don't know where you wanted to go there. I think I may have mentioned that as we progressed with the Shuttle, of course we had to design an airplane that would go to space and fly back, that being the Orbiter. A lot of emphasis was put on that early on. But it wasn't too far into the process that we said, well now wait a minute, we're going to be carrying payloads to orbit, so we better start paying some attention to payload accommodations and payload requirements and so forth. I think maybe I touched on that before. Also as we got down that path we said, well we also need to develop some payload safety criteria. Because we'll be dealing with the customers and what is it that we expect the customers to accomplish and bring to the table. So we had quite an effort back there. I think we started about 1972 to start defining these requirements and spend a lot of work on that. We came up with requirements documents and implementation documents. How do you implement the requirements? Interpretations of the requirements documents. Verification documents. Of course ICDs, interface control documents. All these things to put some meat and muscle into the program control and so forth for the customer, that the Shuttle would have with regard to the customer with its payloads.

We took this very seriously, and we created a lot of boards and panels and so forth to accomplish that task. We also created now, on the helpful side, some documents that described to the customer what accommodations the Orbiter had to offer in the way say of electrical power or possibly one or two of the inhibits that he would need to meet the requirements and perhaps the use of a computer and so forth. We generated a whole series of technical handbooks for the benefit of the customer. These were in areas of structures, mechanical systems, batteries, pyros, wiring, safe distances before you allow the customer to lift the inhibits on firing his engines on his upper stages for example. So as we progressed in defining those requirements, then we said, well we'll have to have a review panel to review all that. So we created that. I think that was in about 1977 that we started that and put together a panel representing different groups around the Center, Engineering and Program Office and so forth.

I'd say a word too about -- this is in general. We wanted to create a comfort margin so that we would have -- if like a manager when he goes into designing these systems, he wants to keep something in his hip pocket as a margin. That could apply to weight. It could apply to safety tolerance, must-work functions. So way we defined that was that if you have a single string, again we call that zero-fault-tolerant. If you have two strings with two independent inhibits or whatever it's single-fault-tolerant. Three would be two-fault-tolerant. For the payloads, what we did is we designed or set up a classification of hazard level and tied that then to the amount of fault tolerance that we would require. We defined a critical level hazard and, a critical level and a catastrophic. What was critical? Critical would be like if you had injury to the crew or impairment to the vehicle or the mission. Then catastrophic would be of course loss of crew, loss of vehicle, and loss of mission. If it was deemed to be a critical level hazard then our requirement would be single-fault-tolerant. If it was deemed to be catastrophic level hazard, then we would require two-fault tolerance. Of course this would be applied to functioning systems, and that's why I just talked about functioning systems.

If it was in the case of structures or pressure vessels and tanks and that sort of thing, then we do the same thing, but we talk in terms of safe life design and so forth. We put margins on that and I talked about that earlier, about limit load, then yield ultimate, and putting factors of safety and margins of safety on the hardware in those cases. So that's what we laid on the customer. Then I can go into a little bit of detail if you like on the history of the payload safety review panel. The reason why that might be important is because not only did it accomplish some significant help for the total program for mission success and for safety, it also was used as a model for how we did the Station. So would you like for me to go into that a little bit?

ROSS-NAZZAL: Sure. Why don't you talk about the model that was used for Station and then we can talk about some of the payloads once the Space Shuttle was operational.

WREN: Let me say that the PSRP [Payload Safety Review Panel], we started that in '77, and I think I may have mentioned before, we established a review panel as part of an assessment process to be required of customers for their payloads. We always expected, by the way -- this is pretty important I think -- is that the customers in the end bore the responsibility for their payloads, for the design and that their payload -- first of all that they understood the requirements, second of all that they implemented those requirements, incorporated those into their designs and their builds, and then they had to come show us what they did and prove it through a satisfactory demonstration of all that.

The panel as I recall was -- and I may have mentioned this earlier -- we first started -- the first chairman we had was Harold [E.] Gartrell. Leonard [S.] Nicholson and a bunch of us were involved in all that. I think Harold was actually the chairman. Maybe Leonard was the alternate chairman or assistant or something. Then Cliff [Clifford E.] Charlesworth, [maybe Larry Williams], and Dick [Richard A.] Colonna, Bob [Robert L.] Blount, Harold [F.] Battaglia, and Skip Larsen [backed by David E. O'Brien and Jeff Williams]. Then the Engineering rep where I was located, first one was Don [Donald G.] Wiseman, as I recall, and then Larry [E.] Bell, and then Helmut Kuehnel, and then myself.

Of course the panel was made up of -- as I maybe said before -- representatives from the program office, S&MA [Safety and Mission Assurance, Ed Schlei, Richard Serpas, safety engineers, Betty Ann Davies, etc.] and Engineering Directorate, Mission Ops [Operations], [Dave A. Ballard, Bob Alexander, and later, J. Mark Childress], Astronaut Office, [Gerald Griffith, Guion S. "Guy" Bluford, Jeffrey A. "Jeff" Hoffman, Robert A.R. "Bob" Parker, etc.] Space and Life Sciences, [James M. "Jim" Waligora, Martin E. Coleman, John James, etc.] so on and so forth. We had the Cape [Canaveral, Florida] involved, Chuck Billings (phonetic) and those guys. [For efficacy and safety guidance related to crew experiments, we relied on review and recommendations from Dr. Larry Deitlein and the HRPPC (Human Research Participant Protocol Committee).] The DOD [Department of Defense] as required. Oh, the Marshall [Space Flight Center, Huntsville, Alabama] Spacelab, when the Spacelab was involved, Bob Lake, [Alan Thirkettle] and so forth, and the Russians for Russian experiments and later on, Station experiments. Now there's an example here of what the panel did. If you'd like for me to talk about the Russian docking Mir.

ROSS-NAZZAL: Oh, absolutely, yes.

WREN: We were charged -- and this now occurred in about, I think it was '94, October '94 to February '96 as I remember, and I was with -- at that time I was in the Engineering Directorate office working with John [W.] Aaron and Leonard Nicholson. But we had a challenge, because the task was to use the Orbiter, the Shuttle, an Orbiter to deliver a Russian component to the Space Station Mir [on STS-74]. So to us what that meant was that the Russian docking module was a payload. Therefore it had to meet what I just finished describing, the payload requirements. Well guess what? The Russians had no clue about what are these silly payload requirements, what's all this paper you guys are working, we don't need all that paper business.

They of course had a whole different philosophy. As I may have mentioned before, they didn't have very many computers. They didn't do as much analysis perhaps as we do. But they made more beefy and robust designs and equipment. They did more testing. Kind of like by the way what [Wernher] von Braun and the Marshall bunch did with the Saturn. A lot of beef and a lot of testing. The Russians of course weren't familiar with our requirements. So now what do we do? Now we're stuck, because we can't expect the Russians to go do all these things we've been expecting of all these other payload customers. Uh oh. Time out. So I said, “Well look. Why don't we do this? We got an awful lot of sharp people in the Engineering Directorate. Why don't we create a special support team? Our normal support team plus add-ons if you like. We'll help the Russians. We'll be friendly here and we'll help them and we'll assess the whole docking module, the whole payload, we'll core-drill it and assess it technically ourselves, and we'll do this by trying to talk with the Russians and understand their systems and work with them. But we'll actually lead, and take the lead, and show the way. In a lot of cases actually do it, like fracture mechanics.” We actually did all the fracture analysis: [Glenn M. Ecord, Royce G. Forman, A.R. Shamala, that group. We were looking for “equivalent safety” as against specifically meeting our established and published requirements.]

