NASA Johnson Space Center Oral History Project
Oral History 2 Transcript

Arnold D. Aldrich
Interviewed by Kevin M. Rusnak
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Rusnak: Today is May 24, 2002. This interview with Arnie Aldrich is being conducted in the offices of the Signal Corporation in Houston, Texas, for the Johnson Space Center Oral History Project. The interviewer is Kevin Rusnak, assisted by Rebecca Wright and Sandra Johnson.

Thank you for taking the time out this morning to spend with us and to share some of your recollections of your involvement with the Space Shuttle Program.

Aldrich: Well, with your permission, I wanted to make a couple of comments about my last interview.

Rusnak: Absolutely.

Aldrich: We developed some confusion about a man that I was talking [about] in the last interview that was involved in the initial architecture and design of the Mission Control Center at Cape Canaveral [Florida] for Project Mercury, and I got that name wrong. The man's name is Frank [J.] Chalmers, and I confused that with Tom [Thomas V.] Chambers and other names, and so it's corrected in your transcript, but I wanted to be sure that people know that I finally got Frank right.

Also, I made a little bit of inaccurate summary of the remote sites in Project Mercury, the tracking stations we had. I was trying to list them, which ones had voice contact with the control center at the Cape and which didn't and what those sites were, and those are corrected in your transcript also. That was pretty accurate on the tape, but a little confusing.

Finally, the people that were with me at the reentry sites for Mercury 5, Mercury-Atlas 5 and 6, I got switched. For MA-5, which was the flight of Enos, I was out at California, and [L.] Gordon Cooper and Dick [Richard P.] Rembert were with me, not the two people I mentioned in the tape, and you've corrected that. Then for MA-6, John [H.] Glenn's flight, Wally [Walter M.] Schirra [and Ted White were] … with me out at California at the tracking station. So those were kind of glaring errors, and everything else, you know, we kind of tuned up. But I wanted to be sure I had straightened that out.

So today I would like to talk about the Space Shuttle. In fact, we finished the last interview talking about Apollo-Soyuz and the flight and how successful it was and the very good involvement we had with the people in the Soviet Union that we worked with and their part of the program.

The way I got involved in Shuttle happened directly because after the Apollo-Soyuz flight, that [activity] really stopped. The people in our program and at the Johnson Space Center kind of assumed there would be a follow-on set of activities, either maybe another Apollo-Soyuz kind of flight or perhaps a Shuttle-Soyuz or a Shuttle-Mir. Shuttle-Salyut, I think, was up at that time. Anyway, we thought we would continue a program of working joint operational missions.

In fact, right at that time there was also a change in the administration in our government, and, for whatever the overriding reasons were, our engagement really stopped. We did not have any follow-on activity from the mission or flight people in NASA with the Soviets. [It] ended, and the only part of our [joint] space program that continued was the people that worked life sciences in both nations. The Soviet Union and the United States continued to work together, continued to exchange data and had an ongoing set of relationships. But none of that involved anybody else that I know of in the NASA flight program.

In fact, that went on for a long time. I can't remember what I said last time about working with the Soviets, but for me and for the people that I knew that were involved in the Apollo-Soyuz Test Project, it was seventeen years before we re-engaged in terms of working together in 1992, and maybe we'll get to that today. I'll talk some more about that. It was a very interesting re-engagement and led to a lot of things that are even yet going on today.

But, anyway, the way that led to me becoming involved in the Space Shuttle Program was that we now had an Apollo-Soyuz Test Project [ASTP] and an Apollo Program Office that no longer had any Apollo missions. It was time to terminate the office. So what the Center did, what NASA did, at that time was to—this project office was under Glynn [S.] Lunney and I was his deputy, and they assigned the whole office to work Shuttle payloads. We were coming into a time where the initial development of the Space Shuttle was pretty far along, and we were approaching the time for the first flights of the approach-and-landing vehicle, *Enterprise*, and it was time to start thinking about payloads and who would fly and what the rules of engagement would be and what facilities the Shuttle needed to support payloads

So it was big piece of work, and it was very timely, and Glynn Lunney's whole office was moved off Apollo-Soyuz, off Apollo, and into Shuttle payloads. In fact, it was called SPDP[O] [Shuttle Payload Integration and Development Program Office], Shuttle Payloads Operations Development Office, something like that. But that's what they did, except for me. And at that point in time, Shuttle development was pretty far along, and as in any major development program, there were a lot of technical challenges the program was dealing with, and things were coming along, but there was a lot of interest to be sure we were doing everything right.

Bob [Robert F.] Thompson was head of the Space Shuttle Program, and he asked me to come to the Shuttle Program Office and start a little office there that was called the Program Assessment Office, and that was something that interested me a lot. I was a lot more interested in working on the Shuttle flight vehicles and systems than I was on planning for payloads, and so it really resonated with me.

I went to take that job. I didn't know anything about the Space Shuttle. I had been too busy with all the Apollo things. I mean, it was a brand-new thing to me. But over the next year, I put together a team of about half a dozen good people, and we started to look at all of the Space Shuttle systems and the Space Shuttle plans for how the missions would be conducted and how we'd support those missions. And so we had a very engaging time. It allowed me to get to know the Shuttle very well, and it allowed me to get engaged with all the people that were working on it.

Some of the people in that office, one of them was Gary [A.] Coultas, who worked for me in a number of jobs after that. He was a very competent guy. I believe I had Frank [C.] Littleton [and Bob White] in it for a time, and also Bob [Robert W.] Moorehead, although Bob Moorehead was in the Orbiter Avionics Systems Office. I think he came and worked on some of the projects. And Don [Donald H.] Peterson, one of the astronauts, came.

One of the interesting things that I was going to tell you about that time period was, I decided if we were going to do that, we ought to do it right. So I went after some fairly good people at the Center, and most of the people I wanted to consider being in the office were from the Engineering Directorate. And so I ran smack into Max [Maxime A.] Faget, who supported the idea of having a Program Assessment Office and looking at the issues, but he didn't support the idea of giving any of his key people to that initiative. So, in the end, I got enough talent to do the job, I think, well, and I had a good time doing it.

Two of the things that we looked at during that time period had a lot of impact on my later career. Probably the most significant thing that I found in reviewing the Space Shuttle design had to do with the solid rocket boosters. … Always before in our manned space program, the vehicles we flew had more capabilities during ascent and ways for the crew to get off, at least during the first part of the flight and hopefully recover from a booster failure or launch failure.

So when I looked at the Shuttle, we studied how it all came together, we found that the solid rocket boosters on the Space Shuttle ignited [at] liftoff and they both have to burn for two minutes. There's no way to separate them. There's no way to get off. They have to burn for two minutes. Then at two minutes they separate after they stop thrusting, and they fall away.

But if you try to separate them, there was no way to shut them down, and if you try to separate them while they're burning, the momentum of the thrust holds them in their places. They're connected. So even you blow the bolts to separate them, they won't separate because the thrust keeps them where they are.

I was quite alarmed that one failure could cause a catastrophe. There would be no way to recover from a failure [of an SRB] during the first two minutes of flight. So that was one of the findings, and I took it and I briefed it to Bob Thompson, and I brief[ed] it to Chris [Christopher C.] Kraft [Jr.] and others, and what I found was that everybody knew that. They'd already dealt with it. They'd already accommodated their thinking to the fact that that was going to be the way the Shuttle ought to be put together and that we would simply rely on the very high reliability of that system and press on in that manner.

So it was a big surprise to me, and, of course, you know where that story leads [(*Challenger*)]. We did talk about ways you could maybe shut a solid rocket booster down, and you can blow something off the top, and it will dissipate the thrust. But no system like that had been developed that was operational, that you could use. The analysis of it was that it would take some period of time after you blow it for the thrust to phase down, and it would cause an [unacceptable thrust] imbalance. In the end, it was thought that that was probably not something that was really reliable to implement that would be any safer than just trying to do the rockets right and keep them like they were. So the Shuttle system did not change, and that was probably the biggest surprise to me when I first started looking at the whole set of things that were going on.

The other area that I looked at and found a lot of interest in trying to make some changes was in the Space Shuttle avionics system. The avionics system in the Space Shuttle, I kind of felt at the time, and I actually still do, is one of three major technological developments that we had to do to make the Space Shuttle system work. Probably the most complex technical challenge was the Space Shuttle main engine, which is a liquid-oxygen, liquid-hydrogen engine that operates at very high pressures and temperatures for the materials that were available to be create it out of at the time, and it has to be of a size and weight that fits on the back end of the Orbiter.

So it was a huge design challenge to make such a high-performing engine and make it so reliable and make it with the materials we could make it with, and I think it's the most complicated, most elaborate machine I've ever seen. It's a wonderful piece of equipment, and, of course, it's been very successful. But it had a long development program, a long test program, and there were problems and difficulties that were solved during the test program. It didn't just start out being wonderful, but it's been wonderful ever since.

The second technological challenge was the thermal protection system on the Orbiter. The Orbiter now had to fly up like a rocket and return like an airplane, and so it couldn't have a blunt heat shield on the bottom like the earlier spacecraft had. It had to have an aerodynamic shape to fly like an airplane, but it had to have thermal protection all over it. And to meet its performance requirements, the thermal protection had to be as light as it could possibly be, because we had a goal of what the cargo capacity could be in terms of weight for the Space Shuttle, and so the Orbiter had to be lightweight, thermally protected all over, and be aerodynamic in its configuration.

And that led to the system of tiles and tile mounting to the structure that was developed for the Shuttle, and it was a wonderful system. It also had development problems, but it has come along well as well, not just the tiles, but the way that they're mounted to the aluminum skin of the Orbiter is quite complex. There's a strain isolation pad that goes under it [each tile], that's called SIP, and then it's held down with RTV [room temperature vulcanizing rubber], and there are, … there['s] gaps between each tile so that when the vehicle flexes you don't break the tiles, you just spread the gaps a little bit. But in some places you can't stand to have a gap, so there's a thing called the gap filler made out of several different things. It's a very elaborate system that we developed, and it has worked very well also. We learned a lot about it as we flew it, but it's a very good system.

Now, the third technical challenge is this avionics system. The avionics system in the Space Shuttle was very revolutionary for its time. The way the Space Shuttle works, everything in the vehicle, just about, is actually controlled by a bank of computers. It's not controlled by the manual controls the crew has. There's a bank of four computers in the Orbiter that, in parallel, operate through data buses to receive information from a whole variety of sensors on the Space Shuttle and then send signals out to all the different actuation systems that control the Shuttle. The aerodynamic … [surfaces] are controlled by these computers, and the main engines and the separation of the tank and the rockets and the nose wheel steering and the landing gear, all those things that control where the Shuttle goes and how it flies, are all controlled by these computers.

Even the cockpit where the crews have control sticks and switches, they don't go back to the engines or the aerosurfaces; they go to the computers, and the computer then tells these things what to do. So it's a very complicated system, and the fact that it's all done electrically through the computers is a kind of a flight system that's called fly-by-wire. And I believe the Space Shuttle was the first operational vehicle to be a fly-by-wire [mult-computer] vehicle.

Not long after, the Air Force had a fly-by-wire version of the F-16 fighter plane, but I think the Shuttle was built first and flew first with this fly-by-wire capability. In fact, we had a test demonstration airplane out at Edwards prior to that time that we used for research on how the Shuttle system would be, and we test-flew that [system] and then put it in the Shuttle.

So even though today it's thirty-year-old technology, at the time it was very at the forefront of the design of avionics for flight vehicles. And for the Shuttle, because of the nature of reliability and safety we wanted, we wanted this four-computer system to be what we called fail-operational, fail-safe, which meant you could take any failure in any part of this avionics system and still press on and complete the mission. And you could take a second failure and maybe not complete the mission, but you could safely return with what was remaining. And that's a big complexity in design and in the architecture of how the system's laid out. But that was the intent, the goal, and that's what was created.

So I was very, very interested in this avionics system, and at the time I was doing work in the Program Assessment Office. The avionics system was coming online for the approach and landing test [ALT], the test program we did out at Edwards Air Force Base [California] with *Enterprise*. The *Enterprise* was built to separate at 20,000 or 30,000 feet from a 747 and fly down and demonstrate the approach and landing part of the Shuttle mission, but didn't fly any other part of the mission.

So when I came on, *Enterprise* was just about built and just about ready to move into that test program, and it had the four-computer suite and the fly-by-wire, but all it had in it for its software program was just the approach and landing part. It didn't have all the things you would need to fly a total space mission, the ascent and the stuff on orbit. And so it was a smaller, simpler software program that went into this avionics system.

So when I came onboard with the Program Assessment Office, what I found was this avionics team was now struggling to step from what they'd created to go on *Enterprise* for approach and landing to the much bigger job to build all of the software and do all the testing to create the programs that would fly the Space Shuttle in orbit. And so that's a little background on the avionics system.

Now I'll switch back to Program Assessment. What I found was, and I guess it probably wasn't obvious just to me, but there was quite a lot of tension in the team that was doing the avionics system, because Rockwell International was the prime contractor for the Space Shuttle Orbiter, and they had the team of people doing the avionics out there that had recently been in their Autonetics Division, and they had built the avionics system for the F-111 Air Force fighter plane, fighter bomber, I think it was. So they were very confident that they knew how to do this avionics system and how it ought to be done, and they were the prime contractor. But the software was a subcontract to them by IBM Federal Systems, and IBM Federal Systems really had a heritage of complex and very capable software. There had been quite a lot of tension about who had the say about how this [Shuttle system] would be architected.

So right about the time I came onboard, that kind of friction between the prime contractor and the software developer had caused the Johnson Space Center to change the contract, and they had taken IBM off being the sub to Rockwell International and put it in as a prime … contract for the Center out of Johnson. So now we had two separate organizations rather than one reporting to the other, one doing the software and one doing the hardware.

At the Center, our Engineering Directorate people had a long heritage of working with Rockwell, and they were very kind of familiar and in the groove with the way Rockwell did things, and so they were sympathetic to how Rockwell wanted to approach the development of the avionics. But the software, the IBM organization, had spent a lot of years working with our operations directorates doing the ground systems for the earlier flight programs, and so their connection into Johnson was with another set of the management and a team of people that were really very confident in them and had worked with them.

So we had this tug of war going on while we were trying to build this very elaborate system for the first Space Shuttle flight. So I jumped right in the middle of that and kind of got caught up in it in terms of trying to understand what could be done. I'll talk some more about that in just a minute. But that's one of the findings in the avionics. The other two were more technical.

The second was, as people started to look at all of the software we were going to need for the orbital flight tests and the orbital missions to follow, it was clear that the programs we had to build for ascent and for entry would not fit in the memory of this computer. This is an AP-101 computer, also built by IBM. It was built up in Owega, New York, by IBM, and it was called an AP-101. It had a graphite solid-core memory, and that memory could take 64,000 sixteen-bit words. That's what the approach and landing test computer was, and it worked fine for that software program. But as we looked at all of the things that this software had to do to manage the Space Shuttle and control the flights, do the mission, do the steering, it couldn't fit. So one of the problems was the computer memory size was not adequate to do the job. Something had to be done about that.

The third thing I found was that this fail-op, fail-safe system that the avionics system was supposed to [be] for the vehicle, so that you could take two failures and still recover, was quite well architected. There were some issues with it. There were some places where they'd tried to make a choice of four things for the four computers flow into or out of three sensors or actuators rather than four, just for—I always thought it was just to make it more complicated-but some things, like the inertial measurement units—I think there were three—because they were big and they took space and someone thought we could cleverly work them in a way that you could get a voting choice of four out of the three if you worked it cleverly and used the right kind of algorithms.

