JOHNSON SPACE CENTER ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is March 20, 2012. This interview with Bill Readdy is being conducted in Washington, D.C. for the Johnson Space Center Oral History Project. The interviewer is Rebecca Wright, assisted by Jennifer Ross-Nazzal. How did you become interested in becoming an astronaut?

READDY: How I became interested in being an astronaut—when I was in elementary school, there was no such thing as astronauts of course. Starting out, John [H.] Glenn's flight—I was about nine years. Up to that point though, we were around airplanes, and there was a geography book that they used in school that was the story of an airline pilot and his son that flew around to all kinds of exotic places. That got me interested in geography and maps and flying, and we knew lots of fliers. My dad was a flier in Korea in the [U.S.] Navy, so aviation was something that always interested me.

In the early '60s, all of a sudden there's the Space Age. Not just the Sputnik orbiting piece of metal up there, but people, and that got me very very interested. I kept on following that, and when I was in high school we landed on the Moon. Then we landed on the Moon a few more times and then did the Skylab and Apollo-Soyuz [Test Project] as I was going through college. Then I was an aviator in the Navy, flying off aircraft carriers, and then a test pilot. Lo and behold, while I'm in test pilot school is when they started asking for volunteers for the Space

Shuttle program, so I went down and interviewed. It was when they picked the '84 group, so that probably would have been 1983.

As a student test pilot they took us on a field trip to Edwards [Air Force Base], California, to what used to be the General Dynamics [Corporation] Fort Worth [Texas] fighter factory where they built F-16s [aircraft]. And we stopped in St. Louis [Missouri] and visited McDonnell Douglas [Corporation], but we also stopped at the Johnson Space Center. This was before STS-1, and one of the places we went was the old WETF [Weightless Environment Training Facility]. Captain John [W. Young] and Captain [Robert L.] "Crip" [Crippen] were in the WETF practicing closing payload bay doors for STS-1.

When they got done with that, they had us all out to the Gilruth [Center], and we had a keg of beer and had a chance to talk to them and all the other astronauts there that were training and supporting STS-1. If anybody was ever trying to set the hook, that's what did it. I was pretty pleased with myself, you know. I was a Navy test pilot and flew the most modern airplanes that there were and thought that was pretty cool. But all of sudden, I mean, I was really really hooked.

First time through, Mike [Michael J.] McCulley was one of my instructors at test pilot school, and I went down there and interviewed. He was the one that got picked, and I figured they made the right choice. I still needed a few more years of flying experience. Then fast forward, I wound up getting picked in the '87 group.

A little footnote—there was an '85 group and then an '86 group that, after *Challenger* [STS 51-L accident] happened, basically went away. There was no '86 selection. There were several of us that had interviewed for that, and we got invited down to Houston to work in different support jobs until the next astronaut selection. The support jobs were all related to return to flight after *Challenger*.

The job that I had out at Aircraft Ops [operations] was to procure and modify another [Boeing] 747 Shuttle Carrier Aircraft, because the Rogers Commission [Presidential Commission on the Space Shuttle *Challenger* Accident], in all their different analyses of the program—not just simply the causal factors in the accident, but the entire program from end to end—highlighted the fact that likely as not, there were going to be about 50-50 landings in Edwards and in Florida [NASA Kennedy Space Center], and the single point failure in the system was the carrier aircraft.

If the carrier aircraft was broken, you might have a number of your orbiters out there at Edwards waiting for a ride home, and of course that wasn't possible. We went through a long involved selection process, and, surprise surprise, at the end of it turned out to be another 747. Getting that all put together also gave us an opportunity to upgrade the existing Shuttle carrier airplane with better engines. Fortunately we did, because we lost an engine later on in the ferry program, and because we'd upgraded the airplane it had enough thrust to fly away.

It was quite an education. The modifications were beyond just what you see on the outside. It was a very involved structural modification with all the truss structure and everything else. You want to empty the airplane as best you can so that you can support all that weight, but then you find out that because of where the orbiter's located on it, on the back of it and fairly far aft, that you need to keep the airplane in balance. We used to fly with baggage containers of pea gravel in all our ground support equipment in the forward cargo bay of the 747. The Space Shuttle, weighing only about 220,000 pounds, and fuel on the airplane was less typically than a 747 full of passengers and bags would take off with.