So we did that, and we went through that. It took quite a while. It took about a year or so to go do all that. It turned out that with a few changes here and there, and I don't recall what they were, but they were minor, it turned out it was going to be okay. So we recommended to the program management, “Let's go ahead and fly the Russian docking module.” The reason I wanted to bring that up is because it was excellent technical work on the part of the entire Engineering Directorate team. It was outstanding, and I think you'll see in the documentation somewhere that there were some awards that ensued based on that. But it was a monumental effort that we did that one time to try to help the Russians and good international relationships.

I would say that another good thing that came out of it for me personally was that I had the opportunity, since that was the first time that we actually worked in detail with the Russians

-- yes, we flew with them in ASTP, the Apollo-Soyuz Test Project, but we didn't really deal with one another a whole lot in the technical level [other than the docking system]. In this case we were going to have to do that and so they sent over -- on their very first delegation they brought the heavy guy, and they brought Dr. Boris Sotnikov who was the lead designer for the Russian Buran. Of course it was kind of a copy of our Orbiter. But nevertheless the Russians held him in high esteem, and I enjoyed working with him, of course through an interpreter.

I also found out by the way that in that world -- and I got corrected right away -- they're not translators, the folks that do that interpretation. If they're interpreting speaking when you're speaking to the Russians or whomever, they're interpreters. If they take the written document and transcribe it then they're translators. So I was calling them translators and I got corrected on the side, no, they're interpreters. Anyway it was the technical group that did the interpretation and translation. Does excellent work. But so I did get to meet and have some social activities with Boris Sotnikov. He had a twinkle in his eye and a smile on his face and a little older gentleman and just fun to work with. Of course he brought a sizable group along with him of his technical experts. That's what they refer to their subsystem managers and so forth, is technical experts. So we started coining and using that term too. It's a good term. But I wanted to be sure that mention was made of that special effort to help the Russians on that particular payload.

ROSS-NAZZAL: Did you go to Russia at any point?

WREN: No. No. I tried real hard whenever somebody needed to go to Russia that somebody else would go. I didn't really want to go to Russia myself. It was kind of a personal thing. So no. I was asked and encouraged several times to go to Russia, but I did not want to go at the time. So no, I didn't go, but I had other people go.

ROSS-NAZZAL: What was it like working with the Russians when, for so many years early on in your career, they were our opponents?

WREN: That's a good point, because when we first met one another, why, we were uptight and they were uptight. Then slowly as time went along, why, as we became more familiar with one another and looked at one another and smiled and saw that hey we're all humans, and we're all engineers, and we all have families, and we all have to eat and drink and put on trousers and all that sort of thing, so we're people, and we came to realize that if there were any differences it was in the area other than the engineering. It was in the political world or something. It was not at -- or maybe even the highest level of management in the different space programs maybe, but probably political, and that we didn't really have any differences at the working level. So as we came to realize this, why, then the tensions eased. So we relaxed and we started having fun. We made jokes, kidded one another.

The payload customers tended to have a different philosophy than what we had in our program. Our program, I think I may have mentioned before, is very kind of formal when we started out. We had coats and ties and expected to dress properly and so forth and behave properly. So all of a sudden these payload customers start showing up from Japan and Russia and Italy and Germany and they oftentimes marched to a different drummer, they've got different cultures. What do I mean by that? Well, for example, they believe in gifts. So they bring little gifts. We had gone out of our way in our program to put in requirements about you can only accept a gift up to $5 or $20 or some number. They weren't used to that. I wouldn't say it's payola. It was just a kind of a custom to be nice enough. And so we had to kind of smile, and of course we did most of our meetings off-site over at the conference center. So we weren't inside the gates if you like. But we're still under the control of the program and our requirements. So we had to kind of let them know that well, we appreciate it and we'll accept it maybe this time, but we don't normally do that. So we scrambled around and we went out to some of the stores around here and bought a few little gifts so we – you've got to have something to give back. Not just accept. Of course in a couple of cases, why, it was way too much. So we just had to politely decline. "Appreciate it."

Well, it extended with the Russians a little bit further, because the Russian culture includes vodka. (Laughter) So on our first meeting, why, Dr. Sotnikov had his troops roll in towards the end of our first meeting. It's time to celebrate, had a good meeting. So he had them roll in all these boxes of vodka. I mean they're good Russian vodka I guess. I don't know much about vodka. So you put them on the table in front of [you]. My God, now what do we do? Not only that, then we were expected to have one opened, and then they had brought in little shot glass things and we were supposed to all take a shot to celebrate success of this big meeting. We weren't used to that. Oh my God, what do we do now? You don't want to hurt their feelings because you've got a relationship thing going on here. So that was kind of interesting. We went ahead and had a shot by the way. But we didn't do it again. It was a one-time thing. We kind of let them know that we really appreciate it, but we couldn't really do that.

ROSS-NAZZAL: That's not the work culture in the United States.

WREN: Right. You don't drink while you're in a working place. But anyway that was kind of fun. Certainly different. It took some getting used to. I think several of us still have a few trinkets, if we haven't given them away, of little things the Japanese brought, little sachet things or something, I don't know. Oh fans, you know these fans that you cool yourself with and so forth. They brought a lot of those little gifts, because that's the culture. But yes the vodka one, it was something else.

ROSS-NAZZAL: What were some of the bigger gifts that you recall that you had to say you couldn't accept? Do you remember?

WREN: No. I prefer not to try to remember. (Laughter) I don't remember. But they looked like they might be kind of expensive, with a little gold and silver or something. So we declined those. Said, “Well, either take them back, or we'll give them to the Smithsonian or something.”

ROSS-NAZZAL: Oh, that's a good idea, yes, gifts given to NASA. That's a good idea. How many people were working this effort with the Russians? Do you recall?

WREN: No I don't recall the number. Like I said it was our normal support team augmented. Oh we maybe had 50, 60 people I guess, because we would normally have 20 or 30 at that point from the different disciplines. At that point we were using, instead of a subsystem manager approach, we were using technical experts. So we had a person from structures, several from different kinds of avionics, so forth, had a laser expert, battery expert, mechanisms, thermal, active thermal, passive thermal, so on and so forth. Then I had a team created and I would call upon those experts as required.

Some payloads may not have any lasers for example. So we didn't need to bring the laser guru over. But we'd use them as required. But for the Russian effort, we probably pretty much doubled that effort. Instead of one person from an area, why, maybe we'd have two or three. Because we were actually doing the work ourselves in a lot of cases, instead of just reviewing what it was that the customer had done. We were actually doing it. So we had maybe even a little more than double in some cases.