But, anyway, the system that got created really was fail-op, fail-safe, except there was quite a worry that what if there's a failure in this software that works in the four computers so that one software failure would cause you to lose the whole thing? The way these computers worked together was that they synchronize with each other twenty-six times a second. They each tell the other where they are and check to make sure they're all marching in parallel and computing the same thing, and they each take independent inputs and then they provide independent outputs over these four data buses that go out and control the things I was talking about. But they all check each other's outputs, and if the bank of computers sense that one of the computers doesn't sync right, twenty-six times a second, or doesn't compute the right output, it'll vote that [one] out, just instantly take it out of the loop, and so that computer … ceases to be part of the voting logic unless it's re-initialized and put back in by the crew.

So that logic that's in the four computers where they crosscheck each other and crosscheck their outputs and decide who's good and who isn't, it's … [a set] of logic we called fail-to-sync logic. The computer, it's dealing with one of the computers that fails to synchronize with the rest of the set. And this fail-to-sync logic was unique and very difficult to prove that you knew all of the possible bugs that could be in it and it could never make a mistake when it was doing that. And that's the software that I was talking about in this other issue with the avionics system.

This team of people and other people I talked to, many of them were concerned that there might be something in the software where instead of … [voting] out a bad one, somehow they'd all get out of sync and it wouldn't work anymore, and then the Shuttle couldn't fly. So it was really determined that we ought to have fifth computer with a separate software system in it that was independent, and so if for some reason one failure took this big elaborate set of redundant logic down, you'd have something to switch to that could fly [the vehicle].

So at the time of the Program Assessment Office, I talked to you about the solid rocket booster and what we found there, and then in the avionics system there were three things. They were having difficulty with the program team converging on a flight architecture, and the computer was too small, and there was concern that even though it was supposed to be two-fault-tolerant, it might not be. So that led to my next job.

What frequently happens when you turn up a spade with stuff like that in it, was that I was asked to become head of the Orbiter Avionics Systems Office in the Orbiter Project Office and take charge of those … things in the avionics that I just talked about. So I was in the Program Assessment Office maybe for a year, probably a little less than a year, from mid-'75 to mid-'76.

Then I moved to the Orbiter Project Office, now knowing a lot about the Space Shuttle and also kind of having a focus on these problems in the avionics system. I think one of the reasons I was selected, I'd had quite a long history of working with Rockwell and North American, as they were called before, on the Apollo Command Service Module vehicle for quite a few years. I had good relations with Rockwell, and also I'd worked in the Mission Control Center for a number of years, and I was very familiar with IBM and with the software kind of things that they did. And so I was kind of a neutral person for the two, and so that was the job I was given.

It was interesting that right at the time that I started doing that work, it was just the time when the team of Rockwell and IBM and [NASA] engineering and flight operations were all getting together to define in detail the content that we would have to have in the computers to fly a full Space Shuttle mission. Within a matter of a couple of weeks from moving into that office, I was in charge of conducting reviews out at Rockwell where we would define and create the documentation for the detailed requirements for the software for the ascent flight phase and another package for the on-orbit flight phase, and a third one for the entry flight phase, and a fourth one for systems management. These were multi-day reviews at Rockwell, and all of these different elements in the program would present what their system has to do and what the mission is and what the software would have to have in it to operate.

That was also a very strong learning process for me. It was the kind of thing that I was familiar with in terms of those kind of systems, and I knew a lot about space missions and space vehicles. So, I mean, it was totally new in terms of all the uniqueness, but it was just exactly the kind of thing I was familiar with dealing with.

So I had a very good time conducting those reviews. I think they were very effective, and what we created out of them was a series of documents that are called flight software [system] requirements documents, or FS[S]R's, and they were written by IBM, and they had these requirements at a very detailed level, in English so you could read what the software was supposed to do.

One of the mistakes a number of software initiatives did in the early years, maybe they still do, is not documenting the requirements well. You can document the software requirements at a pretty high level and give it to the software team, and then they'll define what they're going to build in software language. And so there's no English language for the people that might want to get engaged in exactly what was being created to look at. Well, in the Shuttle we didn't do it that way, and I think I credit IBM for the process and the way … [to cause] it to be done. These FS[S]R's were very detailed. They talked about all the subtleties that had to be built into the logic in each of the different areas, and they were really excellent documents, and we built this whole set of them.

The way the Shuttle works, I'll talk about how we got the computer size bigger in a minute, but even with more size in the computer, you still couldn't load all the software in the computer that you needed for flight and have it all in there at once. What you had to do was, during the countdown there was a preflight checkout load that would be in, and then when you got close to the time you're going to launch, there's a mass memory unit. There's a couple of those. They were redundant mass memory units in the Orbiter, and you roll the software out that was doing the checkout and roll in the ascent load from the mass memory. You fly ascent, and then when you get up, you roll out the ascent and roll in the on-orbit, same thing for entry.

So each of these was really a separate stand-alone computer program to do those different phases. It still is today. It's still the same way. You could have the systems management in there, because it managed the systems and the vehicle the whole time and it wouldn't change. But it would be resident in one part of the computer, and then these other loads would come in and out, depending on the mission phase.

So we had a flight software requirements document built for each of these phases, because it was a separate computer program, and after these reviews out at Rockwell where we defined the broad capabilities that we would have and tried to define the details, in the time frame after that these documents were continually refined.

What got to be my role was Chairman of the [Orbiter] Avionics Software Control Board [OASCB], that we had at Johnson, and all of the organizations on the Shuttle at Johnson were members, and IBM was a member, and Rockwell was a member. We met every week for a day-long meeting or longer, for years, and what we were working on is the baseline of these requirements.

Once we built the FS[S]R's, their configuration was frozen, and the only way to change anything in there, whether it's the detailed color of a light or the rate … [that a surface] moves … [at] or, anything you wanted to change had to come to the Software Control Board with a documented change, review it, get it approved, put it in. And each change was a change packet that I would sign. I think I must have signed thousands of change packages for the software, but the configuration control was very rigid. The documentation was very thorough, and I give that quite a lot of credit to how well the avionics system [has] worked over the years, because it was a very rigorous process that was created.

One other thing I'd really mention about that time. When we had those first reviews of the requirements … [for] the Orbiter software, I met a person that I respect about as much as anyone that I've worked in the space program with, and that's Sy Rubenstein out at Rockwell International. He was the man, at that time, in charge of the avionics system for Rockwell, and later on he became head of the whole [Rockwell] Shuttle Program, and then he was head of Space Station initiative that Rockwell had. They didn't win [Station], but he was the leader of that.

Sy was a very capable, competent man, still is, and I enjoyed working with him a lot over the years. He added a lot to our system. In fact, he became the [Rockwell] Shuttle program manager at a time later when we were having problems with the tiles on the first vehicle, and he was involved in solving that problem and many others. But Sy was really a very outstanding technical leader for the Space Shuttle and deserves a lot of credit for it.

So now I had my new office, the Orbiter Avionics Systems Office, and I was well into the software requirements, and I was running the Software Board, but we still had these other two problems I talked about. We had a computer that was too small.

During that time frame, Aaron Cohen was the Orbiter Program Manager, the fellow I worked for, Project Manager, Orbiter Project Manager, and he didn't want to buy new computers if he didn't have to. So this was probably the Christmas of 1977, I think. It turned out at that time he had Fred [W.] Haise assigned as a special assistant to him, and Fred told him that he could kind of re-formulate these requirements so you could skinny them down and get them into the 64,000-word computer. And Fred took, like, a ten-day leave over Christmas, and I think he went to Big Bend [National Park, Texas] or somewhere and sat and mulled on the computer requirements and came back and made a pitch about, you know, "If you did this and did that and did the other thing, you could cram them into the box," and it was a great effort on his part. But, really, too many things fell off the table, and we couldn't step up to some of the loss of redundancies and some of the loss of capabilities that it would take.

So we had to have a bigger computer, and at that time IBM came forward and said they could do what they called a double-density version of the computer. It essentially doubled the memory in the same box, still the core memory. So we worked that change, and Aaron approved it, and we increased the memory from 64,000 sixteen-bit words to 104,000 sixteen-bit words. And then we got a shot at cramming these ascent and entry and orbit programs in. It was still a challenge. We still had to do some scrubbing and be careful with growth, because it wasn't an easy fit, but it fit, and that's how that problem got solved.

We took this issue with perhaps needing a backup system, an alternate to the four-computer bank, all the way up through Center management. A lot of people felt strongly that we ought to have a backup system, and we worked on what it could be, and what it turned out to be was, it turned out to be an identical computer, but a fifth one, and a switch, kind of a lever switch sort of thing that the crew could operate that would take the four sets of data buses that went in and out of this big primary computer bank and switch them over so they would all be controlled by this one computer, and it wouldn't be redundant, but all four of them would get driven by that single computer.

Then it was proposed that the software in there would be a skinnied-down [single load] version, just for a safe recovery, of these bigger programs that had to go in one by one into the four-computer bank. We would have that software built by somebody else so it would be new, unique software, and it would be physically separated from the other set.

We took that forward as a proposal for implementation. Chris Kraft didn't really think that was the right thing to do, and we had a very intense set of meetings telling him the preponderance of the people who actually thought that was a failure mode worth providing coverage for. [I believe that Chris felt that we had to work the primary computer system until it was highly reliable and once we'd achieved that a backup was not only unnecessary but perhaps a distraction from doing the primary system right.] In the end, he acquiesced, and we did built the fifth computer, and we had Rockwell build the software, this new program that would do all the things you needed to abort and get home, and they tested it independently, and it was different. It was the same requirements but different software, and that became part of the now five-computer set of orbiter avionics system that controls the whole Space Shuttle. So those were the things that went on at that time.

The other part of my job was when you're doing, particularly doing software, but also doing these kinds of systems, you have to do a lot of test verification. So I was also in charge of the test verification programs for both the software and for the full avionics. The software was verified by IBM. I think they had a very, very capable way of doing that. There's been a lot of talk in the years since that time about the right way to do software is to have independent verification and validation [IV & V]. Whoever builds the software would build it and test it as they build it, and then you'd turn it over to some other organization, and they would do a test program to prove that they couldn't find any bugs that were in there that you didn't … [find].

The way we did the Space Shuttle, the way IBM did it, they had independent verification, but it was within their organization. They had a development organization to build the software, and they had a verification organization to test it, and they were physically separated, but they were all IBM and they were all in the same building, and they used the same facilities.

The way that works, you agree on these requirements that are in these FS[S]R's, and then that's what IBM takes away to build the flight software code from, and they have an organization that will create software logic to meet those requirements, and they'll do development testing as they build it. This verification organization takes the same requirements, and they construct a test program that they would have to show that the software would do what it's supposed to do. So when the software is coded and the development organization thinks it's correct, they hand it over to the verification organization, and they start all over, and they run this test program they've created, and they do their tests. So that's the way the flight software was done, I think it's still done that way, and it certainly was rigorous and thorough.

But that's not the end. After you get it all verified and deliver it as the flight software package, then you have to test it with the hardware. The way the Shuttle Program does that, they have a very elaborate test facility over in Building 16 at Johnson called the SAIL, the Shuttle Avionics Integration Laboratory. It is a physically accurate representation of the Space Shuttle Orbiter in terms of the wire runs, the electrical power, the data buses, all of the avionics, the electronic boxes in the front end and in the back end and in the payload bay. It's all there laid out in the specific configuration that it is in the Orbiter vehicle, and it's got a big test laboratory around it, and you load the software in it.

So now you have a full representation of the Orbiter. You have all of the hardware in the avionics, all of the software in the avionics. In the laboratory around it, you have a series of math models. The math models simulate the flight environment that you're going to fly through, and they simulate the other elements of the Shuttle. We don't have a solid rocket booster or a tank there or a main engine, so they simulate those. But the electronics are all there, and so you can fly a full mission.

There's a cockpit station, and you can fly a whole mission in the Shuttle Avionics Lab, and because of the physical layout you can test things like EMI [electromagnetic interference] and electrical transients and things that you find in the integrated system in the vehicle that wouldn't show up in the design testing of these individual components. And you can fly the whole stuff together and see how the software and the hardware works and check [response to] faults and see if the right things occur the way they're supposed to. So it's a very elaborate test program in the SAIL before you're done, saying that the whole avionics system is flight-worthy. So that program was part of this Orbiter Avionics Systems Office [responsibility] also.

I don't know how enthusiastic this discussion has sounded, but this was one of the nicest job[s] I ever had. I really enjoyed this. I did it from about 1977 to 1981, and it was really a fine job. Maybe 1982, because what happened after that—yes, it's 1982. What happened after that was Aaron Cohen moved on. I think he went to be head of [JSC] engineering before he got to be head of the Center. But in any event, he left the Orbiter Project Office. So in 1982 I was asked to become head of the Orbiter Project Office and moved up from this avionics job. But by then all of the software had been developed, and we'd flown four flights with the Space Shuttle, maybe five flights. I think … [I] started around flight six, was the first flight I was in charge of the Orbiter and not following in the avionics.

So that was a nice package of work, '77 to '82, when all of this came together, and we made this avionics system work, and it's really worked flawlessly all these years since. It's a wonderful system. People always talk about needing an avionics upgrade and how it's old technology. Well, it's very thorough technology and it's very elaborate, and for the time it was cutting-edge, and it's still darn good stuff.

In fact, as they talk about upgrading the avionics, particularly the crew cockpit, you have to be very careful when you go in to modify any part of this system, because it's all interrelated, and if you're not careful, some of these very elaborate protections that have been built in and tested and redundancies that are in there, you could perhaps alter in some way that's subtle, that could make the thing less reliable rather than more reliable, if you go in, just because it is so complicated, and there are so many thousands, millions, I guess, lines of code that have been created and tested over the years.

RUSNAK: One of the current astronauts was just telling us yesterday what the software may lack in flexibility now, it makes up for in its essentially 100 percent predictability, because you know exactly how it's going to react in any given situation. And so to mess with that, as you point out, can be unpredictable.

ALDRICH: This fail-to-sync logic in these four computers was very complicated to build, and there was a fellow at IBM named Lynn Killingbeck that was, I guess you'd call the technical guru of that. And when we first started doing that in the lab, we would have fail-to-syncs. We'd [have] the computers break up and come apart functionally. But over a few years of intense testing and work by this IBM team and this Lynn Killingbeck, we may not have ever found all the bugs, but we found all the ones that were likely to occur, because when it finally got solid, it was rock-solid.

RUSNAK: The first Shuttle flight had some sync issues, though, before it ever took off.

ALDRICH: I was going to talk about that. Actually, I've got that listed down as one of the things to make a point of. It relates back to this Rockwell and IBM contention for who's the real expert.

We're now at the time of the first Shuttle flight in 1981, and so all the software's been built. It's all in the mass memory, or in the computers, and the backup system's there. It's been built and provided, and it's been certified and tested also. The way the launch sequence would work is that the four-computer bank and the checkout program was in there from the time you powered the vehicle up, twenty-four hours or longer before the launch would occur, and it would do all the things it's supposed to do down to about minus twenty minutes. At minus twenty minutes, the primary system is required to synchronize the [backup flight] software with a logic update for guidance and positioning, so the backup system can start in the right place, because it hasn't been [engaged]. The way the primary system works is, even on the launch pad, it navigates during this whole period pre-launch. So it really know[s] exactly where the Shuttle is, what its position is, because the Earth's rotating.