ROSS-NAZZAL: You mentioned you were using technical experts instead of subsystem managers. When did that switch begin, and why was that the case?

WREN: Well, the subsystem manager approach was used in Apollo. We didn't have it in Gemini because most of the work was done by McDonnell Douglas and we had a very small program office. Mercury was about the same way. In Apollo, we made full use of subsystem manager approach. There again the subsystem manager was responsible for everything to do with his subsystem: technically, schedulewise, costwise and so forth. Then it would interplay with other subsystems. The contractors involved and civil service. We continued the subsystem manager approach on the Orbiter and the Shuttle, but we veered away from it on the payload relationships.

Probably the biggest reason why we did that is because it was not our hardware. It was the customer's hardware. So the customer had a whole team of people back at his plant or wherever he came from that had -- oh, however they did business. They had their subsystem managers or technical experts or whatever. We were more in a mode of, like I said, being sure that the customer understood the requirements and then how did he incorporate those in his designs and his equipment. So we weren't responsible for the hardware per se, so we didn't need subsystem managers. It really wasn't appropriate. But we did need the technical expertise to be able to pass a judgment on what the customer had done. Like I said, the main thing was to assure safety for our crew and for our hardware as well as the public. But also to help them achieve mission success, because we didn't want anybody to fail. But that's when we kind of went over and said, "Okay, when we do this process, we're going to use technical experts instead of subsystem managers."

ROSS-NAZZAL: When the Russians came over, were they here for that entire time? Or were they here for periods of time?

WREN: No. They would come and go. They would come for review sessions. Usually those would last -- since they had to come such a long distance, instead of just a few days we'd make sure that we'd bunch together subject matter and so forth so that their visits would be a week and a half to two weeks, say, maybe some cases three weeks, to optimize their travel time and expenses.

ROSS-NAZZAL: Did you socialize outside of work with the Russians?

WREN: Oh yes. (Laughter) Yes. They like to put their vodka in the freezer. Of course we would oftentimes, in addition to just going to local restaurants and so forth, why, we would go to people's homes that would be gracious enough to open up their homes and we'd have a function at someone's home. It's good a) to build relationships, because you get to socialize and relax and so forth. It's a huge help. So then when you go back the next day to the session in the big review room, why, you feel a lot better about -- you know the person on a human basis and a social basis. So not only are you more likable to one another, you probably trust one another more also. It's a positive kind of thing. It's a very useful and positive thing and a very human thing. So it was very good.

ROSS-NAZZAL: Were they here when the mission launched? The Russians?

WREN: I believe they were. I believe they were. Traditionally we have, for operation of the Shuttle and the Orbiter, we have a payload support room. We had that all set aside. Actually we have it over at mission control, Building 30 area. Later on, we established one up at Marshall in Huntsville. In fact my son, [Kiley Wren], did a lot of that sort of work. He would man the -- I guess I [should not] talk about my relatives here, but he worked a payload support room here, and then he kind of followed the operation when we moved it up to Huntsville. So he kind of spent a lot of time up there. [He was the science officer support lead on *Columbia*, e.g.] But yes, for the launch of the docking module, the Russians, I don't remember, but I feel sure that we had the Russians involved in the payload support room and set aside space for them and so forth, tied them into the intercom through interpreters. Yes, we had probably. I'm sure we had them involved in that.

ROSS-NAZZAL: Did the mission go as expected? Everything went fine?

WREN: Yes, yes. We got it up there and took our RMS [Remote Manipulator System] and installed it and everything went fine, yes, went fine.

ROSS-NAZZAL: You have any sort of landing party or any celebration afterwards?

WREN: We probably did. (Laughter) I don't recall. It would be like us to do that after the mission. Of course there's always that vodka. I understand there's a Russian beer now. Somebody was telling me about that the other day. I may have to go investigate that. Couldn't imagine that the Russians knew how to make beer, but evidently maybe this is part of the new Russia or something. I don't know. Anyway I veer.

ROSS-NAZZAL: I associate Germany with beer, not Russia.

WREN: Germany with beer, right. Oh yes.

ROSS-NAZZAL: They brought beer?

WREN: (Laughter) No, but they knew how to drink it.

ROSS-NAZZAL: One of the other missions that I noticed that you were involved in was the first Hubble Space Telescope servicing mission. Would you like to talk about your involvement?

WREN: Yes. Of course, again we worked very closely with Goddard [Space Flight Center, Greenbelt, Maryland] on the equipment to go in the Orbiter payload bay. First of all, to deliver the Hubble Space Telescope, and then some special equipment to carry equipment for servicing missions. What was created to go in the aft section of the payload bay was a chunk of hardware where we would grab the telescope with the RMS, with the arm, and could gently put it into a berthing location on this device in the aft end of the payload bay. Therefore it was solidly attached to the Orbiter at that point. Then our crew could go out and do the spacewalks and open up the [HST] bays and pull out the equipment that needed to be replaced and so forth. Then we had stowage areas in the [Orbiter] bay. So I can't recall all the names of the people at Goddard that we worked with [in Frank Cepollina's group, and others,] but it was a very ingenious and good design for that device, for holding the telescope while it was being worked on, as well as the carriers for the different pieces of equipment that would be coming and going that we put in. So we supported all of that as normal business for a payload customer. So in that case, why, the telescope and the Goddard folks were treated as customers.

Oftentimes -- in fact, most of the time, it turned out, by the way, that the "customer" was really another NASA Center. We had envisioned early on that a lot of the customers would be commercial customers that would not be NASA Centers. But somewhere along there, why, I guess it was probably certainly after *Challenger*, it was decided to deemphasize the commercial aspects and encourage the commercial customers to fly on expendables where crews, manned aspects, were not involved. So they flew on Deltas and so forth, other expendable vehicles. So then it kind of became like I said, the customers became mostly other NASA Centers.

Actually that's probably the main driver for why, when we created the requirements, that we put so much extra margin in there and pad in there, because we were anticipating working with commercial customers that we didn't know anything about. The experimenter might be working out of his garage or something. We had no idea about his process control, his manufacturing control, his quality control, that sort of thing. So that gave rise to putting extra pad in to cover those unknowns and maybe some defugalties in their equipment that we didn't know about, even though we would try to have exhaustive reviews and see what they'd done. But yes, so we were working mostly with other Centers, and we did work a lot with Goddard for the Hubble Space Telescope.

ROSS-NAZZAL: Did you feel any pressure at that point that NASA had to succeed at that mission?

WREN: Oh yes, yes. Yes, because its eyesight was no good, because of the error in the curvature. We're talking about very small amount of tolerance there where it works or doesn't work in this huge mirror. It's just mind-boggling. But it didn't. So the experts and the smart people had to go figure out a way to correct the eyesight, just like your eyeglasses. They did that, and it was just amazing to me that they did that. So we carried up this -- in modular form -- something that would go in the line of sight and work just like eyeglasses to correct the aberration that resulted from the error in the creation of the main mirror of the telescope.