In space, you call it the state vector, about where the vehicle is and where it's pointed. Well, you still have a state vector when you're on the launch pad, and the primary system's doing this, but the backup one is not involved in this until minus twenty minutes. So at minus twenty minutes, the primary system has to tell the backup all this information so it can start, and from there it tracks and does its own thing.

That was the flaw on STS-1. At minus twenty minutes, when it was time to load the backup with this initialization from the primary system, it didn't take. So we had to stop. The preponderance of the colleagues thought all of this wonderful elaborate IBM software and this big four-redundant-set system that was so fine was in great shape, and this little backup with the software built by Rockwell had some problem that they didn't get right. And so over the course of the next evening, the next twenty-four hours, about halfway into the reviews we conducted to find out what was wrong, it turned out that the backup system was fine, and the primary system did not send the initialization in the way that was correct, and it was an IBM software problem, which was easy to fix.

I think we just went one day later. We found the little thing and adjusted it. But it was interesting that the initial reaction was that Rockwell didn't do this right, but in the end IBM kind of had to step back and take credit for having something they hadn't quite gotten in the right place. And that was easy to fix. It didn't have any further impact. It pressed on from there.

RUSNAK: Jack [John R.] Garman was telling us that that episode caused him a few headaches, I think.

ALDRICH: Well, he led the team that worked all of those aspects of that, all the issues related to it. I can't remember how long it was. It wasn't more than a few hours before everybody was not blaming Rockwell anymore.

Let's see what I've talked about here, because that was interesting. I wanted to tell you about that, and I think maybe there's one other thing about that time period.

RUSNAK: When you had first become involved with the avionics, at least in this capacity, had the approach and landing tests flown?

ALDRICH: Tell me the time frame again.

RUSNAK: Well, the approach and landing tests were about mid-1977. I think they finish up in October, and I was wondering if you were in charge of the avionics at this point, or if you had any involvement of the results of tests of avionics that were uncovered through the ALT Program.

ALDRICH: I really was in charge at that time, but I'd just come onboard, and all of my focus was on the first orbital flight. The computer programs for ALT had been built, and they were available to be in the vehicle, and they'd been tested, and they really weren't a big issue. This redundant-set thing had had some testing, but the whole computer program was smaller. It was more simple, and so there weren't issues with that. I did participate in monitoring the flights and the flight readiness reviews, but I didn't really focus on doing much for the ALT. [Earlier there had been some fail to sync and maturity issues with the ALT software but they had primarily been worked by people in the JSC Space Software Division (SSD) on the NASA side and by their directorate head, Bill Tindall.]

RUSNAK: As far as the avionics go, how was the pacing and the scheduling of that through the late 1970s, I guess, comparable to other areas of the Orbiter, the Shuttle Program, as a whole?

ALDRICH: Well, when we found out that we had to put in these bigger computers and we found out all this software that was going to get built and we had some of these problems, like this fail-to-sync problem, it looked like the schedule was very tight to make the first flight for that. I'm sure we thought we were behind schedule. But I'm sure you have talked to other people about the fact that when *Columbia* was built, and it was built in Palmdale, like all the Orbiters were, and then it was flown to Florida, when it took off on the back of the 747 from Palmdale, a whole bunch of the tiles just came off as they went down the runway. I mean, they didn't have to fly a long time. They just fell off.

That led to the requirement to have a lot better understanding of how the tiles were attached and how to know they were well attached, and that problem took two years to solve. The Orbiter did go to Florida, but it got down there, and it had some large number of tiles missing, and, not only that, we had to figure out why they came off and how to be sure you could mount them so they wouldn't in the future.

That was a two-year problem, so the launch of the first flight slipped from 1979 to 1981, which, for people who were behind in the software and behind in getting the computers updated, was a great window of additional time. So by the time the tile problem got back on track, all of the stuff I've been talking about in the avionics also was on track for first flight, and I'm sure we would not have made the initial flight date with the things we were doing in the avionics program.

RUSNAK: What sort of direction were you receiving from the Program Office, from Bob Thompson, for instance?

ALDRICH: Well, the Orbiter Project Office was a very strong JSC project office, and Bob Thompson and Aaron Cohen were almost equals in terms of where they were in the management structure and the scope and the size of their responsibilities. And so, I mean, I worked daily, hourly with Aaron Cohen during all this time. But I didn't get a lot of interfacing with the Space Shuttle Program.

We were doing the software that … [interfaced with] the main engines. The main engines had their own computer[s] provided by Marshall [Space Flight Center, Huntsville, Alabama], and they were mounted on … [each] engine. But then there's an interface unit in the Orbiter for each engine that is part of the Orbiter equipment, and it was part of this avionics system that I … [worked] on. So there was quite a large interface with the main engine and a smaller interface with the boosters and the [external] tank, and those, of course, are Bob Thompson, other projects at the Marshall Center. So we had to have the software requirements right and tested for them as well.

But there wasn't anyone who did avionics in Bob Thompson's office. I essentially did it for both Bob and Aaron, but did it primarily in the focus from Aaron with an engineering team that included people from those projects as well. So I didn't feel closely guided or directed by the Shuttle Program, but we knew very much what we were doing in conjunction with them and how we were doing it and how the teams worked.

RUSNAK: What sort of involvement did the flight crews, the astronauts themselves, have with development of the software?

ALDRICH: They had a big role in it. This Orbiter avionics stuff, we had a control board that always had a representative from the flight crew, and during most of this time Bob [Robert L.] Crippen was the representative. He would come to every meeting, and most of the things we'd do would have some crew-related consequence or impact or requirement, and so we had to work those things carefully, and he had to be sure that they were worked in the way that would suit the crew, but yet also that the vehicle could actually accommodate.

One of the things I found in these detailed requirements we put together, even after we had a pretty good set and we were working forward, was that the crew interface was very complex. You know, the crew has a lot of indicator lights that turn various colors for different things. They have lots of switches, and they have other controls, and then they have cathode ray tube displays with data on them, and all of those things operate with the computers. They don't operate around the vehicle. They go to the computer, or they come out of the computer.

If you got into the "what if" discussions about some of those controls and displays, many things in the Shuttle can occur automatically, or the crew can override and do them themselves, or they can take some other action based on the data they see. So you have a very intricate involvement with the crew procedures and the crew checklist and what the crew's choices and options are.

So when you build the software, the software doesn't just do it one way. It has to also interact with the crew and the displays and the controls, and it has to give them alternate manual control in many instances, if that's the way we choose to proceed. So that makes a very intricate set of requirements on lots of details that go on in the crew area.

I'll just tell you one example that we found along the way. In the past programs, I spent quite a lot of time in my role as the operations systems person for the control center in analyzing these space systems in detail and how they worked. So analyzing these kind of things came kind of natural to me, although I was now running [this] Software Board. If you probed in a little bit about "what happened if" with some of these things, you could find they didn't cover all of the situations that might occur.

For example, when the Space Shuttle does an entry, after the de-orbit burn, the first phase, well, it turns around. It does a de-orbit burn back end forward, but then it turns around and starts in like an airplane. But there's no atmosphere yet. So it controls with its little rocket engines to approach the atmosphere, and as it enters the atmosphere, you get to start having some control with the aerosurfaces and you still have the rocket engine authority and the two work together. And then after you get down heavier into the atmosphere, and you get into the high-heat-load phase, it's all aerosurface. The little rocket engines don't have enough authority anymore in that atmosphere to control it.

Then when you get through the heat phase and you've taken off a lot of the energy and … [you're coming into the vicinity of the] landing field, you get into a thing called the heading alignment circle, where you approach and you fly at a high altitude around the runway to get lined up with just the right amount of speed and altitude to do the right kind of approach for landing.

So there are phases. You don't have just one entry sequence. You have a series of modes in entry, and they're called 301, 302, 303, 304, [etc.] and you want to do them in sequence. I mean, you want to do 301 first, and the flight system can step through those, or the crew can call them. They have a capability to engage these modes, and they can manually step through them at the right time. And that's the way the software was built.

But what we found was, if for some reason the crew inadvertently presses the wrong one, like when you're supposed to go to 302, you press 303 instead, it would go to 303, and you don't want that to happen. So that's the kind of thing that I was saying is subtle with the crew interface that we had to think through. We had allowed the crew all the things that they had to have, but you also wanted to have all the protection so they couldn't do something that was really inadvertently bad and could get them in trouble. So that took a lot of talking through and analysis and thought, and some of the times it just took another line of questioning. You'd say, "Well, but what if such-and-such were to occur?"

"Oh, well, that wouldn't happen."

You'd say, "Well, we don't want the software to let it happen."

So we did a lot of that, and it did involve the crew, and Bob Crippen was a wonderful person to work those kind of things with, but we worked them with other crew people, too. Sometimes there'd be more than just one person at the meeting.

In fact, you talk about first flight, I was in charge of the avionics system, and because of my role at that time, I wasn't as sensitive to some of the other things in the Space Shuttle that are very challenging things to do. I didn't know much about the main engines at that time or the ascent. That wasn't a focus of mine. But I was really concerned about this entry because we had worked on entry and the control logic. The avionics controls the vehicle during that time frame. It does during ascent, too, but it is so much more, I guess you'd call it automatic, during ascent. The entry, there was really a lot of concern about how much control authority the vehicle had to have with these little engines and with the aerosurfaces and the amount of atmosphere.

The biggest anxiety I had during first flight was how well this vehicle would fly through that entry sequence, because we'd never been able to fly it. We'd only done it in laboratories and testing and analysis. And so the biggest moment for me for STS-1 was waiting to see it come out of blackout, because if it came out of blackout, it was now in a very easy, straightforward—… [landing's] still a challenge, but we're now in a lot more certain regime of the flight. Approach and landing testing had done landing. But the blackout thing was my time of most concern during first flight. And, of course, it came out of blackout fine. It was just fine.

The other thing we did wasn't really part of my job, but we had been concerned about this thermal protection system on the Orbiter, the challenges of creating it, and then this problem we'd had with the tiles not being mounted as thoroughly as we thought they would be. A lot of us were of the opinion that you probably couldn't afford to lose a tile during flight. Just the loss of one tile would create a place that would overheat and burn through, at least on the bottom tiles.

So we didn't know a lot about the flight performance of the thermal protection system. The fact is, it's much more flight-tolerant than we initially thought it was, which is good because we've had damage on many flights of the tile system.

But, anyway, after the first flight, Chris got together a group of the senior people on the program, and we all flew out to Edwards, where the vehicle had landed, to look at the tiles. There was a lot of damage on the underside, but there was one tile on the body flap that had a really big ding into it, and when you get a big hole in a hot area, then the heat kind of melts like an inverted snowcone. It just kind of melts into the tile. And so there was this one that was really quite damaged in a very heat-sensitive area, but it didn't melt all the way through. It had survived. So that was interesting to go out and look at that, and that got to be another feature of my next job, worrying about the tiles.

That was the first flight, and during the first half dozen flights, we found that there was quite a lot of material coming off the solid rocket boosters and the [external] tank during ascent, and invariably it would come off. It would hit the bottom of the Orbiter and make little dings that now would be threats to the entry phase, to cause thermal damage.

That was during the time Glynn Lunney was the Space Shuttle Program Manager. He'd replaced Bob Thompson. We made a number of changes in the Shuttle Program to the external tank and to the solid rocket booster mounting mechanism for things, so that some of the stuff that would come off no longer was there.

For example, the big external tank had a lightning-rod protection system on it. It had a metal ring around the top of the tank. I think it was copper and then … [a wire] down so that if it got hit by lightning, it would have lightning protection. And this ring was under the thermal protection system on the tank so you couldn't see it, but it was there. This was probably the most glaring example of things that got fixed during that time period, but we found out that during ascent, in fact, the ring was breaking apart and coming off, and the copper was hitting the Orbiter and making some of the damage on the Orbiter that we were seeing. So it turned out you actually didn't have [to have] a lightning protection system on the tank. The whole launch configuration is protected for that, and so we took that off.

Another thing that caused damage was ice on the tank, and our monitoring and controls for being sure not to launch with ice on the tank got worked extensively during that time period, because little pieces of ice would come off.

So the early flights were kind of test programs for the Shuttle vehicle and the thermal protection system and how to tune it up, and I worked on that both before I got to be the Orbiter Project Manager, which started with flight six and then during the next fourteen flights or so, working with Glynn Lunney on the whole Shuttle system and the effects on the Orbiter thermal protection system as a major activity.

The top of *Columbia* initially had a lot of very small white tiles, and they were hard to maintain, and they were damage-prone, and the upper surface, the big areas that weren't in a high heat mode had this—it's kind of a felt pad with a white layer on top. It's called FRSI; it's flexible surface reusable insulation, I think, is what FRSI is. But in the higher [upper surface] heat areas, they had these little tiny tiles, and it was hard to maintain, and they weren't a very good thing. So during that time period Rockwell developed this thing, this material that's a blanket called advanced flexible reusable surface installation, advanced FRSI, and we started to use that.

But we found the surface of that would erode and break up during the flight phase, and so they had to get a surface coating to paint it with. So now the high-heat areas in the top of the Space Shuttle orbiters have this advanced FRSI on them, and it's a nice blanket you can put on [in] big pieces, and then it's coated with a material that toughens the outside surface, so it has a long life to it. So we made that change.

The other thing, if you look at an Orbiter today, you'll see most of the top surface is white. But on both of the OMS [orbital maneuvering system] pods, on the front of the OMS pods, there's a black area of the tiles on each one. That's because those two areas stick out kind of in the jetstream flowing across the front of the vehicle to the back, and we were continually getting damage on the OMS pods on the tiles there, and these black ones are a tougher tile that Rockwell developed. They're still tiles, but they're—I can't today remember what we call them, but they're significantly tougher than the white ones you see on the rest of the OMS pod and the rest of the vehicle. And they were put there specifically because we always get some amount of little material coming by that in most flights was damaging the front end of the OMS pods, to the point where if you had a really big piece of damage there, that could be flight-critical, because the OMS pods are needed to control the vehicle [and they contain the tanks and lines of high energy propellants].

That's sort of the TPS story, and I think I've kind of moved into this new job. In 1982 I got to be the head of the Orbiter Project Office, starting with the sixth flight, and from there through the twentieth flight, I was in charge of the Orbiter system, and some of these things I've just been talking about with the tiles was after I moved on from avionics, although I think it started while I was still on the avionics job.

Another thing we did during that time period I was in charge of the Orbiter, the first four flights were called development flight test [flight] flights, and there was a big rack of instrumentation. Essentially the payload was an instrumentation package that had many sensors all over *Columbia* to sense temperatures and pressures and dynamic loading all around the vehicle to really get much better analysis of what the real flight loads and temperatures were. So about the time that I took over the Orbiter, the data from those flights was becoming available, and what we were seeing is that in many areas the Orbiter was over-designed. It was too strong, too beefy, and what we could actually do was take about 8,000 pounds out of the Orbiter by redesign. That was very desirable because that would be directly related to payload.

So those changes were under way when I took over. Both *Columbia* and *Challenger* were built to this heavier design because they existed, but *Discovery*, *Atlantis*, and then *Endeavour* weren't yet created. So they could take advantage of this knowledge of areas where we could take some of the weight out, and that was in the plan, and that was in work when I took over. But I managed the time frame that *Atlantis* and *Discovery* were built and delivered, and they were lighter vehicles.

In fact, today *Discovery* and *Atlantis* and *Endeavour* go to Space Station, and they fly Space Station missions because their performance is suited to it. *Columbia* isn't used for Station missions because it's almost 10,000 pounds heavier, and it can't carry the payload to Station that the other vehicles can. I mean, this is hard fact in … [metal] that happened in the time frame I'm talking about, but it's still part of the way things are.

On the other hand, not everything was over-designed. What we found was that there were certain areas on the underside of the Orbiter, I think forward of where the main gear doors are, that actually were under-designed for thermal protection. The loading on the vehicle when it flies ascent and then entry, the most stringent design requirement is not the structural load of flying the vehicle, it's the thermal load when the temperature rises. It puts a stress in the vehicle, and, of course, the load you have to deal with is with the combined thermal and structural load, but the entry thermal load on the underside of the vehicle is the most strenuous thing that the vehicle see[s]. These areas forward of the main landing gear doors, the thermal protection system wasn't quite up to the design requirement, and so we either needed thicker tiles or we needed some other kind of correction to keep from overstressing the structure inside.

You couldn't just exactly change the tiles, because you had to have the aerodynamic smoothness of the vehicle to fly the thing aerodynamically. So I think we might have changed the thickness of the tile a little bit, but we also added heat sinking on the inside, and we beefed up the structure on the inside of the Orbiter. So for *Discovery*, and later Orbiter[s], while, for the most part, we were taking weight out, in some areas we were doing beef-ups, and this was all based on what we learned from the flight instrumentation on the first four flights, before we took the DFI [Development Flight Instrumentation] rack out of the payload bay.

RUSNAK: How did building the second two Orbiters compare with *Challenger* and *Columbia*?

ALDRICH: Well, of course, I wasn't … [actively] involved in building *Challenger* and *Columbia*, but we've talked about some of the development problems that happened for the first flights, which was *Columbia*. I talked about some of the avionics problems. We talked about the tile problems. I'm sure there were many, many difficulties with developing these vehicles and building them, and it was much more smooth for *Discovery* and *Atlantis*. I mean, we were now building a known configuration, even with these changes. They … [flowed] quite smoothly, and they were in excellent shape when they were delivered.

Kennedy [Space Center] would always complain about some of the unfinished work that would come when you deliver an Orbiter, because for various reasons, it got to be time to send it, and you'd send it, and there'd be this big package of stuff that was still [to be done] —but that was really trivial in terms of the scope of creating an Orbiter.

One of the things that I enjoyed a lot, I accepted both *Discovery* and *Atlantis* for the government at the roll-out. I went out to the ceremony for the roll-out [for each], and I made a speech on the viewing stand to take note of delivery of the two Orbiters to the government.

The second speech I did, the one after *Atlantis*, at that time we thought that was the last Orbiter that was going to be built, so it was kind of an emotional speech about the wonderful job and all the things that the Rockwell team had done in creating these orbiters. And they liked it so much that they used my speech in their HR [Human Resources] program for literally several years afterwards. People would come up to me and tell me they'd seen my speech, because they used it as part of their motivational program for their new employees. That was a good time, and they were—well, they were good vehicles. They still are good vehicles. They were well done.

Then *Endeavour* was a replacement and a carbon copy, and it was even cleaner. I mean, it flowed through and came out. That was after my time, but Rockwell got a lot of kudos for how well *Endeavour* came ahead of schedule. I don't remember the cost story, but it was all very successful.

RUSNAK: Do you remember if there were any discussions of building a fifth Orbiter prior to—

ALDRICH: Oh, yes. The reason that we were able to do *Endeavour* in the time frame we did is because we had a program called the Structural Spares Program. The thing that takes the longest time when you go to build an Orbiter is to build all the major structural pieces.

The cabin, for example, is a very elaborate module that's made up with complex shapes and complex welds, and it takes like a year to make it a cabin. The cabin fits inside the outer shell. There's a lower and upper shell. It's what you see, but inside is contained almost a spacecraft in itself, which is the pressurized cabin. Then all the other structural elements are also massive. Well, they're not all massive, but what I was about to point out is massive, and that's the mounts for the main engines. They're a very large structure in the aft end to take the main engines, and they take a long time to create and build.

So during this period that I was the Orbiter Project Manager, we were concerned about maybe having to have another Orbiter, and no one wanted to move out to build one, but we did move out to build structural spares. And so at the time of the *Challenger* accident, we had these. These major structural pieces already existed, and all you had to do was decide to put them together and then outfit the thing and do all the stuff it takes to make an Orbiter. But the long lead time things were already in hand.

RUSNAK: Interesting. I think I had read somewhere that the *Endeavour* was one of something like three government projects that year to come in on schedule and under budget, so it's quite an accomplishment.

But we're about at the time to change out our tapes. So this might be a good place to take a short break.

ALDRICH: Good.

RUSNAK: All right, we're back on.

ALDRICH: Okay. I was going to mention a couple of other things. I was head of the Orbiter Project from flight six to flight twenty. But during that time, [NASA Associate Administrator for Space Flight] Jim [James A.] Abrahamson decided that our … [numbering] system was not elaborate enough. So starting with the tenth flight, he caused us to start using a numbering system which would include the last number of the year, like 1984 would be four, 1985 would be five, and then a second number which was the launch site. One would be the Cape, and two would be the West Coast, and somehow there was maybe going to be three at some point. I can't remember how that would work. And then a letter for the number of flight in the year, like, the first flight in the year would be "A," and the second one would be "B." So flight ten was not STS-10; it was STS 41-B. And from that time up through the twenty-fifth flight, which was the *Challenger* accident, we had this new numbering system.

Anyway, I was in charge of the Orbiter up either to or through flight twenty, and then I became the Space Shuttle … [Program] Manager at Johnson, where I was managing the whole Shuttle system.

Another thing I'd talk about, though, during the Orbiter time frame was, I talked about how we had used the data from the first few flights to tune the Orbiter design to be a better match for the actual flight environment. But the other thing we were also doing was doing a series of things at Rockwell that are called "load cycles" for the Shuttle vehicle. A load cycle is an even more elaborate modeling of the flight environment as we were getting to know it, where you would operate the vehicle in this math model. You'd simulate the vehicle with the best data you now had from what its real flight parameters were, and play it against the environment you knew that it would fly against, which we were also learning more about, and then you'd introduce all the variances that you could see. You know, the vehicle has to have the capability to fly through with margin in all of the things it does, and so you've got a series of margin parameters.

Each time you do that in a very elaborate way and test all of the components, you'd come up with a further refinement of the vehicle capability, and then you could change the software—this is primarily an ascent problem—you'd change the software parameters so that you could optimize them, and you'd know what your margins were and where they were and so forth. We did several load cycles, which were many-month activities by the Rockwell systems integration team, and they were quite expensive things to do. I mean, it was a big project to essentially re-do the entire design with updated known parameters from the vehicle.

We also would use that information to create the day-of-launch parameters we'd load in the computer. They're called I-loads, initialization loads, and there's a fairly large number of parameters that you load into the vehicle right before flight, so that it's tuned up for the specific winds of the day. You know exactly what the environment is it's going to fly through on the way up, and you, again, tune the vehicle to have the most margin as it flies through in terms of angle of attack and what it sees.

So this knowledge of the instrumentation from the first several flights and these refined load cycles we were doing and this evolution of the I-load process all occurred during this time frame I was talking about, and it led to a very mature design over time. But there was a lot of engineering and analysis to it. It didn't happen all in one step. It really kind of evolved from flight to flight and period to period.

So then I took over with STS 51-J in October of 1985. I became the Shuttle Program Manager, and I was in charge of the Shuttle Program from there through the *Challenger* flight and all of the analysis that followed the *Challenger* flight.

Then in the fall of 1986, I was asked to come to Washington to be the Director of the Space Shuttle Program, which was the next phase in my career, and I moved to Washington and led the program during the recovery from the *Challenger* accident and all the changes we made and all the fixes.

So I don't know much more to say about that. I've been talking about these jobs that I had and how really wonderful they were and how much I enjoyed them, and one of the jobs that I enjoyed the most of all of this was, in spite of the terrible tragedy of the *Challenger*, the period that followed that, where I led the return to flight, was probably as great an opportunity as anything I've ever had.

I took on an approach to that that I'd seen George [M.] Low take. I think I mentioned this in the last interview also. After the Apollo fire, George Low started leading a series of program reviews with all of the technical people on the program, both NASA and Grumman and Rockwell, then North American, and looked at everything in the vehicle, didn't look at just what had caused the problem, but he looked at all of the systems and all of the flight performance and teased out those things that people had some uneasy feelings about or that were known to be not quite as good as they could be.

After the *Challenger* accident, I started having reviews like that with the team here [JSC] and with Rockwell and with the other projects, the tank and the engines and the solid rocket boosters, and we made a list of all the things that we were concerned about in terms of the Space Shuttle systems and what we thought were things we would want to have changed but we never had the time or the money or it didn't fit [the schedule], and also areas where we felt there was real risk.

We made over 200 changes to the Space Shuttle during the period after the *Challenger* accident, and only a handful related to the solid rocket boosters. Others were these Orbiter systems. They were things with the main engine, a few things with the tank. We changed a lot of the software. We added new abort modes. We created new down-range landing sites.

This was an opportunity to look at the whole system and make it as good as it could be, and I think the Shuttle benefited tremendously from that for the period that's followed. There's been other improvements since that time, but nothing of that magnitude has been done since, and it made a much more solid vehicle.

What we found was that [with] all of this pressure to get to first flight of the Shuttle, there'd been a lot of decisions made about, you know, "We'll live with this for now, but we'll fix it later," and so there were a lot of things that troubled people, that we would have wanted to have fixed, but there was never time. And then once we started flying, the flights came so quick one after another, you couldn't stop and fix anything.

So we got all of this on the table, and we made a lot of changes and made the Shuttle a lot better, and some of them we required them to be done for first flight, for the first flight after the *Challenger*, and some we allowed over a longer period of time. In fact, some of the changes to the main engine have literally taken a decade to make. They were just completed some ten years later. They've come into the upgraded versions of the main engine in terms of the manifold and some of the other things that were done to it. So it was a time to take a lot of stock, and it was really good. [Two of the more major were the development of the new Pratt and Whitney LO_2 and LH_2 Turbopumps].

I was going to talk a little bit more about the period before *Challenger*, and I jumped [forward]. The period before *Challenger*, we were increasing the flight rate quite dramatically, and we were also just about to increase the scope of what the Shuttle could do. The launch site at Vandenberg Air Force Base [California] was just about completed. We'd actually had a ribbon-cutting. It was all in place. There was one concern with trapped hydrogen in one of the ducts under the launch pad that we were still debating. But other than that, it was ready to go, and we were planning to launch out of Vandenberg sometime in the first half of 1986.

So that had been a big piece of work, and in addition to having the launch site, we also had to have a launch trajectory out of Vandenberg that would work. Out of Vandenberg you do polar orbits, and so we were going to fly it straight south over the ocean, past Los Angeles, and down over the South Pole, and we wanted to have the equivalent to our trans-Atlantic abort sites on the East Coast. We … [wanted to] have a trans-Pacific abort site, and we looked at, you know, you could come all the way around and land in Alaska, but you wanted one sooner than that. And we looked at Diego Garcia in the Indian Ocean as a place.

What we finally picked was Easter Island. The Shuttle Program actually enlarged the runway at Easter Island to be able to take a Space Shuttle. Of course, we never landed there, but I'm sure that the tourist industry has benefited greatly from that maneuver while we still thought we were going out of Vandenberg and when we increased [the runway size]—in fact, one of the things that bothers me is that all the time we were doing that, I had multiple opportunities to go down there, and I would love to have gone to Easter Island, but I kept putting it off and then it never happened. But the runway happened.

The other thing that was going on at that time, we were working on two solar system exploration payloads, the *Galileo* spacecraft and the *Magellan* spacecraft, and they needed a high-energy upper stage to fly their missions, and so we were working on a Shuttle version of the Centaur upper stage, the liquid-oxygen, liquid-hydrogen upper stage, that General Dynamics makes out in San Diego. There was an Atlas-Centaur version and a Titan-Centaur version, and now we were working on a Shuttle-Centaur version, which the tanks were changed in shape to fit nicely in the payload bay with these other vehicles.

We were really a long way along with that, too. We were having acceptance reviews out in San Diego for the Shuttle-Centaur at the same time we were having readiness reviews at the Vandenberg launch site, and these two missions, the *Galileo* and the *Magellan*, were going to be also flying during 1986 with the Centaur. That wasn't quite as far along as the launch site, the West Coast launch site, because there was still questions about the safety of the flying the Centaur in the Shuttle payload bay. We'd kind of committed to fly it, but we weren't sure for some of the abort modes, if you came back with it in the bay, what to do with that problem.

So there were some issues like that still in work, but these things were built and ready to deliver. It was really just a question of finding ways to take care of those certain flight phases that we were still concerned about. So that was a busy time.

Then when the *Challenger* accident occurred, we elected not to continue with the Centaur Program. We elected not to continue with Vandenberg, and we moved into this period I talked about where we made all these changes to the Space Shuttle to make it a more sound system, in our view.

RUSNAK: What was your personal opinion of the use of the Centaur?

ALDRICH: Well, you know, up until the time of the *Challenger* accident, we were on a pretty good roll for doing things. We had a lot of confidence, and I felt like we could pretty much do what we set out to do. So we were concerned about all these questions we could come up with about how to operate it, but until the *Challenger* accident, I think we thought that was one of the right roles for the Shuttle, to fly high-energy upper stages and do missions like those.

We actually did those missions, anyway, but we used the solid IUS [inertial upper] stage, which doesn't have nearly the energy, and it caused the flight times to the planets they were going to to be much longer. But we still did the missions. They just changed the mission profile.

After the *Challenger* accident, so many things changed about how we looked at things, and it was pretty clear that flying the Centaur was not a very good idea, and we stepped right away from it.

RUSNAK: In this pre-*Challenger* period, what sort of coordination were you yourself doing with the Department of Defense?

ALDRICH: I wasn't doing a lot of interfacing with the Department of Defense. I'm trying to think about what our relationships were for working the Vandenberg issue. But we had our own teams of people there. Primarily Kennedy Space Center people out at Vandenberg was the government team, and then there were several additional contractors that were working out there. But then we had our Shuttle contractors as well. So it wasn't a strong interface.

The thing I remember most about the Department of Defense was that Pete Aldridge was down at the Center [JSC] training to fly, I think, on the first flight over at Vandenberg, and he was there over in the crew training facilities a lot, and we saw him.

RUSNAK: Did you have much involvement with the couple of Shuttle flights that were dedicated Department of Defense missions?

ALDRICH: Yes. I was cleared for the missions we were flying. But, you know, we were sort of a delivery system. We didn't get into what their missions were going to be afterwards and that sort of thing.

RUSNAK: Sure. You know, I find most people still can't talk about what their involvement was there, so I understand that.

What were some of the other perhaps significant missions from this early period prior to *Challenger* that really stick out in your mind?

ALDRICH: Well, one of the missions that sticks out in my mind a lot is STS-9, John [W.] Young flew, and the thing that sticks out is that I was talking about the redundancies in the Space Shuttle, in the Orbiter, and some things we had four of and some thing[s] we had three. One of the things that we chose to have three of was the auxiliary power units [APUs], and the auxiliary power units we used for entry to work the aerosurfaces and they're the primary means, I think, of—I guess gravity does the landing gear, but they're involved in some way in the landing gear also. I guess the brakes. You have to have the auxiliary power units for the vehicle to fly the entry phase and the landing, and you've got three of them. You turn them on in orbit. You kind of do a little check to be sure they're all right. You also use them for ascent to control aerosurfaces during ascent, for [balancing dynamic] loading.