Yes, we wanted to be sure we got that up there and got it installed and corrected the vision, because it was worthless. Here was this great hope and opportunity to be able to advance science and see things, and couldn't see anything, blurry vision. So it was very satisfying that the fix worked. Then of course my goodness, what a difference. That's, in my opinion, probably the most significant payload that we've ever flown, as far as advancing science and understanding the universe and so forth. You've seen the pictures. It's beyond belief. The classic pillar is just mind-boggling. So many light-years from the top to the bottom of that thing you're looking at.

ROSS-NAZZAL: You won an award for your work with that servicing mission.

WREN: Yes.

ROSS-NAZZAL: You mentioned the *Challenger* and the impact that it had on payloads in terms of getting rid of the commercial side of the house. What other impact did the accident have on payloads or your career during that time when we weren't flying any missions?

WREN: Well, it turns out that *Challenger*, the actual cause of that failure didn't have anything to do with payloads. It had to do with the joint in the SRB [Solid Rocket Booster]. That was bad. It took a lot of work to understand it and then fix it and then prove that the fix would be okay. But it really wasn't a payload problem. So from a payload point of view, we wiped our brow and said, "Ah whew, thank goodness it didn't have anything to do with payloads." Because when it happened --

ROSS-NAZZAL: Were you concerned?

WREN: Oh yes, because we didn't know. As a matter of fact, I recall when it happened we were in a review room. Of course you always have the TVs up when the mission is going and you're doing your work, but you keep your eye on the monitor up there as to what's happening. And it came time for launch and so we stopped for a minute and all watched the monitors and when it went up, why, right away we knew that something's not right, because we could tell from the vapor trails and smoke trails and so forth, hey, something's not right. Then of course it became obvious that things were coming apart, and that was a bad day.

But we didn't know what caused it. We said, "Wow," and I don't recall what the payload was on that mission. But did the payload cause it? Did we do something wrong, those who are working payloads currently? Yes, you feel a very heightened sense of responsibility, and wow, did we do something wrong. We thought we had built in enough rigor into all these requirements I was talking about for the customers that we wouldn't have problems with the payloads.

I think I described the other day about we did have one on Superzip, on one of the payloads. So it could happen. Another thing we were leery about along the same line is flying some payloads that had the possibility of being super volatile. For example, we were going to fly the Centaur upper stage and before *Challenger* a lot of us had many reservations about the risk involved in flying a cryogenic upper stage. The characteristics of the Centaur are kind of unique, because first of all, it's what we call an integrated tank vehicle. So in other words, instead of two tanks, [where], it was two completely separate tanks, it's kind of like one tank but with a bulkhead in between separating the hydrogen and the oxygen.

The other thing is that in order to save weight, General Dynamics had designed the Centaur with real thin skins. It was pressure-stabilized. What that meant was that you had to have pressure inside the tank in order for the tank wall to serve as a satisfactory structural member to take this launch and boost when it went up on an expendable. What controlled that pressure? Well, they had an ingenious design of several computers as I recall. I think it was five computers that voted, and they controlled the pressure. As long as the pressure was at a satisfactory level, then it had enough structural strength to accomplish the mission. Well, if you had a failure in a certain number of those computers resulting in a decrease in internal pressure, then you had a structure that wouldn't hold. Of course if you had a structure that wouldn't hold, then not only did you have a possibility of an ensuing failure, but then you had hydrogen and oxygen coming together and you could really have a bad day.

So it was decided to put one of those Centaur stages, instead of a solid propellant or a more benign liquid propulsion stage, in the Orbiter payload bay [for higher performance, higher Isp, specific impulse], and we thought, "Oh boy, that's kind of risky, what happens if the computers—"and oh boy, oh boy. So we had many reviews on that subject even before *Challenger*. We brought in some extra help. We beefed up our team. Here's another case, we beefed up our team both as to the numbers of folks and to the level of involvement. I don't recall, I know we went -- I think we even had -- at the time -- I don't recall who was the head of Engineering Directorate, for example, but he was involved directly in the review process when we had reviews out at General Dynamics. Even the crew [led by Frederick H. "Rick" Hauck] was kind of nervous about it. So then after *Challenger* it was decided to cancel that and not to fly that Centaur, and never has flown in Orbiter.

So there was a case of where no that's too much risk involved in that payload. So it flew on an expendable. Made its delivery. I don't recall now what the payload was. But it was just too much risk. So we breathed a sigh of relief that "Okay, it's not going to be pushed from [NASA] Headquarters [Washington, DC] or wherever to fly that confounded" -- Centaur is a good one but it was too risky for use in the Orbiter payload bay.

ROSS-NAZZAL: What did you do during that time between the *Challenger* accident until we flew again in September of '88?

WREN: Well, we went back and revisited all the payload requirements; be sure we had plenty of rigor in there. The first thing we did was to be sure there wasn't anything wrong with the payload. I can't recall what the payload was.

ROSS-NAZZAL: I think it was a TDRS [Tracking and Data Relay Satellite]. I think so.

WREN: TDRS, yes, yes. That's right. It was, because that's right. We lost that first TDRS. So the first thing we did was to exonerate, if you like, that the payload didn't cause a problem. So we did a lot of work on that, to make sure that was not the problem. Then when it was discovered that it really was on the SRB, well then that reinforced our finding that no, it didn't have anything to do with the payload. Then after that, why, like I said, we went back and revisited all of our requirements to be sure we had sufficient rigor in there and we hadn't missed anything, even though it wasn't a direct cause of the event.

ROSS-NAZZAL: How do you think that ideas or policies about safety changed after the *Challenger* accident, if at all?

WREN: Probably it went back to the same thing about what I touched on earlier about functionality. You might have what appears to be a good design and it's good manufacturing and quality control and it's built to print just as it was supposed to be, but did it really function like you wanted it to function, the end function? Did the way the joint was designed to stop the gases, and considering the thermal expansion and contraction and the structural bending and all the other factors, was all that taken into account and then was sufficient testing done under different conditions to demonstrate that that design would work?

So to me it reinforced the overall philosophy of, boy, when you're dealing with people's lives you've really got to be careful. When it's man-rated, it's more than just launching something on an expendable where there's no people involved, and if you lose it, well, you lose some dollars. You haven't lost life. So it's serious business when you've got crews involved, people involved. So in my mind, it just reinforced to do a lot of testing.

I'm big on testing. Maybe that's from my roots when I started back at the bomber plant. But after all the analysis and all the computers and the CAD models and so forth we have, and thank goodness we have them, and they're great, but the proof of the pudding is still in your testing. You cover something that you couldn't anticipate, you couldn't think of. Because that's usually what gets you, is something that you either forgot or you weren't aware of. What you did think about and did design, you probably did a pretty good job. But it's what you didn't think about. That's where the testing will help you. It's like those parts falling off the IU (phonetic) in the vibration test on Apollo. That's the proof of the pudding. Let's test it. I know that there's money involved in testing. So you can save money in your budget if you cut out some of the testing or don't do any testing. Bad move, I think. It's money well spent.

ROSS-NAZZAL: One of your biosheets indicated that for a period of ten years, you served as the alternate chairman for the Space Shuttle Payload Safety Review Panel. Any special thoughts you had about that time and some of the issues that you dealt with? Or were they just the basic issues that you dealt with on a regular basis?