Anyway, we flew STS-9 and brought up the APUs for landing and flew the entry, and just as the vehicle touched down, two of the APUs failed. Two of them. At that time, and probably still today, we're not certain you can really fly with just one, at least not some of the most dynamic requirements the vehicle … [ought to see]—so that was about as close to a very serious incident as anything I can imagine, that I can remember during that time frame.

It was so close to touchdown, the vehicle just touched down and rolled out, and there was not much made of it, but we in the program office and in the technical areas were very concerned that two of these things could go down at once. Of course, there's some very high-energy little components in these APUs that produce so much horsepower from a small unit, and there was some kind of an injector stem that had a degrading failure mode that we didn't know about that had to do with its lifetime, and the two of them had failed almost at the same time. We had to redesign that part of the APU, and it was okay. But if it had happened on the way up and we'd lost two, we'd been very concerned to try to come all the way down with one and whether it would have failed also.

I think we also had one flight where we lost several computers for some reason, but then I think we got one of them back online and I don't remember that problem as well.

RUSNAK: Then on one of the flights, too, there was an issue with the landing gear, where they had both blown out a tire and locked up the brakes.

ALDRICH: Oh, I had a terrible time during this time period with landing gear and brakes. The landing phase is a phase that the crew is principally involved with, and it requires expert performance, and they all train heavily for it. But they're all nervous about it because they know they have to execute, and it's a very high-energy landing that comes in steep and fast, and you only get one chance. So the crews have always been very concerned, I guess, about landing. It's something they have to do and they're skilled to do, but it's something they think about a lot.

We were having these problems with the brakes and with the tires, seeing a lot of damage. The brakes, when you used them, would tear up to some degree or another on most of the flights, and the tires were getting damaged. In fact, we changed the surface of the runway at Kennedy to make it more smooth during the touchdown period to keep from having such a really rough wear on the tires. That period went all the way up into this post-*Challenger* period I'm talking about. We were trying to find out what you could do to the brakes to make them better. There were material changes and there were dynamic changes in the hydraulics that operated the brakes that come from these APUs, and I think there was another set of changes, also, with different materials for the whole brake system.

We were still trying to figure out which change to make and which would solve the problem when we had the *Challenger* accident. So during this period where we fixed things, we made all the changes at once, and when the vehicle flew again, the brakes were fine, but we don't know today which change is the real one that was the biggest part of making it right. It was kind of an interesting thing, but, yes, every flight had some, just like the tile[s], some degree of brake damage and a lot of concern because the crews weren't sure what the worst thing might happen with these tires and brakes. The one that was the worst is the one you mentioned, where the tire blew, but, you know, that one turned out all right, but you didn't want to have tires blow during this landing process.

RUSNAK: While we're on the topic of landing, had you had any involvement at any point with developing the auto-land capability for the Shuttle?

ALDRICH: Yes, we developed auto-land early in the program. We thought it was a mode the vehicle ought to have. In fact, we as an avionics organization felt it was certified for use starting with flight four in the Shuttle Program. There … [have] been some changes and refinements since then, but the vehicle has this auto-land capability in the software, and it could be used, and it's been tested and certified to the point where we think it would work with a high degree of success. It's never been used, but it's there.

RUSNAK: How do the flight crews feel about that?

ALDRICH: The flight crews, again, it's one of these aspects of this approach and landing phase which they're very concerned that go well every time, that they have everything that they can at their control to make sure it goes well, and what they were worried about is not that the auto-land system wouldn't fly the vehicle right, what they're worried about is if there was some glitch in the auto-land system right at a critical [point] of approach, and they had to take control back over, the transient of getting off the auto-land and getting back into manual control might be something they couldn't deal with. So they just didn't want to commit the vehicle to this auto-land mode when they were more comfortable having full control and being on top of the problem all the way down onto the runway, which I can certainly understand.

It does bring up another thing that I was really interested in during this time period. We were talking about new launch systems and new capability during this time period. I'm not sure exactly where it fits in this sequence of things we're talking about. For example, there was a time period over at Marshall where they were working on a version of the Shuttle called Shuttle C, which was a tank and solid rockets and then the engines mounted on a cargo carrier, and that was to fit the kind of thing I'm talking about, where you could fly cargo missions and you wouldn't have to have a crew.

What I was really interested in doing was making a few lash-ups in the software and flying the Space Shuttle without a crew, because it's got just about everything you need. So you could fly a mission all by itself. The whole ascent, it can fly today. You'd have to fix it so the payload doors could be opened, because right now the crew opens the payload bay doors and closes them. The vehicle can do the de-orbit burn. It can fly the landing; it has the auto-land. The crew drops the main gear with a switch, because that's the way it is, but that could be automated. So, with not too many quite simple changes to the software, you could link all these things together and you could fly the Space Shuttle just with some amount of ground control and do a mission and deliver payloads. I was quite interested in seeing if we could cause that to happen, but it was enough of a change and it didn't have the right priority. I never could find a good enough reason to sell that idea to be done.

RUSNAK: What were the advantages of that?

ALDRICH: Well, you could fly missions without a crew and you could make it a cargo delivery vehicle that you would fly. There was a lot of discussion about why you would risk a Shuttle crew to fly a commercial satellite, for example. So I don't know how far we'll get today, but during this time period and my later work at NASA Headquarters, I spent quite a lot of time looking at ways that we could have a different kind of launch system or other launch systems, and one of the quickest ways you could do that, if you wanted to, would be to fix the Shuttle so that you wouldn't have to have a crew onboard.

RUSNAK: Clearly these discussions in terms of value of payloads versus the risk of the crew's lives came into great play after the *Challenger* accident.

ALDRICH: After the *Challenger* accident, we stopped flying missions like that, because the value proposition didn't make sense, that you'd risk a crew to put up a satellite you can put up lots of way[s].

RUSNAK: In your position in Shuttle management, what were your thoughts on having these non-astronauts, like the Teacher in Space or, later, the Journalist in Space, that kind of thing, flying on the Space Shuttle?

ALDRICH: Again, pre-*Challenger*, this seemed like absolutely a great thing to do and the right direction to move in. I mean, we were expanding the use of the Space Shuttle in many ways during that time, and the *Challenger* caused a lot of pulling back in. But before *Challenger*, you know, we talked about the West Coast launch. We talked about the Centaur. We talked about the Teacher. Our flight rate was increasing. I mean, we were viewing the Space Shuttle as just a series of opportunities yet to be stepped up to in many directions.

RUSNAK: Did you have any interaction with Administrator [James M.] Beggs?

ALDRICH: Yes, but not very much. I was occasionally at meetings with him, but I didn't work [directly for him]. I mean, there were several people between me and Jim Beggs, and I didn't go to Washington too much in those days. This was really a Houston- and Kennedy-centric kind of activity during the years I was working Orbiter with Rockwell.

RUSNAK: Can you explain maybe practically how the levels of management worked at this time in the Shuttle Program?

ALDRICH: Well, the Shuttle Program is made [up] of a series of projects. There's the Orbiter Project that I've talked a lot about. It's a Johnson project, and it really fit the tradition of Johnson in terms of a [manned] spacecraft development organization.

Marshall had three projects. They had this main engine I talked about a while ago as being such an elaborate, refined, high-technology machine. They had the external tank, and they had the solid rocket boosters and motors. The motor is the solid rocket before you put the controls on the back. So the booster and the motor are not the same thing. But when you talk about the booster, you talk about a little more stuff than what Thiokol makes.

Then there was a launch project at the Kennedy Space Center, and there were the various other elements here at Johnson, the astronaut training and the flight simulation and mission control and flight control teams. They weren't called a project, but they're another big aspect of the organizational structure.

Then the job I had, and Glynn Lunney before me and Bob Thompson before him, was the Space Shuttle Program Manager, and that was a Johnson job that integrated all those projects and caused the Shuttle to be one element as a total set of all those things coming together. Then that job reported to the Associate Administrator for Space Flight in Washington.

Let's see. During the time, John [F.] Yardley had [that job for] many years, but then—I'm trying to think of the time frame—… [it] changed to Jess [Jesse W.] Moore after John Yardley left, and that was just a fairly short period of time before the *Challenger* accident. Jess Moore, before him, Yardley, reported to the Administrator, Jim Beggs, then Jim [James C.] Fletcher. Also the Center Directors, Chris Kraft, and Bill [William R.] Lucas at Marshall, reported to Beggs. So Beggs had the Center Directors and the Associate Administrator. The Associate Administrator had the Shuttle Program Manager, and then the Shuttle Program Manager had all these projects across the various NASA Centers. That is the way the organization was wired together, I guess you would say.

RUSNAK: Perhaps we can compare that with the changes made organizationally after the *Challenger* accident.

ALDRICH: The biggest change that was made after the *Challenger* accident—well, there were two changes, two significant changes. One affected the Shuttle and one affected the Space Station. The change that was made in the Space Shuttle is the one that I talked briefly about. Early in the program, the Associate Administrator for Space Flight had had a Director for the Shuttle Program in Washington. It was Mike Malkin. At some point in time, he left and that job was never filled. So … [there] might have been on the org chart, a director, but there wasn't a director during most of this time that we've been talking about.

The most major change in the Shuttle Program was the re-creation of that director job in Washington, and that was the job I was asked to come to Washington to take, which I did. Dick [Richard H.] Truly was the new Associate Administrator for Space Flight, and I moved up to work for Dick and be the Director. The Shuttle Program Manager job here still existed, and I think it was Dick [Richard H.] Kohrs became Shuttle Program Manager here at Johnson, still integrating all these projects at the other Centers. But now there's this director that daily, full-time, is managing the program from Washington.

That was one of the recommendations of the Rogers Commission, to strengthen the Washington control. It essentially moved the control of the programs to Washington. That's a change now that's evolved to a new era now, where in the recent time frame they've moved control of programs out of Washington and back to the Centers. But after *Challenger* that was the recommendation, and I think it was the right one for the time. There needed to be a lot of attention to everything in the program, a lot of tightness and pulling together. So that was the change for Shuttle.

For Station, they also said it ought to be run out of Washington, and the Station Program, Space Station Freedom, had been working well for a number of years here at the Johnson Space

Center and had the program office that was in charge and the other centers reported to it here. The decision that was made was to move the Space Station Freedom Program to Washington, and so they created a whole new program office at a new place out in Reston [Virginia]. They had a hard time attracting key people, because Washington is not a big aerospace-centric employment area, so they had to bring people in and create a new team. It was a very difficult and laborious thing to do, but over a couple of years, the program was moved from the Johnson Space Center to Reston as the key top program office for Space Station, even though there were various Station projects still out at the centers.

So those two things came out of *Challenger*, and actually the change to Space Station was bigger than the one to Space Shuttle, and they both happened in the same time frame.

RUSNAK: We've talked a few times about some of the effects of the Rogers Commission [Presidential Commission on the Space Shuttle *Challenger* Accident] and the *Challenger* accident, but can you share your memories of the flight of 51-L?

ALDRICH: Well, I was certainly directly involved in all the flights during that time frame, and I was there in the launch control center, we launched, and you could see the vehicle up, and it came apart just within—it was actually at 70,000 feet, but it looked very close, and we didn't know what had happened, and it wasn't for a couple of days of looking at data and looking at various videos that we finally realized what had caused it to come apart.

There was a team immediately created there at the Cape to start to analyze those things, and we met full-time for days to do that. It was actually video footage from whatever cameras, it was a very clear day, and so the video coverage was great. When we started getting those in and looking at them, you could see the flame coming out of the joint on the solid rocket booster. Then … [when] you more subtly went back, you could see at liftoff a little puff of black smoke came out of the same joint.

But, no, I was right in the middle of all of that during that time period.

RUSNAK: Can you describe for us the events of the next few months, your participation in the investigation and that whole process?

ALDRICH: If I can remember. We had this team at the Cape but then after, well, they created an independent team, and they took it away from the team that had been responsible for the program up to the time of the launch and put a new set of teams. I think there was a team at each of the Centers, as a matter of fact, plus an overall team. It got to be a much bigger set of people involved. I wasn't involved in the downstream analysis. I think those teams worked for nine months maybe. There was a lengthy period of assessment that went on after *Challenger*.

What I did was turn directly to this thing I was talking about, which is, what are we going to do to recover? What has to be fixed? How do we get the program together? I was working on where we're going, and all these other teams were looking deeper and deeper into the data and they're finding what the analysis was.

RUSNAK: What were your thoughts on the conclusions and recommendations of the Rogers Commission?

ALDRICH: Well, I don't know if you've looked at the Rogers reports, but I was very involved in the hearings for the Rogers Commission, and I testified quite a lot at the hearing, and that's well reflected in the reports. I think there's five books, and there's a lot commentary from me there, mixed with a lot of other key people, and I thought their findings were thorough and accurate and well done, and we tried as hard as we could to work with them to cause them to be that. I mean, no one was—I don't know, maybe some people were negative. I was not negative about the

Rogers Commission at all. In fact, I enjoyed working with Chairman Rogers and several of the other people that were part of that review.

RUSNAK: At what point were you asked to step up into this new role as the Director?

ALDRICH: You know, the Rogers report came out in, I think, June. I think that's when we first saw what they were going to recommend, and I was busy, again, working on what we were going to have to do and how we were going to do it, [and who was going to do it], and working with Dick Truly by that time. I was still a program manager here; I wasn't in the Washington structure.

I can't remember exactly when Dick moved out to make that—I don't think the Rogers Commission change was specific to create a director in Washington. It said, "Take control up from the Center and bring it into the Headquarters," and so I didn't know what change that was going to be or how it would play out.

I think it was like three, four months later that Dick Truly called and said he wanted to come down and talk to me, and he flew down to Ellington Air Force Base [Houston, Texas], by himself, on the NASA plane, and I met him out there, and he told me that I could either take that job, or if not, he was going to have to fill it with somebody else. I wasn't at that time really thinking I wanted to leave the Johnson Space Center and leave Houston, and so I didn't give him a really positive answer. Within a day or so, I could see, you know, I was either going to be in that job or I was going to work for someone who was in it, and so I went up there, and I said, "Yeah, I want to take that. That's what I want to do."

RUSNAK: Had you worked for Dick Truly much prior to that point?

ALDRICH: Yes, I'd worked with Dick over the years. That takes me all the way back to Skylab, when Bob Crippen and Dick Truly were kind of new green astronauts. They were assigned to some of the Skylab systems in the … [Orbital] workshop out at Huntington Beach [California], and I was involved in Skylab in that time frame. I remember going to several reviews out at Huntington Beach, where they were there, and they were working on the things that we were working on as a project. So I got to know them in that time frame, and so I knew him quite well.

RUSNAK: Obviously he must have had great faith in your ability, asking you to step up into this position.

ALDRICH: Well, it's always hard for me to sound immodest, but I think based on all this Shuttle work I've talked about, I probably knew as much about the Shuttle system as any one individual that might be available to him at that time. I knew the people. I knew the programs. I knew the mission operation side of things, and I knew these-I've explained how the whole Shuttle system is flown by the avionics, and I was a principal in developing that. Then … [I'd] been head of the Orbiter Project for a number of flights, and the Orbiter's really the most elaborate part of the Shuttle, and so I think I was probably a very useful person at that time, and I did have a good relationship with Dick, so it worked out.

RUSNAK: How did you go about consolidating this level of management at Headquarters?

ALDRICH: Well, I started doing all of the reviews that I had done here [JSC] as the Shuttle Program Manager. Since the time I had become the Shuttle Program Manager, I was head of the Shuttle Configuration Control Board, and so I just changed, and I just managed it from there [Headquarters]. I took charge of the Shuttle Control Board. We had a daily noon meeting on the Space Shuttle, every day. They probably still have it, and I ran that from Washington. I had two secretaries. I had one in Washington, and I had one here [JSC], and I would come back. I'd spend like three days in Washington and two days here for a long period of time.