WREN: No, I think that probably the way I would look at that was I was appreciative and honored that I would be considered to take that role on occasion. Probably wasn't so much me personally as the fact that, like I said before, the largest amount of support to that effort, to the panel's effort, came from the Engineering Directorate. Just by its nature of all the equipment and subsystems involved and so forth. Yea verily, it was large support from Ops. Mark [J.] Childress and all his folks. But just by its nature, there was a large degree of support from the Engineering Directorate. So it would kind of be natural, I guess, that somebody from the Engineering Directorate might stand in as an alternate for the overall panel effort, since you pretty much knew everything that was going on.

ROSS-NAZZAL: Any special concerns during that time, or things just pretty much went smoothly?

WREN: No, no problem. I have no problem managing things. (Laughter) Rightly or wrongly. Just manpower and resources.

ROSS-NAZZAL: I noticed that in '95 that you won the JSC certificate of commendation. Would you like to tell us about that award and what you received that for?

WREN: Ooh, let's see. I believe that was probably for the -- I don't recall what it was attached to at the time. I guess I was with John Aaron and Leonard Nicholson and the Engineering Directorate office at the time. It may have come after the effort that we did on the Russian docking module delivery. Also, one other thing we haven't discussed yet is how we set up the Station review process. Maybe it came as a result of that. I don't recall. But somebody decided that I guess some good work had been done to contribute to the effort. I don't know.

ROSS-NAZZAL: Let's talk about that Station review process. Was that based on the Space Shuttle experience that you had developed?

WREN: Yes. I'm glad you ask that question. (Laughter) Came time to do the latest version of the Space Station, which we call the International Space Station [ISS], the current one. We decided -- I say we. There’s a lot of folks involved in these kinds of decisions. But we decided that -- let me back up. For most programs we do what we call concurrent engineering. What we mean by that is -- we did that for Apollo and for Shuttle, Gemini, Mercury, all that. You usually do that for your aircraft activities. What I mean by that is that when you have all your different teams involved in the design and development process, and you have your reviews all set up for program control and process control and manufacturing control and all that, you'll have the different disciplines and then you'll have -- for the safety aspects, you'll have that as just another one of those team members. So it's just concurrent with all the other team activities. That works real fine when it's your own hardware and you know what everybody's doing and you really have your hands on it.

I discussed earlier that with the payloads, we took an entirely different approach, because we didn't know what they were doing back in their garages. So we wanted to put the onus on them and then review what they did and so forth. Okay, what has that got to do with the Space Station? Well, turns out that the Space Station kind of took on the aspects of payloads in the sense that here were a bunch of people contributing modules for the Space Station not in their garages, but kind of removed. They had their own teams and in some cases they were other NASA Centers, in the work package scheme that was set up. In some cases it would be the Russians and their modules, the Canadians and their hardware, the Europeans, ESA [European Space Agency] with their Columbus module and so forth, and Japanese NASDA with their Japanese experiment modules and so forth. The point being is that guess what, they were starting to look like payloads. Same idea. So why don't we create, instead of trying to have concurrent engineering applied to the safety aspects for the Station, why don't we borrow upon what we developed for the payloads. Management says, "Wow, what a great idea, let's do that!"

So we set out to set up what we call -- for the ISS the Safety Review Panel [SRP]. We set it up, copied the exact same approach that we did for the PSRP, for the Shuttle payloads. It turned out that that was a good move. That was a smart move, I guess, and it worked fine. So that way we could come in and have reviews, phase reviews, and I guess I didn't talk about that, but we'd have a series in both payload process and in this SRP process where we keyed the reviews to where the customer was in their development cycle. So we'd have a phase zero review at the start to get everybody on the same page and see if they understood the requirements at the get-go, and then we'd have what we called a phase one review, and we'd have that along about the time or right after their preliminary design, their own PDR, their own preliminary design review of their hardware. Then we'd have a phase [two] likewise right after their CDR, their critical design review. That way it made sense in the flow of where the reviews were keyed to where they were in their development cycle. Then we'd have a final review [phase three] at the end to assess all their results after their testing and so forth. So we set up that same approach for the Station modules and it worked great.

Like I said, we worked with the Russians now in two ways. One with their modules, and then of course we worked -- we decided that any ISS station experiments, we'd run that through the PSRP and the payload safety review process for the experiments. But for the modules, we'd run it through this newly created panel. We set this new panel up so it was cochaired by not only the Shuttle Program Office but also the Station Program Office. Then of course we had our usual cast of support characters, Engineering Directorate, myself and Mission Ops, Mark Childress and on down the way. Then we also added in representatives as appropriate depending upon what we were reviewing. People from the sponsoring modules, the Japanese or the ESA folks, [Hendrik Wessels, Tommaso Sgobba], the Germans, the Brits, French and so forth. Then the ASI [Italian Space Agency], the Italians, [Giovanni Rum], and NASDA, the Japanese, [Yashihiro Harada and R. Kobayashi], and the CSA [Canadian Space Agency, Dave Madely and Hank Williams] for the Canadian arm and so forth. Of course the Russians.

The Russians, we worked with Energia and Khrunichev. That was their two contributors over there, manufacturers, design and manufacturing groups. Energia, the guy that led that team was Ernst Demchenko, and then Khrunichev was Mr. V. Nagovfkin. It all worked fine. It was a good approach to take. It's still operating today. Anyway that's what happened on the SRP. Kevin [A.] Klein, Gregg [J.] Baumer, they kind of were the Station chairmen of that [backed by Harold Taylor and Jerry Holsomback and, of course, Randy Brinkley, and later, Tommy Holloway and William H. "Bill" Gerstenmaier of ISS], and Skip Larsen for the Shuttle, and the engineering rep I guess was me. Mark Childress, bless his heart, always shows up for Mission Ops. You know Mark Childress? Long tall drink of water? He's a great guy. The olden days, you'd see him on console a lot, on the monitors in payload. He's a great guy. [And, of course, Rich Patrican and Leo Perez from headquarters, Gil Bonse and Blaine Hammond from the Crew Office, etc.]

Oh, and then I guess to follow up on that, I talked about concurrent engineering, but we also had a panel set up to address Shuttle integrated process. In other words, to be sure that all the parts of the Shuttle played together. The Orbiter, the SRBs, external tank, the main engines and so forth. That was set up out of Skip Larsen's office. Dave [David W.] Whittle chaired that. Then we had some participation from the Engineering Directorate. I was involved in that integration panel review effort. It was not nearly as exhaustive perhaps as the PSRP and the SRP. But it played an important role, and I guess it's still operating today, an integrated process of review. I think that pretty well covers all of that as far as our different processes.

ROSS-NAZZAL: I think those are great explanations for people wondering why things changed, and why they were set up that way. One of the things that I saw in your notes, you seem to have a list of professional organizations that you belong to. Is that something that you wanted to talk about?