So Dick and I were up there, and we were totally in charge of everything that was going [on]. It was being run from Washington, but I was really still also operating with all of the scope and interfaces here at Johnson that I'd been involved with for many years.

RUSNAK: How did the rest of the Shuttle Program respond to this change?

ALDRICH: I don't think it was a big change for them. I mean, I was the same person, and I was doing most of the same things. Whether I was on the phone from Washington or on the phone from Houston was a little subtle. There were changes in personnel at each of the projects, and the new people were of the same motivation I was, you know, "We've got to solve this terrible problem and make things right and get back to where we need to be with the Shuttle Program," and so it was a very cooperative, energetic team that came together to do that. I didn't have difficulty having a tight—and we would meet face to face once a month somewhere as a Shuttle Program management team also. In addition to having the weekly change boards and the daily telecoms, we would come together.

I remember the first meeting we came together after the accident, and we'd moved out of this mode where we were just analyzing what happened, and we were now starting on building, putting the project back together, we met at Marshall, which was a very emotional meeting. But everyone was wanting to go forward and ready to do whatever it took.

RUSNAK: I had the opportunity to speak with J.R. Thompson at some length about the changes he made at the Marshall Space Flight Center and the kind of attitude going on there. This is the same idea as you're expressing here.

ALDRICH: The people that were most impacted by the *Challenger*, other than the family members themselves, were the people at the Johnson Space Center. They were literally devastated for a long, long period of time. It was more here than anywhere else.

RUSNAK: Why do you think that was?

ALDRICH: Well, I think it was partly because these crew members were our friends and neighbors, part of the Johnson family, and I think because we felt here like we were entrusted with their well-being, and we'd let them down. It was a very emotional time, as you can see.

RUSNAK: But completely understandable, though.

ALDRICH: And the people here at Johnson had that attitude I was talking about earlier, about we had been on such a roll. We really thought we knew how to do things. We knew how to do things right. We could do just about anything we decided we wanted to set into. This was a big shock.

RUSNAK: Did you find the technical changes necessary to getting the Shuttle system where you wanted, these things that you had mentioned a little bit earlier, were more or less difficult than the organizational or attitude type of changes that needed to be made?

ALDRICH: Well, I didn't mean to strongly indicate attitude changes were a problem. I mean, everyone was so impacted by this, and then there were certain personnel changes that got made, and when the team finally came back together, there was no problem getting the team to work together and the team to pull in the right direction. It was a unified effort right from the start.

The changes that had to be made to the vehicle, some of them were hard changes to make, and some of them we wanted to make before first flight. Some of them we just wanted to make and get them when we could get them, like these—I can't remember the several changes to the main engine. But if you think about the last ten years, changes have come online in the main engine with new turbo-pumps for oxygen and hydrogen, and they're made by Pratt & Whitney. They're not made by Rockwell, Rocketdyne. That change was instigated at this time. It took years to develop these new pumps and then certify them with the engines and get them delivered.

Also, the manifold on the engine had some number of ducts leading into the thrust chamber. You either went from three to two or two to three, I can't remember which. That change took half a dozen years to get developed and get certified, and it's come into the main engine. So we talk now about main engine upgrades, and they happened over the last four, five years. But those are changes we approved during this post-*Challenger* time frame, and it took that long to develop them.

Others, the number one concern on our list, other than doing whatever had to be done to the solid rocket booster, is there's a seventeen-inch valve in the line that goes from the external tank into the Orbiter for the oxygen and another one for the fuel [hydrogen], and that valve is open at launch and then when you separate from the tank, it closes, so that you have a … closed-[off] place. You don't have an open duct. There was great concern that that valve might flap closed during the boost phase, while the propellants were flowing through it. It was a valve that was moved open with a small amount of tension, and then the dynamic flow of the propellant going through it would kind of hold it open, but there was no latch. It was just open and flow. It was a little hard to rig for each flight. It had to be set up and rigged so that it held open with a certain amount of spring tension. So the whole thing seemed a lot less certain that it was going to perform correctly than we'd like to have it.

We went to look back at the design to see why it was we were so certain the flow would always work in such a way the valve was held open until all the propellant had gone, and then you could close it with the closing system. Rockwell couldn't really produce the certification in any depth that would give us any more confidence. This maybe … [wasn't] a risky thing, and the fellow that designed it had died. So we ran a major test program to see if we could build some certification data, and there was enough uncertainty in that that we said, "We're going to fix this thing." It was the number one … [change on] our list other than solid rockets, and we were going to do two things. For the first flight, we were going to put a little latch in so that it not only was held open, but there was a little latch that kept it open. Then for later flights, we were actually going to design it to a thing that took the flapper right out of the system and it was going to be a whole new valve.

Well, we did build the latching system, and it's on the seventeen-inch tank shutoff valves today. But the new one was going to be a fourteen-inch valve with a thing that moved out of the way. We couldn't build it so it would pass certification and be effective. So the change we made for first flight worked and is in, but the more elaborate change we couldn't develop, and so we've stuck with the one that—we did do that change for first flight.

I didn't have to worry with the changes … [to] the solid rocket booster, because the Rogers Commission created several review teams to work forward of their efforts, and one of the teams they created was the one for the redesign of the solid rocket boosters, and they were charged both with overseeing the redesign and approving it. So if whatever design change NASA was going to make that NASA said was okay, we still couldn't go forward unless they also said they were satisfied. So it was a very tight process. There were expert people on that review, and we had to do all the things they thought were necessary before we could say the solid rocket booster could fly again. [This team was led by Guy Stever and Jim Mar of MIT was a team member.]

If you've talked to anybody about that, we kind of did a belt-and-suspenders set of changes on the solid rocket booster. We changed the O-ring material and the way—maybe we didn't change the O-ring material. We changed the way the O-rings can be tested so that you could verify that they were redundant. We changed the way they fit in the metal overlapping parts of the booster cases, so that when you pressurized the booster, they would close on the O-ring rather than tend to relax them, which the old system would do.

Then we filled in the flow through the … [liner] material on the inside of the case. In the old design there was a gap there so that if there was a path through the O-rings, it could go right through the … [liner] material, and this [change] caused the lining material to overlap. It caused the joint to pressurize to close, rather than pressurize to open, and it changed our ability to test to be sure both O-rings were perfect and good.

Then we put a heater system on so they would never get cold. We felt we had to make all those changes. Probably just to change the way the joint worked would have been enough reliability to expect that it would work, but we wouldn't stop there, and it was probably driven because we had these expert people overseeing what we were doing, what Thiokol was doing. So that got done.

The things that I was working on changing, like these changes to the main engine and changes to the seventeen-inch valves, and those are changes to other parts of the system that, I mean, we could decide to do it or not do it, but we really did just about all of the ones that we came up with. We either changed them for first flight or changed them sometime during the next few years.

RUSNAK: What about the re-investigations of crew escape systems?

ALDRICH: Well, that was another thing. You know, there was a lot of speculation that when the Orbiter broke up, that the cabin pressure maybe was still intact until the cabin hit the water. So the crew might have had an opportunity to do something if there was something they could have done. One of the recommendations of the Rogers Commission, I believe, certainly one of the recommendations we took away was that we had to have some kind of an approach to give the crew some action they could take if that kind of a situation occurred again.

We looked at something that we looked at a number of times before, and that is, the first four, I think, flights of *Columbia* had just two crewmen and they had ejection seats and they could come out through the roof. But when we went to increase the number of crewmen, there was no way to mount that many ejection seats effectively so they could do that job and you'd have still a cabin you could use.

But on several occasions we looked at whether there was some clever way to put enough ejection seats, or if you could have some kind of an ejection rocket pack that a crew could wear and they could go out two at a time through the holes that already exists. The windows … [in] the roof pop out, and you can go out through the roof. We tried hard to come up with some way we could provide for crew escape that would get the crewmen out, and it never seemed feasible that a workable design could be created.

But now we'd had the *Challenger* accident, and we had an event [where] it really might have been good to have some way to get people out. So the first thing we did was change the hatch so you could blow it from the inside. You couldn't open the hatch in the way the Orbiter was before the *Challenger* accident. Now the crew could pyrotechnically open that hatch if they needed to. We looked at how you get the crew out, and what we found is that if you open the hatch and the crew jumped out, they're going to hit the back end of the Orbiter, one of the tail surfaces, more times than not. So they can't just jump out.

We, again, talked about having some kind of a rocket pack that they could wear, that … would propel them out. But no one really wanted to fly every flight with seven rockets in the cabin. So what we did, someone over here in the JSC Engineering Directorate came up with this idea of this pole that once you open the hatch, you could extend this pole out and you hook a ring on it, just like when you parachute from an airplane, but you slide the ring down the pole to the end, and then when you fall off, you're going to miss the back end of the Orbiter, and you can open your parachute.

So that was what was concluded to be the best compromise of providing the capability, but not tearing the thing up so bad that you caused other problems. I don't think the crews particularly like it, but it's better than not having an option. That is what the configuration of the Orbiter is today for getting the crew out [in flight].

RUSNAK: Were there any other significant changes than the ones you've talked about to this point that were either examined and discarded or in some other way perhaps saved for a later point in time?

ALDRICH: Well, let's see. Of course, one of the big changes, it got to be a job I had a little later, for a long time, there was a lot of emotion about building a new solid rocket booster instead of fixing the one we had, even though these fixes from an engineering sense were quite a thorough approach. A lot of people wanted a new solid rocket booster. In fact, J.R. Thompson was a very strong proponent of that. So we instigated this program called the Advanced Solid Rocket Motor, and it was a contract to Lockheed as the integrator, even though they're not a solid rocket maker, and then Aerojet [General Corp.] was the company that was going to build the rocket itself, the propellants.

We were going to have a great new plant over in Mississippi, just across the line from Alabama. It's about an hour's drive from the Marshall Center in Iuka, Mississippi. That plant was mostly built, created. Making a solid rocket motor plant with all of the things you'd like is a big undertaking. I mean, we were going to pour these things in pits, and there were big protection things that if there was an accident, personnel would always be safe. It was a very elaborate plant, and it was just about completed, and we were about to start manufacturing advanced solid rocket motors when we finally got back to flight with the redesigned solid rocket motor, and you could see it was going to perform well.

So from the time we started to fly again, the support for this very elaborate and expensive advance[d] solid rocket motor started to wane, and it waned and waned and waned to the point where finally in one of the budget years, it was decided not to proceed.

RUSNAK: Since you've mentioned the return to flight, can you share your memories of STS-26 with us?

ALDRICH: In what [manner]?

RUSNAK: The preparation, the building up to that flight, and then the actual mission itself.

ALDRICH: Well, I'm not sure what you want me to talk about.

RUSNAK: Your personal feelings on that and what you were doing at the time, that kind of thing, of the actual mission itself.

ALDRICH: Well, the actual mission was—I mean, I've already talked about it. It didn't happen.

RUSNAK: No, I mean STS-26.

ALDRICH: Oh, STS-26.

RUSNAK: Yes, the return to flight.

ALDRICH: I thought you were talking about the *Challenger*.

RUSNAK: No. Sorry.

ALDRICH: STS-26, you know, we literally worked for years on these changes we've been talking about, and worked very hard because some of them were tough to do, and they took a lot of intensity in terms of reviews and oversight. For a while, it seemed like we'd never get there, you know, because part of what Dick Truly's response to this Rogers Commission and all of the other emotions for this is we were going to do everything with total caution and total care, and everything was going to be perfect.

We wrote down a lot of guidelines and ground rules about what it would take to make this an absolutely the safest flight we could make in terms of what the launch criteria would be. We just set about to do it as perfectly as we could. So it was a long period of time. I think it was two and a half years, something like that. I could probably tell from this.

RUSNAK: Right around thirty months, I think.

ALDRICH: Yes, two and a half years, from January of '86 to September of '88. But then we finally got it all at the Cape, and we got it on the launch pad, and we got it checked out. The night it was supposed to launch, we were in the [launch] control center, and we had a tremendous thunderstorm come through at one or two in the morning, and we thought, "You know, the weather's probably not to make it." So all of the things it took to get to that point, we still aren't going to get to go. At about five in the morning, it cleared, and all of a sudden you could tell that all of the stuff we'd worked on so long was all coming together and was all going to go, and it did. It was absolutely incredible, absolutely incredible.

Then we had this long period. I talked about the conservatism that we set for ourselves, to have everything as careful and right down the middle as possible. But we caused the whole Shuttle Program to be very conservative, and then for years afterwards, after the time I left the program, there was this tremendous feeling of caution and concern and oversight and checks and balances, to the point where the team had a very hard time getting to each flight, because no one wanted anything that looked at all like it might have some issue with it to go untouched. We really built in a tremendous amount of conservatism that I think over some number of years returned to a proper balance for that, but we kind of were overdriven for a long time in terms of everyone being so cautious and conservative.

RUSNAK: Some of the programmatic changes in terms of dropping the Department of Defense flights, not doing the commercial satellites, these kinds of things that we talked before, kind of give the Shuttle a different focus on, like, these science missions and that kind of thing. What impact did that have on things like the flight rate and the preparations for flight, I guess, from a management standpoint?

ALDRICH: Well, I'm not sure how to answer that. Some of the changes we made during the down period and flowing out of the down period, I believe we built another Orbiter preparation facility at the Cape so you could process three Orbiters instead of two at once. We upgrade[d] another crawler so that we would have three crawlers instead of two. We got a second 747 aircraft so we could ferry. I mean, we were thinking in that time frame, post-*Challenger*, after we got back and going, that we could make a flight rate of fourteen flights a year, and some of these changes we made to these preparation facilities and support facilities were tuned to what you would really need to do that. I think the launch pads had to be, not upgraded, but they had big maintenance re-work on the launch pads, and one had been done and one hadn't. So we got both launch pads up. We got more Orbiter preparation capability. We got more crawlers. We got this carrier aircraft; they have a pair of them.

We did something with the solid rocket booster facility, but that might not have been for flight rate so much as doing the assembly in a more careful way. I can't remember what we did there. It was a new building of some magnitude.

So we were thinking that the Shuttle [flight] rate would build, and I don't think we were thinking we'd move back into commercial satellite launches. Nobody thought that was a very good idea. I don't think the DOD wanted to be invited back. They wanted to [be] off on their own.

But we still thought the Shuttle, the scope of what it could do and would do and NASA would want to do, would require these kind of changes in flight rate. Then over time, and this conservatism I talked about in terms of being even more careful with testing and checks and anybody's concerns, we never really built the flight rate up close to that magnitude again, and for a variety of reasons, it's actually less now than it was then, partly because, I think, of what the mission requirements are right now. It certainly could fly a bigger flight rate than we're flying here in 2002 if that's what the nation wanted to do with it.

RUSNAK: Before you moved on to your next position, what sort of interaction did you have with the Space Station Program?

ALDRICH: In the Shuttle period I was in, I really didn't have any interaction with them, because we weren't close enough yet that the two programs had to come together. Dick Truly had both programs under him, and—no, he didn't. Dick Truly had the Shuttle, and there was another program office, another Associate Administrator, [Andrew Stofan], that had the Space Station Freedom. One of Dick's frustrations during that time period was, you did need to work Shuttle and Station together at his level, and he had a co-equal. So some of the things that he felt ought to be done, he couldn't always make happen the way he wanted to make them happen.

When he got to be Administrator, he changed that. He brought in Bill [William B.] Lenoir and gave Bill Lenoir both the Station and the Shuttle, all under the Associate Administrator for Space Flight. So it was the reverse of what I started to say. They really were independent during this time frame of Shuttle recovery. But then later Dick combined them so that one person would have more opportunity to make the two programs fit in a way that was good.

RUSNAK: Why did you then move on from heading the Shuttle Program?

ALDRICH: Well, after we returned to flight, I was the Shuttle Program Director for six flights after—STS-26 was the first one and then five more. That was the time period when Dick brought in Bill Lenoir and put both the Shuttle and the Station under Bill, and I was really of a mind that I would have liked to have been the head of one of those two programs, but they both went under Bill, and so I thought it would be time maybe to move on to do something else.

I talked to both J.R. and Dick about it, and Dick was looking for someone to be the Associate Administrator for the Office of Aeronautics and Space Technology, was the name. It's had a number of names, including a couple while I was there. But it was a long-term office at NASA Headquarters that had been the Headquarters oversight for the aeronautics program for a number of years, and some of the advanced technology for space also was in it. So I was asked if I'd like to do that, and it sounded like something I'd like to do.

So I moved to that office for the next three years. That was 1989 through '91. It wasn't quite three years, I was Associate Administrator for Aeronautics and Space Technology. What that work entailed was primarily the aeronautics programs … [in] NASA. Now, you've heard me talk about my whole career. I hadn't done anything with aeronautics until this point. But I knew a lot of the people, and a lot of work in aeronautics is not that different from space. We were doing several really interesting programs at that time.

One of the programs I worked on was what we called the High-Speed Civil Transport Program. That's sort of code for a supersonic aircraft, like the Concorde. We were building one back at the time of the Concorde—"we" United States—and for several technical reasons, we didn't proceed. One of them was that the engine effluent from a high-speed supersonic transport contributes to deterioration of the ozone layer, and the other was that the sonic boom is a problem flying over land, and if you don't fly the plane [supersonically] over land, you'd only gain half the advantage of the mission of having a supersonic aircraft. So it was considerations like that in the decades prior we stopped working on supersonic transport in the United States.

But when I took over the Aeronautics and Space Technology Office, there was a new program that was called the High-Speed Civil Transport, which was a supersonic transport for commercial airlines, and it was working directly on those two problems I talked about: how can we deal with the sonic boom, and how can we deal with creating an engine that won't damage the environment. It was a great program. It was being done in conjunction with Boeing, and that was in place all the time I was there, these several years I was in the office.

But after that time we, again, moved away from doing a supersonic transport, and that program came to an end. It might reappear. Right now if you read the papers, I read that Boeing's working on a high-speed jetliner that's almost supersonic with some different configurations. So the idea's still around, but this program I was working on was quite an expensive program, and I think people didn't want to go at the end and actually create it.

Another one I was working on in that office is the National Aerospace Plane Program [NASP] with the Department of Defense, and the NASP is kind of like a single-stage-to-orbit spacecraft except it is built on the concept of being air-breathing. So the NASP sits on the runway, and it collects air and makes liquid oxygen out of it to get enough to take off, and then as it starts to fly in the ramjet and in the scramjet mode, it gets its oxygen out of the atmosphere.

This was thought in the mid-eighties on into the early nineties as being perhaps the way the next space transport vehicle would be, and had a lot of support and enthusiasm, but, again, the technical problems caught up with it. It was very hard to do, and it got to be expensive, and the DOD [stopped] wanting to fund it, and so at the time I was in the office, we were working on it, but it also ended.

Another task that Dick Truly asked me to take on in that office was-this was the period following President [George H. W.] Bush's commitment to the Moon-Mars Project, and I was in charge of the planning we were doing and the program for that, out of this Aeronautics and Space Technology [Office]. It's got a name.

RUSNAK: Space Exploration Initiative.

ALDRICH: Space Exploration Initiative. So that was in this office as well, and we didn't get very far beyond the planning … [with] that, but it did involve quite a lot of interaction with organizations and people, and during that time frame I was going around speaking to groups quite a bit about going to Mars and why and what it meant and how we'd do it. So I've got a little stack of speeches at home that we built during that time that were supportive of going to Mars. It seemed like a great thing, but it was unaffordable.

The other thing that that Associate Administrator has the responsibility is the reporting channel for the aeronautics centers of NASA. So I was in charge of Langley Research Center [Hampton, Virginia] and Lewis, now Glenn, Research Center [Cleveland, Ohio], and Ames Research Center [Mountain View, California], and all their facilities, and that all flowed up through me to the Administrator, who was Dick Truly. So … [not a] small part of the job was that interaction, and I spent quite a lot of time working with the Centers on their plans, their programs, their budgets and so forth.

RUSNAK: What kind of priority was being given to aeronautics at this time?

ALDRICH: Well, I was going to say something about that, and then I didn't branch down into it, but these two programs, I particularly mentioned the NASP and High-Speed Civil Transport, were big expensive programs, and the Aeronautics Program had a big budget, and these were kind of far-reaching advanced vehicle programs. They weren't just doing technology; they were working towards a program that would lead to a vehicle.

There was also a lot of other aeronautics programs as well. There was one to improve the civil transports we have today in terms of making them more efficient and quieter. There was a program with the FAA [Federal Aviation Administration] on improving the FAA's capabilities and roles in the national aerospace system. The FAA doesn't really have a research capability like NASA has, and so we had this cooperative arrangement where some of the programs FAA wanted to do were being done at Langley and being done at Ames. It was through my office. So it was quite a robust program in those years. It's been sometime after that when NASA started this reduction in funding for aeronautics and not featuring program[s] of this type so much anymore.

In fact, during this period also, we were building at least one wind tunnel, and I think maybe making plans to upgrade several others. We were investing in more wind tunnel capability, a new tunnel at Ames, and I can't remember the name of it now. So it was a robust aeronautics time frame, and it was good for me because it was all interesting and a whole bunch of new things.

One of the things that happened during this time frame was the United States Air Force decided to no longer keep the SR-71 fleet, and so they shut down the SR-71 program. But they gave NASA, which is my office, three of them, one two-seater and two single-seaters, and a whole building full of spare parts, and a whole tank farm full of the special fuel it flies. So we were the curators of the SR-71 for those years I was there, and then sometime after that, the Air

Force reactivated it again, and I think they've deactivated, but we still have out at Dryden these SR-71s that came at that time frame.

RUSNAK: I think it's been a while … [since] you could have said that NASA's aeronautics program was robust. But actually this may be a good time to pause again since we're running short on tape.

ALDRICH: Okay, that's good for me.

So, to summarize, I really enjoyed this time working in the aeronautics program, even though, as I say, it wasn't really my background. I'm an electrical engineer; I'm not an aeronautical engineer. The things I found there that I managed were things I could relate to. I thought it was a productive time for me to be there, and I certainly enjoyed it a lot.

But in 1991 there was a new office created at NASA Headquarters called the Office of Space Systems Development, OSSD, and I was moved to be the Associate Administrator for Space Systems Development. What Space Systems Development had under it for responsibilities was Space Station Freedom, which now, of course, was all up in Headquarters. Dick Kohrs was the Program Director for Space Station Freedom, and he was at Headquarters, and the whole program team was out in Reston. It finally had been pulled together and was making pretty good progress. So that this new office had Space Station Freedom. It had the advanced solid rocket motor … [that] we talked about…. It was still a program that was going on.

It had a thing that was called the National Launch System. It was a joint program with DOD and involved a lot of the launch industry working on technology improvements in various components in launch vehicles to create a new expendable launch vehicle for use by the DOD and commercially to replace the current expendable launch vehicles that were going on. So we had quite a few NASA programs in support of that through Marshall and other places, and that was in the office, and then a series of smaller technology projects of various kinds across the Centers that were working space technology.

What made this a really interesting job for me, though, had to do with the re-engagement of my career with the Soviets, now Russians, that occurred during this time frame. In the Space Station Freedom program, Dick Kohrs was a very competent manager, and he was right there, and I didn't really need to go in and over-manage him or manage past him in his program, so I didn't get heavily engaged with managing Freedom, other than it's just where he was part of this office that I had.

But there was one project that I did take on that interested me, and it came about in the following way. This was just after the time when the Berlin Wall came down and the Soviet Union came down. There got to be quite a lot of interest in the United States in terms of engaging or exploiting or taking advantage of what we could do with the Russians that might be of benefit to us.

During the same time frame, the Space Station Freedom Program was wanting to create a crew rescue vehicle, and they had initial contracts with both Lockheed and Rockwell to study what we called at that time an ACRV, Advance[d] Crew [Return] Vehicle. But we had the same kind of problems with the Congress at that time frame that we've had in the recent time frame, and that is that nobody really wanted to give us any money to do it. They would give Space Station Freedom the money it needed to do Freedom, but [when] you said, "I want to have a crew rescue vehicle, and that's another so many hundred million dollars," it would never get funded. So we were struggling with—I mean, we thought we ought to have a rescue vehicle for Freedom. We were struggling with how to get one.

Barbara [A.] Mikulski [D-MD], who was the head of our Senate authorization committee, called a hearing in the fall of 1991, and she called Dick Truly and she called Yuri Semenov, who was the head of NPO Energia in Russia in Moscow, and she called a high-level official from the State Department. I think she asked the number one guy, but he sent the guy directly under him.

The purpose of that hearing, and Semenov came over and we had the hearing over in Congress, over in the Russell Building, and her question was, why is it we couldn't use the Soyuz to be a rescue vehicle for Space Station Freedom.

Of course, Semenov thought it was a great idea, and Truly said, "You know, okay, we probably can do that." The State Department guys said, "Well, you know, I don't know." So she kind of lashed out at State and why … [they] wouldn't let us start working this program. So that happened without directly connecting with me.

I think I talked earlier today, and I think also in the last session, about how after Apollo-Soyuz we stopped working with the Russians, but the medical team kept working. The life sciences team kept exchanging data and analyzing human performance in space. So we had a group there at NASA Headquarters that had maintained a contact with the Russian people, and the head of that group was Sam Keller. Sam was in the science organization at NASA Headquarters. I can't remember what his title was at that time. But he had a lot of current experience and engagement with the Soviets, now Russians.

We had this hearing with Mikulski in the fall, September, October sometime, and in January I got a call from Sam Keller. He said he's been asked to go over to Russia and meet with Semenov and his team and talk about this Soyuz thing, and it occurred to him with my background in Apollo-Soyuz and with the Russians, that I'd be a great guy to be part of his team. So I thought it was a great idea, too, and what I did was get a little team of key people in the various system areas from the Johnson Space Center that I knew, people that knew about the propulsion systems and knew about the life support systems, and so forth, somebody from the crew. I'm not sure the first trip we had somebody from the crew, but we added a crew group to it later. We took about seven or eight people. We went over, and we had a meeting in Moscow.

Now, during Apollo-Soyuz when we would go and meet with the Russians in Moscow, with the Soviets in Moscow, we would always [meet] in some rented facility downtown, and they would say they were from the "Soviet Academy of Sciences." That's who we thought they were. We didn't know where they actually made things. Even when we sent our docking system over to be tested with theirs in a test facility, it was some rented facility downtown that we went to.

Well, the day we arrived in 1992, Sam Keller and I and this team of Johnson spacecraft engineers, we were driven straight out to Kaliningrad, to this place, huge factory, huge brick wall around it, great gate, through the gate and up and right into the office that used to be Sergei Korolev. But these people that we went and met there are all the same people we worked with back in the early seventies, the same people, but now we know they're NPO Energia. We know where they hang out, what their place is, and we started these discussions about what you could do with the Soyuz.

It became obvious to us almost immediately that there's no reason, if you fix the docking mechanism, you couldn't use the Soyuz for a rescue vehicle. But we didn't treat it lightly. We reviewed each system and what their criteria was and [what] we'd have to do and how it would work. It was a several-day review over there at Energia.

The only problem we found that would be a limitation was that the Soyuz, like our capsules, has one propulsion system when it's in orbit, but when they drop the service module part off and just bring in the reentry part, it has another little attitude control system, and that attitude control system on the reentry part of the Soyuz uses a monopropellant, hydrazine. Hydrazine you can only store for so long, and it starts to deteriorate, particularly if there's any kind of contamination at all. Over some period of time you may not have as good hydrazine as you want to have. So their limit on the length of time they could … [leave a] Soyuz in space was six months. So we were making quite a lot of progress on how we could change that system to put in a bi-propellant or some other propellant and make the Soyuz stay longer. I'll talk some more about that, and we never made that change.

The current Soyuz that's the rescue vehicle on the International Space Station is an unmodified Soyuz and has to come home every six months to be replaced. So we didn't get to make that change. There weren't any other significant changes to be made to the Soyuz.

We had a series of meetings over the next couple of years to work the details of providing this rescue vehicle, and it was very successful.

But some other interesting things happened during this time frame also. When we were there, now we're at Energia … [in] their big factory buildings and things, and they took us down to this mockup area, and in the mockup area was a Buran spacecraft sitting there, and it's a mockup of a Buran, but it's a full-size Buran. Up until that time period, we were still debating what kind of a mechanism we were going to use to dock the Shuttle to the Space Station Freedom. There were various concepts about what to do. The Shuttle didn't have a docking capability in its early years. It wasn't until the Space Station came along that it needed one, and that design hadn't been firmed up.

Well, these Russian[s], Yuri Semenov, Viktor [P.] Legostayev, took us down and showed us this Buran. The payload bay is configured exactly to a Shuttle payload bay, the same kind of rails, the same dimensions, the same latches. So any payload that could have flown on the Shuttle could fit in the Buran bay. And on those rails there's this airlock sitting, attached to the back of crew cabin, pointed up at a docking mechanism on top, exactly what the Shuttle needed to dock with the Space Station, except we hadn't committed to do it yet. They've got it built. It's sitting there.

So this was also the same time period when Dan [Daniel S.] Goldin replaced Dick Truly, and this was probably, I don't know, the second or third trip over. They didn't show us this the first time, but I think after we started talking to them more and talking beyond Soyuz about other things that they might contribute to a Space Station program, they decided [to show] this to us. So I had pictures of it.

When we got back, Dan Goldin had been moved in. I wasn't reporting to Truly anymore, and I went in and told Goldin. I said, "Look at this thing that they've got."

Well, that caused a great uproar of activity, and Rockwell got sent over to look at it and see why it is we couldn't use theirs [Energia's]. Well, I think what Rockwell decided was that it was too heavy or they could make one that was a better fit rather than just take the one the Russians already had. But they created exactly the same thing, exactly the same thing, and that led to the docking mechanism that went on the Shuttle that was used—the airlock tunnel and the mechanism-that was to Mir, Shuttle-Mir, and now for the International Space Station, and it came directly out of the NPO Energia mockup area. We … [might have picked] the same thing after we decided, but we were having these technical debates about different ways to do that and, you know, there was no forcing function. We hadn't decided which way we were going to go, and this forced it. So that was a very interesting thing.

We had other discussions during that time period with Semenov and the team about other things that they might have that could work on Station. But I didn't even get to the point where that happened, because we redesigned the whole thing [Space Station] after a short time later.

Another job I had in this Office of Space Systems Development was, we were still talking about wanting another launch system. I talked a little while about Shuttle C would be a way to lift very heavy cargoes and use the Shuttle. We'd talked about ways you could upgrade the Shuttle itself, and we were talking about other things.