WREN: Well, it's the usual range of things. AIAA [American Institute of Aeronautics and Astronautics], and of course I'm a registered professional engineer. So at one time I was a member, although I kind of let it drop, because the work you do at NASA you don't really need to put your seal on anything. You don't do that. But I kept it up. So I kind of dropped out of the organizations. The Texas Society of Professional Engineers. Even though I'm still registered professional engineer. When I was in doing the acoustical work, I was a member of the Acoustical Society of America. Institute of Environmental Sciences and so forth. Somewhere back there the ASCE, the American Society of Civil Engineers, because I was structures, but I was through the civil engineering department.

ROSS-NAZZAL: Well, in 2000 you decided to retire. What brought about that decision?

WREN: Well, first of all, I reached the age of 65, and of course fully vested. Some personal reasons I guess. The other thing was that there had been created a contractor to operate the Shuttle called USA [United Space Alliance]. It was constituted probably at the start by mainly some Rockwell, North American Rockwell folks. But, rapidly it started absorbing some NASA folks that retired and so forth. So I had kind of an offer to go join them. What was happening over at USA was that in addition to the Shuttle operations contract, there would be upcoming -- it was envisioned at the right point in time, a like operations effort contract for the Station. So USA management set up a Station Project Office.

It was headed by Jim [James F.] Buchli; he's an astronaut, ex-NASA guy, like quite a few of the folks at USA. So Jim was a great guy. Jim asked me to come over and join them and try to set up an S&MA kind of effort and safety effort and so forth in preparation for the time when those contracts would come to pass and be awarded. So did that, and that's why I decided to go over there and do that activity. Turned out that that kind of dissolved, because NASA had decided to change the way they were going to do the operations on the Station and divided it up a little bit more and so forth instead of just having it in one entity. So Russ Turner rightly so decided -- he's the CEO [Chief Executive Officer]-- decided that maybe after a couple, three years, whatever it was, that we would dissolve that office and give up on that effort. So I saw a golden opportunity to retire for good. So I did a second retirement and that's what happened.

When I was there it was kind of interesting, because they were running -- we had USA support on some of the PSRP and SRP at that time. It was running a little bit short because of the folks involved in both quantity and perhaps quality. So NASA kind of, well I wouldn't say begged, but they encouraged USA to get some horsepower involved in that, and so for some reason, they turned to me. So I got back involved in the SRP as kind of a helper if you like. I'd like to say as a consultant, helper. But they were sure happy to see a familiar face return. I still had USA people there to do a lot of the work, but could add perhaps some reasons why things needed to be done and why they needed to be done, because I had familiarization with these requirements when we set the whole process up. Anyway, I retired a second time. I've had some calls for consultations or consultant work and part-time work, and I appreciate that very much, but no thank you.

ROSS-NAZZAL: Ready to enjoy life without work.

WREN: Right.

ROSS-NAZZAL: Were you working at USA when the *Columbia* accident occurred?

WREN: I was, and it was right about the time that we had dissolved the office and I was leaving. Yes, so just about that same time.

ROSS-NAZZAL: Well, we have a couple of general questions we like to ask everyone. One of them is what do you think was your most challenging milestone that you had while you were working for the agency.

WREN: I'm glad you asked that too. I would say that the most important achievement of Apollo -- and I like to think I had a little bit of [a role in this] -- was when we went out and left Earth orbit and headed for the Moon, and this may sound kind of silly, but I think it's monumental. We turned around and looked back from a different viewpoint at the Earth. It's like the same thing as in flying. If you're viewing something in a view angle in almost two dimensions, and you look across at the buildings and the fields and the trees and so forth, you get used to that viewpoint. It's nice. All of a sudden you take off and you go up in an airplane, and now you view that same area from a different perspective. Guess what, it looks entirely different. It broadens your understanding of what things are.

Well, I think the same thing happened when we went to the Moon and we turned around and looked back and we saw the Earth. Before we were always looking up at the sky, and now we're out there in the sky, turned around, and looked back and we see the Earth. We knew it was a globe. We knew it was a ball, a sphere, but we could prove it. Look at it. We see it. We see a sphere there. We see it just hanging there in space. We see all the blue, and we see the white. The blue of the oceans and the white of the clouds and the brown and green of the land. We see how, "Wow, that's what we live on. Wow, look how fragile it is. Look at that thin little old atmosphere." I think that was monumental. Of course later on as we went into lunar orbit, why, we had some photos of the Earth rising over the lunar landscape and so forth, which added to that sort of thing. But I think that was very very monumental.

Now if you were to ask me what were the most important Apollo missions, I won't hesitate on that either. In my humble opinion the most important was Apollo 8. Now why in the world would I say Apollo 8? Well, because that was the first time that we left Earth orbit and we went to the Moon. It was the first time that we left the gravitational pull of the Earth and crossed over into the gravitational pull of another heavenly body. We were in the gravitational pull of the Moon. We demonstrated that we could go to the Moon and return safely. I think that was super important.

It was a gutsy call because the LM [Lunar Module] wasn't ready at the time. So hey, let's just go. We'll prove that we can do it from a trajectory point of view and operations point of view. We'll prove that the Command and Service Module can accomplish the task. We'll just show everybody that hey, we're moving. Of course, we were still in a race with the Russians. But our LM wasn't ready. Yes, we're supposed to go land on the Moon by the end of the decade. It's not ready. So it was a gutsy call to fly the Command and Service Module without the LM. Why? Another reason why it was gutsy was because we didn't have a backup LM propulsion system in case something went south on us. The Service Module had a single engine. So that was pretty gutsy. But I think that was probably most important of all the Apollo missions, was Apollo 8.

Second of course obviously is Apollo 11, when we actually did the same thing but this time we landed and launched. Landed and launched off another heavenly body. I give the JPL folks out there in California a lot of kudos. The task of landing a vehicle, unmanned vehicle, but a vehicle on an asteroid when it wasn't even intended to be landable if you like, those are monumental things. Anyway. So I think that 8 was first and 11 was second in my opinion.

I had a couple more things I guess I'd add to that. You had some suggested sheets back here, and I'll turn to the last page of that. I mentioned the most important thing that I think I contributed was being a part of lifting the mission constraints on Apollo 8 and Apollo 11. You had asked what was the greatest disappointment, and I first said none, and then I thought, well canceling Apollo was kind of disappointing, we may have talked about that earlier on. Delaying the Mars mission, because we'd all come for the -- oh by the way, I can say something about the Mars mission.

In our NASA alumni group, it meets twice a year for dinner, and the fall one is this Thursday at the Gilruth Rec Center. The program is going to be a fellow -- I think he's with Jacobs but the subject of his talk is going to be von Braun's Mars mission. What happened there was that von Braun wrote a novel. A lot of folks may not realize this, but he wrote a novel about going to Mars. It didn't sell very much, didn't have much. But he had an appendix on that thing in the back that had all the technical detail that he and his team, his German team, had created to back up what was said in his novel. Well, somebody encouraged him to take the appendix and publish that as a separate book, and it happened. That's the book that a lot of us read way back then. So when we came to NASA, we were all excited about the Mars mission, because we had read von Braun's Mars book. He had in there a 70-man group going to Mars. It was big time. So anyway, this fellow is going to discuss that Thursday night. So I'm looking forward to it. Should be interesting. But yes, canceling the Mars mission, that was a low blow back then. Of course now it's back on the burner somewhere. I don't know front or back or somewhere, but at least it's on the burner as part of the Constellation Program perhaps.

I think manned exploration to other bodies was very important, and it still is, instead of just being stuck in Earth orbit. Because that goes back to what I may have talked about earlier about the Space Act of '58, and the agency was created to do exploration and to develop hardware to enable to do exploration. We've explored Earth orbit. We know how to do that. Now let's go do something that falls in the exploration category. Again, the Apollo program, I thought, was unique in the fact that it had a singular goal and that made it very very efficient. Everything you did was pointed towards that single goal. So there was no peripheral abstract investigations into something that was loosely tied to what the main purpose was. It was very crisp. We were going to land on the Moon before the end of the decade. So it all flowed together like a big old pyramid. So that was important.

Another thing that we talked a lot about earlier, many years ago, was after we create the Shuttle, it's created, okay, and Max's [Maxime A. Faget] idea about the winged airplane was wonderful. But once we create it, we developed the hardware, now let's get back to exploring and what do we do with this Shuttle if you like. Turn it over to the commercial people to operate it, say here it is. Get the commercial folks involved. We had a big effort back there somewhere of commercial development. Somewhere along the way it kind of left the front burner and it kind of went away. That would go hand in hand with the folks way back there that wanted to be enterprising and put up space hotels and so forth in different orbits, not just equatorial orbits but polar orbits as well. In other words, get the commercial people involved as a money-paying exercise. And NASA go on and leave that and go on and explore.

Some people have said right now the Orbiter is destined to stop flying in 2010. Some folks have raised the suggestion of why not turn the whole Orbiter operation over to a commercial operator. I don't know that that's feasible because it's a huge undertaking and enterprise. But it's a good thought. I know that some of the independent activities from Burt [Elbert L.] Rutan and some of them on flying commercial vehicles that maybe they can provide a service, a commercial service to the Space Station, to replace the fact that we don't have the Shuttle anymore. Of course it brings up the question, what about the heavy modules and payloads. But certainly for people transfer and experiment transfer and so forth, in addition to utilizing the Soyuz and the Russian capability, and also there's activity on the horizon from the Japanese and from ESA for those kind of delivery services. But get the commercial people involved in doing that. But anyway, the commercial operation of a continuing Shuttle program is an interesting concept but is probably nonfeasible, don't know. So I think I've pretty well covered what maybe you had asked in some of your suggested questions there.

ROSS-NAZZAL: The only other question I had is how do you think that JSC has changed since you started working out here when it was the Manned Spacecraft Center?

WREN: Well certainly it's larger. The civil service contingent size, once we had the initial buildup, interestingly enough has not changed much through the years. It's remained I believe around 2,000 folks, more or less. If it got a little bit too big, we may have had a couple of RIFs [Reductions in Force] along the way here and there. Then we'd have some more hiring. Jack [R.] Lister, Jack was instrumental in creating the co-op program, which is very successful program. So we got a lot of our new hires, civil service new hires, through the co-op program where the kids go to school for a semester and then come work for a semester or two and maybe a year back and forth so they get hands-on experience. So we got a lot of new hires. When they finish that program they actually hire in as civil servants. So sizewise it's about the same. Now contractorwise though, that has expanded and then contracted and expanded.

I don't know what the current size of the total JSC workforce is. Maybe 2,000 civil service and maybe 10-15,000 contractors. I don't know the numbers. But I think it's probably stabilized. The contractor support around the country of course swelled in Apollo. Then after Apollo -- and I don't know the numbers or remember them. But after Apollo, of course, it shrank considerably. Of course usually the companies will manage to find other work through the DOD channels or commercial channels. So the size is about the same.

ROSS-NAZZAL: Is there anything you think that we've overlooked? Something else that you wanted to talk about that we have not discussed?

WREN: [I'd like to add that my E&D support teams through the years were populated with very excellent people. It is difficult to try to list them all for fear of leaving some out which is certainly not intentional. Some of my assistants, e.g. John Ashenhoffer, Jim McCarter, and Leo Benal were outstanding. Chester A. "Chet" Vaughan used to purposely rotate his young propulsion engineers through my teams because he said it was a wonderful training ground. Folks like John B. Henderson, John Allbright, Howard Flynn, Rob Moreland, Rod Kujala and many others.

A small-world-bit sidelight of interest. John Allbright told me how he went to high school with my nephew, Topher Wren, in Davenport, Iowa. They played together in the orchestra. How about that for a pleasant surprise?

Among others called upon often or sometimes: Edward I. "Ed" Fendell, Wendel W. Mendell, William M. "Bill" Speier, Stanley M. "Stan" Blackmer, Stanley E. "Stan" Snipes, David E. "Dave" Tadlock, Frank Devos, Kent Dekome, Rodney G. Rose, Richard F. "Dick" Hergert, Carl W.L. Watkins, James Dagam, Gregory C. "Greg" Blackburn, Dr. Lo, Frank C. Littleton, Andrew J. "Andy" Farkas, Henry J.G. Kaupp, John E. Grimaud, Stu Sayers, Robert T. "Bob" Everline, Donald R. "Don" Blevins, John T. McNeely, John Casey, Jerry L. Ross, Harry Maltby, Steve Koontz, Ken Zerbe, Jim McDonald, John J. Zipay, Pat Coleman, Richard B. Davidson, Travis Bryce, Ken Morrison, Eugene F. "Gene" Kranz, John D. Blalock, Dean Moreland, Hal Taylor, Glenn C. Lutz, Ed Copeland, Robert F. "Bob" Thompson, Joseph P. "Joe" Loftus, Donald J. "Don" Mayhew, John H. Casper, Richard S. Serpas, Stanley M. "Stan" Luczkowski, A. Miles Whitnah, Paul R. Johnson, and Bonnie J. Dunbar.

Others were: Mike Ciancone, Grady Beaird, Pat McDonald, Jim Baab, Dan Hartman, Paul Kirkpatrick, Jay H. Greene, John Chapman, Ronald "Ron" Gerlach, Claud Edmiston, John Swanson, Robby Robinson, Bill Bates, Harold J. Taylor, Dennis L. Knutson, Gary P. Gutkoski, John T. Chladek, Thomas J. "Tom" Graves, Bill Hoffman, Barry Whittschen, Matt Martin, Mike Massie, Don Totton, Jay E. Bennett, George Sanger, Lawrence Boyles, Chris Brown, John P. McManamen, Dave McCann, Barbara Fowler, John Kennedy, Bill Acres, Lane Skyles, Bud Murray, Bill Moon, Larry Moon, Jerry Goodman, Bob Pearcy, Jim Seastrum, Tim Pelicek, and George Parma.