We wanted to have a different launch system for two reasons. One reason was that we were already seeing that with the expense that the Shuttle system is and the expense the Station was going to be, too much of the NASA budget was encumbered in these [two] programs, and it was limiting what NASA could do. So we really wanted a new system that was a lot less expensive to deliver payloads to orbit, and we set as a goal a ten-time reduction in the cost of a pound of weight to orbit. I had those discussions with Dan Goldin and with Mike Griffin, who was now in our office and I was working with him, not in my office but in Goldin's set of managers.

So I got asked to lead a study to define an alternate launch system to the Shuttle that would have the same capabilities of performance but would be ten times less cost of payload to orbit. I put together three teams. I put together two teams at Marshall. One of them looked at these expendable launch vehicles that were in use and this new National Launch System we were talking about building, and their role was to define what you might create with that type of hardware. You might put a little airplane or a cargo [carrier], a little spacecraft or a capsule on top, but you'd use these expendable launch vehicles or maybe they'd be partly recoverable, partly reusable.

The second team was to look at a single vehicle that was like the NASP, but was rocketed and [didn't] have this air-breathing thing to it, and it was called a single-stage-to-orbit vehicle. That was a team at Marshall also.

The third team was here at Johnson, and they were to look at the Space Shuttle and what changes you could make to it to have a ten-time reduction in cost of launching a payload.

These teams worked for three or four months. They were big teams. They worked these things in a lot of depth. They worked not only the different configurations you might have in those three categories, but what the costs would be and then what the end performance would be. They all came together with their pieces of this study, and we produced a fairly elaborate report that's got the three studies in it and the recommendations.

The recommendations were that either going down the Shuttle path, you can improve a lot of things but you can't make it ten times cheaper, and with these expendable vehicles the same thing. Too much of that gets thrown away and has to be replaced. You don't meet the financial goal that way either. Even if you have two fully reusable pieces in a two-stage vehicle, you don't get the financial return.

The way you get the return is this single-stage-to-orbit vehicle, and we recommended NASA move out with the program to develop a single-stage-to-orbit vehicle. That's what the report says. The report's still around. People used it up until a few years ago. Now we've gone past that time frame.

So this is interesting because it has another interconnection with these Russians. One of the things that we were doing to make the single-stage-to-orbit concept work was to have a different kind of engine. Of course, it'd be a reusable engine, but people that work on launch systems and propellants often endorse the idea that a liquid oxygen-kerosene engine is good for a first stage, performing down in the atmosphere, and a liquid oxygen-liquid hydrogen [engine] is good for an upper stage that performs in space. So here we had this little single-stage-to-orbit vehicle, and we wanted to have liquid oxygen-liquid hydrogen, but that's not optimum for the first phase of the flight.

So we were talking about building an engine that was a tri-propellant engine, and this single engine would take kerosene during the early time period, and then it would blend and flow with liquid hydrogen and use liquid hydrogen on the upper stage.

We want to do a test program with that, so at some point we got into a discussion of the Russian technology in engines. What they've actually done over these years that we were so enamored with the Space Shuttle engine and we went to oxygen-hydrogen, they've continued to build more modern versions of kerosene-oxygen engines, and they're very good, very high-performing engines, and they have a capability that we had not perfected in the United States, which is to burn oxygen-rich. I can't tell you in a propulsion sense why that's better, but it creates a higher-performing engine, and it's hard to do because if it's oxygen-rich, you have the risk of an explosion if you don't do it right, and they had developed materials and coatings that allow them to run oxygen-rich and have these very excellent engines.

The company that builds those engines is called NPO Energomash, and they're in Khimky, Russia, just outside of Moscow, and they built a modern version of these high-performing kerosene engines for the Energia vehicle that flew the Buran and also could fly with other payloads. You could fly either the Buran as a cargo or a cargo package. There's four strap-ons on the Energia, and each strap-on has … [one] of these RD-170 kerosene-oxygen engines that are new and modern and high-performing, that are built at Energomash.

Well, somehow we got onto the thread of talking to NPO Energomash about using their technology to create one of these tri-propellant engines where we can do kerosene and we could do hydrogen, so we went over to visit and talk to them about that, and with Marshall, and we actually got a little program framed up about doing a test program with a tri-propellant engine. In fact, they had a full-size mockup of what it would be, and they also had a test article under way.

We did that in conjunction with Pratt & Whitney because at some earlier time frame Pratt had gotten over there after the Soviet Union had ceased to exist and had worked a deal with Energomash that they would have all rights on this Energomash RD-170 engine. So if somebody else wanted it, they'd have to buy from Pratt & Whitney.

So we had this little team go over. We had Pratt, we had Marshall, we had a few people in my office there at Headquarters, and we were working this tri-propellant engine with Energomash.

However, given my national launch system job, I'd also been talking to all of the rocket and rocket engine contractors in the United States about what they had and what they could do [to create a lower cost, higher performing system]. One of the people that I'd had in and we'd talked to were the Atlas people, General Dynamics in San Diego. I'd had them in, and we had talked about re-engining the Atlas, because it didn't have an optimum engine system. It had a 1950s configuration engine system, and you could easily see ways that you could upgrade the Atlas and the Atlas-Centaur to make it a better performing vehicle, and I was looking for things we could do in all camps.

Well, when I got over to Energomash to talk about the tri-propellant, we also talked about their RD-170 as it exists, and we got into these discussions about why you couldn't put—the RD-170 has four valves with a single thrust chamber, and we got into these discussions why you couldn't—it's too big to go under an Atlas, but you could cut it in half and you could put half an RD-170, which became an RD-180, under the Atlas, and it's the perfect engine, perfect engine for that vehicle. That didn't happen during my time frame here, nor did we get to the end of the tri-propellant program. But that caused me to get really re-engaged with Energomash, as well as Energia.

The other thing we saw down in the mockup area at Energia was one of these RD-170 engines that Energomash had made, and Energia was making the electromechanical actuators on it, and they were running simulations in their lab with this big engine system and their actuators, and so I got all wrapped up with both of those companies and these propulsion initiatives, these transportation initiatives we were working.

So this was also the time frame I was meeting a lot with Dan Goldin. I found this docking thing and brought it to him, but he was also wanting to make changes to the Space Station Freedom. Initially he didn't like the big solar arrays, and he wanted to make something that looked more streamlined, and so we looked at a lot of concepts. There was a one concept where we could have made a station out of Orbiter, just modified it in certain ways and it could have stayed up for some period of time. I was working these things as head of this Space Systems Development Office. But he also had other people he was calling in to look Station designs. Langley had some designs. Almost from the beginning he was wanting to change Freedom and maybe the Clinton administration wanted to change Freedom anyway. It may not have been that he was so technically unhappy about it. But that's one of the things … [we] started right on.

I had some ideas that were in my head. One of them was that I thought the Space Station should fly at a higher inclination. The Freedom flight plan was to fly due east out of the Cape at twenty-eight and a half degrees [inclination]. So it would fly over things that are as high a latitude as Florida but no higher. A number of the launch sites in the other parts of the world are at much higher inclinations. It makes it very hard for them come down to a Freedom orbit. So if you wanted to launch [to] the Space Station Freedom, say, from Baikonur, it would take a very large vehicle and be very inefficient. The other launch [sites] in China and Japan, the same story. We didn't know at that time, things might fly out of there. But it seemed to me with the Space Station, it was international, it was going to be permanent, it would make much [more] sense to be accessible from launch sites anywhere in the world and to overfly much more of the populated part of the world on a regular basis.

So I … [recommended] to Goldin that he change the inclination of the Space Station to 51.6 [51.2 degrees], I think is what Baikonur's at, and, in fact, I don't know who else might have been recommending it to him, but he made that change. Created a big problem. The Shuttle is most efficient, or any launch vehicle is, when you fly due east, and if you fly at a higher inclination, it takes more propellant to deliver the same cargo. So [we] now … [had] created a deal where the Space Shuttle, as it existed, couldn't fly the missions to Space Station with the heaviest cargoes, because it was now going to be at 51.6 [51.2].

So the next task I got was how could we upgrade the Space Shuttle for more performance. We looked at additional engines, re-engining schemes in some regard, putting engines under the tank. Out of all those studies, there was one change that was most clear that it was something we could do and something that the program could accommodate, and it would give us an additional eight or ten thousand pounds [payload capability], which is just about what we lost on the inclination change, and that was to change the material that the external tank is made out of, and that's what I recommended to Dan, to change it from aluminum to aluminum-lithium, which is a metal that's hard to work and we didn't have huge amounts of experience with it in that time.

Marshall had done some studies on how to weld it and how to repair it and things you have to do when you build the tank, and over a six-month period of time, Marshall got comfortable enough to say, yes, they could buy into that. So that's what I recommended to Goldin, and that's what we've done. The tank is now aluminum-lithium for most flights, and now I don't know if they still make any that are aluminum, but they could.

So that change … [was] something that happened in this time frame also, while I was working with all these propulsion people. My report that looked at replacements for the Shuttle said single-stage-to-orbit is the way to go, and Marshall studied that for another year after I left. But that report led to the instigation of the X-33 out in Palmdale [California] with Lockheed that has since—it didn't make it, but it was the evolution of all the thinking that was going on during this time frame I'm talking about.

Two other stories about Russia during this time frame. By coincidence, I work for Lockheed Martin now, and these two stories relate to this time frame in Russia and Lockheed Martin.

While I was over there during these visits talking about making the Soyuz a rescue vehicle, I met an old friend of mine in the hotel lobby that we stayed in, the Radisson Hotel. It's called the Slavjanskaya, and it was a good place in that time frame in Moscow to stay. This fellow Frank Martin that used to work for NASA up at Goddard was now a Lockheed employee out in Sunnyvale, I met him the lobby at this hotel in Russia, and he said he'd been asked to come over and look at their Proton production facility at Khrunichev, another company in Russia…. So we talked about that, and he was going the next day.

Well, the next day when he got back, his eyes were this big. He said, "I went to this factory, and they had all these huge rockets, and they're just out there. They just build them out there in this factory, and there were cats running up and down the aisles, but they had these tremendous launch vehicles." So he went home and reported that in, and it was not many months later that Lockheed Martin formed this International Launch Services company with

Khrunichev to market the Proton internationally. That's now one of the principal launch vehicles that's in the Lockheed Martin suite. The International Launch Services offers both Proton and Atlas launch vehicles, and if one of them gets delayed for some reason, you can go on either one. So that became an initiative that Lockheed Martin happened to capture right in the same time frame I'm talking about.

The second one is, I told you about General Dynamics recognizing that the Atlas could be upgraded to be a more effective vehicle. Well, in the next year or so after that, Lockheed Martin bought the Atlas business from General Dynamics in San Diego and moved it to Denver. They started manufacturing Atlas vehicles in Denver, and not long after that, the Department of Defense decided to create two new heavy-lift launch vehicles, one with Boeing and one with Lockheed. The Boeing vehicle is called the Delta IV, and the Lockheed vehicle is called the Atlas V, and what the Atlas V is, is an upgraded version of the Atlas. The old Atlas has a very flexible set of tanks. They can't stand under their own weight unless they're pressurized. The new Atlas V has a rigid tank structure so it can be transported horizontally. It can be raised vertically, and it doesn't have to have a pressurization system with it all the time.

But the big change is the engine on the Atlas V. It is half of the RD-170 Energomash engine that we were over there a few years before talking about the ideal fit, to put it on the Atlas through Pratt & Whitney, and Lockheed has put it on the Atlas, it's going to have its first flight here within a month, and they got the RD-180 engine through Pratt & Whitney, which is built in Energomash.

So the last three years of my NASA career was heavily re-engaged with the former Soviet Union, the Russians, the ones that I had known from years past, and it was directly related to the technical interest areas that I was trying work in the United States in any regard, and it was a really very interesting period. I enjoyed it tremendously, doing all that.

RUSNAK: It sounds like you had quite a number of different projects going on at that time.

ALDRICH: Well, you know, there's only half a dozen Associate Administrators at NASA Headquarters, so each one has a series of major programs under them, and I didn't do all this work myself, but I pulled on mostly Marshall and Johnson in this time frame and the aeronautic centers in the previous job I had. But you can get down into the details quite nicely, and we certainly did with going back to Russia. We'd gotten a lot going on.

You asked me over the phone about my role in Crystal City when we redesigned the International Space Station, and I really didn't participate in that. All of these thing[s] I've just talked about are the last things I worked on, and I was still there when some of this redesign at Crystal City started, but there was a whole new team of people. My office was left to keep Space Station Freedom on track and going until we decided to move to something different. So I didn't really get engaged in the redesign.

RUSNAK: Interesting that you got the Space Station Program without the Space Shuttle Program, whereas previously you said that they had consolidated those two under a single Associate Administrator.

ALDRICH: They did, but then they broke them out again. It's a lot like this thing about whether you ought to manage programs from Washington or from Centers. You know, there's good arguments to both and whichever one looks like it's not working very well, well, they'll say, "Well, the other one will fix it," and that goes through cycles.

RUSNAK: Were there any other projects from that time period before you left NASA that you want to cover before we wrap things up today?

ALDRICH: I don't think so. I think I've just about hit all of this. Oh, I did want to say a little more about the X-33. After I turned in that report that recommended that we try to build a single-stage … orbit vehicle, NASA studied it for another year in terms of what it could be and how feasible was it. I was gone, but then they moved into instigating the X-33 project. I was working at Lockheed, and Lockheed happened to win the X-33 program, and so my very next job was, I was moved back to our headquarters for Lockheed Martin, which is in Washington, and the director of the X-33 Program was T.K. Mattingly, who had been brought in by Lockheed to run that program, and T.K. asked me to come and be his deputy on the X-33 program, and I spent the next year and a half working on the X-33 for Lockheed, out at Palmdale and back, which was a direct flow-out from these things that had begun in the early nineties that I was talking about.

RUSNAK: It's only, I guess, somewhat relatively recently that that program came to a conclusion that wasn't perhaps, I guess, the intended one.

ALDRICH: Well, it had technical problems and it had funding and political problems. The first few months that T.K. and I were working on that program, we went out and reviewed it, and our conclusion [was] that it never did start with enough funding to do all the things it had to do, and we predicted many of the difficulties that did happen later. We predicted that that's kind of the way it would flow, because while it sounded like a lot of money, it was a billion-dollar program, building a brand-new single-stage-to-orbit launch vehicle was bigger than a billion-dollar problem, even you're just building a prototype.

RUSNAK: I'm sure you discovered that with the National Aerospace Plane, too.

ALDRICH: Well, the same problem. Some of these things, we have grand ideas, but we want to fund them in a more digestible manner than probably what it takes.

RUSNAK: I'm looking over my list of questions, and we've covered most of the topics that I had planned for today. I did want to check with Sandra and Rebecca if they had any questions for you that they've come up with.

WRIGHT: I think you've covered my questions.

RUSNAK: Okay. Looking back on your career as a whole, are there any particular moments or specific jobs that you really recall as the highlights of all your years at NASA?

ALDRICH: These jobs were all so marvelous that, you know, you couldn't downplay any one of them. I tell people I worked for NASA for thirty-five years and I enjoyed it every single minute. It was really wonderful. The ones that I feel like I made the most contribution to are these Shuttle years that I talked about today. I was so heavily involved with what the Shuttle was and how it came to be and the things that went on with it, that I just had a great experience with that.

RUSNAK: We appreciate your contribution to the space program and to our project here over the last interview and this one. But I want to give you the opportunity to make any final remarks before we close today.

ALDRICH: No, I think that, what I just said, is probably my final remark.

RUSNAK: Okay. Thank you very much.

ALDRICH: Great. Thanks.

[End of interview]