Many others I asked for help were: Ed Schlei, Steve Poulos, Les Goodhart, Frank Buzzard, Mike Hoy, Nanette Cerna, Tony Brown, Alan Piersol, Richard Serpas, Frank Monteleone, Dick Sachen, Gary W. Johnson, Rick Nygren, Don Noah, James Rush, Art Perry, Jerry Hammack, Charlie Harlan, Duane Ross, Mark K. Craig, Jerry Craig, Richard N. Richards, Paul Shack, Roy Stokes, and John Richardson.

Others included: Ben Sellari, Burrel French, Don Cheatham, Lou Bernardi, Paul Johnston, Harley Jewell, Lee Pearson, Bill Beckham, Ned Pendley, Mike Vaughn, Cory Logan, Bill Vantine, Bob Parrott, Mark Schmalz, Bob Driver, Charlie Thorpe, Jerry C. Bostick, Robert Bond, Seymour "Sy" Liebergot, Bill Brizzolara, Howard DeCastro, Jim Shows, Jim Buchli, Loren J. Shriver, Mike Macauley, Tom Snedecor, Mel Richmond, Sigurd A. "Sid" Sjoberg, Marty Cohen, Aaron Cohen, Chuck Shaw, Mike Hernandez, Ed Muniz, Hal Taylor, Mark Geyer, Henry W. "Hank" Flagg, and Dan Remington.

I also worked with Don Robison, John Katsikas, Stan Donahoe, Wayne Young, Bill Kelley, Kenneth B. "Ken" Gilbreath, Jack R. Lister, Homer Dotts, Bob Dotts, Ed Campagna, Tom Ohnesorge, Larry Birdsong, Tom Grace, Norm Chaffee, Carrington Stewart, Art Campos, Bill Brubaker, Bill Fisher, Tom Short, Howard Renfro, A.R. Johnston, E. Bob Stewart, Jack R. Lousma, John Watson, Ron Blilie, Travis Bryce, Harry Maltbe, Lew Wade, Vern Hammersley, Chuck Wheelright, Al Brady, J.B. Fox, Ron Guidry, Ted Hayes, Phil Deans, Bob Spann, Gary Renfro, Bob Senter, James F. "Jim" Reilly, Dean Coulter, Clay Fulcher, Gary Stremel, Dick Moke, Art Hinners, Ed Zeitler, Al Holgun, Ron Swim, Harley Sewell, Denny Holt, Earl Cramp, and Gary Deardorff.

Others I asked for assistance included: Earl Tiedt, Jeff Hanley, Cindy Grayson, Angus Hendrick, John Zarcaro, Duane Weary, John Hedgepeth, Earl Crum, Frank Curtis, Joe Doke, Les Sorge, Steve Doering, Wally Corcoran, Kirk Shireman, Burton G. Cour-Palais, Stanley "Stan" Faber, Claude Graves, Bruce Goss, Pete Zamora, Scott Wolf, John Temple, Carl B. Shelley, Ray Zetka, Jim Broadfoot, Bob Brock, Rudy Trabanino, Jim Sauser, Alan Wylie, Lambert Austin, Don Terkanian, Jim Colovin, Mike Singletary, Vernon Shields, Charlie Teixeira, Art Sulkin, Bill Geissler, Dick Chandler, Ray Tanner, Les Talley, Al Scioneaux, Bob Swint, Norman E. “Norm” Thagard, Robert T. “Bob” Savely, Don Chilton, Bob Schwartz, Gary Whitsit, Kathy Tamer, John Selmarten, Barry Wolfer, Bob Voss, John Dolan, Bill Faries, Harrison Storms, and John R. “Jack” Garman.

I must not forget Mike Fodroci, Lee Wible, Harley Stutesman, Warren Tyree, William E. “Bill” Thornton, Edward G. “Ed” Gibson, Robert Stanley, Jim Willis, Bill Chastain, Jim Shannon, Warren Gillespie, Art Green, Bob Stuckey, Ted Skopinski, Deed Vest, John Wilhoite, Barry Waddell, John Defife, Bill Fink, Pete Volpe, Charles Whitlock, Gary Syfert, Mike Suffradini, Jim Duggar, Charlie Felts, Robert Swansom, Hal Ferese, Jess Goree, James Vanderploeg, Jim Visentine, James Vincent, John Hodge, Jim Schaffner, and Stan Goldstein.

Finally, let me add these names: Denny Holt, Leo Chauvin, James Donaho, Linda Godwin, John Christman, Jay Honeycutt, Roy Glanville, Wayne Huddleston, Chuck Schuessler, Jim Gilbert, Paula Gothreaux, Bill Huber, John Rummel, Steve Kimzey, Reagan Edmiston, Russ Turner, Jim Eyman, Randy Stone, Larry Wier, Paul Dye, Dan Germany, George Abbey, Floyd Bennett, Lamar Bowles, Frank Perez, Bob Montgomery, Bob Mitchell, Richard Meyer, Vince Lipovsky, Dot Lee, Tim Kropp, Tom Kloves, Gary B. Johnson, Chuck Jacobson, Al Jowid, Rodolfo Gonzales, Murray Epstein, Mike Dennard, Bill Dusenbury, Marvin Matthews, Bev Steadman, Frank Morgan, Bill Creasey, Bill Parsons, Wayne Hale, Jim Oberg, Lou Vosteen, Chuck Filly, Lou Bernardi, Fulton Plauche, Gordon Ducote, Hugh Baker, Larry Wier, Pat Patnesky, Brian Harris, Al Stefan, Joe Bores, Russ Clickner, Sid Carmines, Charlie Hartman, Billy Smith, Vic Maria, Ken Gurry, Jay Gurry, Roger Neubaueer, Axel Kolb, Dale Myers, John Francis, and Curt Broussard.]

I'd [also] like to make [another] closing comment.

ROSS-NAZZAL: Please do so.

WREN: I'd just like to say that -- well first of all I appreciate the opportunity for the interview.

ROSS-NAZZAL: Well, thank you.

WREN: You've done extremely well, and I appreciate it. Very professional. I guess I'd say that I feel extremely fortunate to have been in the right place at the right time in my career. That the work that we did with NASA and Apollo and on is very technically challenging most of the time, if not all the time. I would say it was for me personally very exciting and rewarding. Most important was the opportunity to meet a lot of great people and to work with them, and perhaps what we did was meaningful. I would hope so. A lot of great folks.

I think technically challenging, because we did a lot of things that hadn't been done before. Like in the airplane work, yes, you progress but you kind of made small incremental advancements. We got into the space work here. Nobody had done it before. In a lot of cases, we had to figure out, well, how do we do that? Again, answering the question what to do and why, perhaps when. But then the big how. How do we do that? Like creating fuel cells for our electrical power. I can go down all kinds of lists of innovations and creativity that was expressed by the working troops. A lot of smart sharp people that were involved and I had the pleasure of working with. A lot of sharp people. You talk about the cream of the crop, top of the class, wow, it's great.

ROSS-NAZZAL: The program that you were involved with is considered one of the greatest accomplishments of the 20th century, if not the greatest. We thank you for sharing your experiences with us. We certainly found them interesting and hope you enjoyed it as well.

WREN: Yes, I certainly did, and again I thank you so much.

ROSS-NAZZAL: Well, thank you.

[End of interview]