It was interesting learning about all the differences. With the Shuttle on the back of it, you had to not fly through visible moisture. You had to fly much slower than the 747 normally would have, and you had to fly lower because you didn't want to get up above freezing level because of all the fluids in the Space Shuttle. Planning for the Shuttle to do the ferry operation was something that was very very involved. I had a chance to be part of that, setting up for STS-26 [return to flight mission].

WRIGHT: Can you share a few more details about your actual role?

READDY: I was the program manager at Ellington [Field, Houston].

WRIGHT: Did you know you were going to be the manager when you came down?

READDY: I had a hint. They said there were a number of projects that needed doing and that while I was down there I would qualify as an instructor pilot, research pilot, and I would have a program manager job for something. It kind of popped out that that was the one that needed doing right now. I had a chance to fly on the airplane a couple times, but by that time I was already interviewed and on my way out the door, so I had that job in addition to the astronaut candidate training for a while.

Then Dave [David H.] Finney, who became the director at Aircraft Ops at one point, came and relieved me. He was the one that completed the project and got a chance to sign the DD-250 [form to transfer ownership to NASA] and cut the ribbon. While it was being modified it was interesting, because that was the same time they were building the first 747 Air Force One for President [Ronald W.] Reagan's trip home. That's the airplane that they're still flying. The work was done in Wichita, Kansas, so the airplanes were side by side. You've got the Shuttle carrier and the President carrier.

WRIGHT: Did you see the two of them together?

READDY: Yes. The Shuttle carrier airplane was my project job there. Then when I went to the Astronaut Office I was working on subsystems redesign before return to flight. The most problematic subsystem at the time, as I recall, was the Shuttle APU, auxiliary power unit. They'd had a number of problems with the controllers. They had, I think, on a couple flights malfunctions of the APU. It's fueled with hydrazine, which is a really nasty material.

Hydrazine itself, besides being very toxic, also has a very unusual property. When water freezes, what happens? It expands. That's how pipes burst in houses. You've got residual water in there, it freezes, it expands, it bursts the pipes. Then when the water melts, the leaks happen. Hydrazine, when it gets colder, shrinks instead of expanding. Then more hydrazine goes past it, and so you build up this core of frozen hydrazine. When it warms up, it starts to expand. As it expands and warms up, that sets the stage for an explosion and a pipe rupture.

The care and feeding of the APUs with the hydrazine was a fairly major thing, and we were very concerned about leaks and making sure the lines stayed heated properly. I got a chance to spend a lot of time up in Rockford, Illinois, which is where Sundstrand [Corporation] was. They built not only the APUs—there are three of those on the Space Shuttle—but also the HPUs [hydraulic power units], which is the version that's on the solid rocket boosters [SRBs].

Each solid rocket booster has two of those for redundancy, and they cause the nozzle to swivel on the solid rockets. You have two HPUs on each SRB and three on the Shuttle. That's a lot of hardware. The Shuttle hardware was pampered a little bit more because of the environment. The other stuff crashed into the ocean, and [after] the parachute recovery had to be cleaned and refurbished every single flight before they could go fly again.

That seemed to be the one that occupied most of my time. I was still involved in supporting the Shuttle subsystems when *Discovery* was due to launch with the Hubble Space Telescope. Kathy [Kathryn D.] Sullivan, Bruce McCandless [II], and Steve [Steven A.] Hawley were on that crew. One of the APUs wouldn't govern the speed properly when they got it started up at T -minus-five minutes, so they had to scrub for the day.

We took the APU controller and threw it in the back of a T-38 [aircraft], and I went from Kennedy Space Center up to Rockford, Illinois. Had all kinds of people surround the airplane when we got there. They wanted to make sure exactly what went wrong with it, and found the problem. In the meantime, at the Cape [Canaveral] they swapped out the APU controller box and away they went.

WRIGHT: What else did you do for STS-26 on the return to flight? Were you at the launch that day, or were you supporting?

READDY: The way the flight control was organized, there's the Flight Control Room, the FCR, the Mission Control [Center], and there are backrooms for each of specialties and different consoles. Then there's another room where the subsystem managers and their contractors [sit], and all the phone lines to reach the equipment builders, wherever they happened to be, [are].

That was called the MER, the Mission Evaluation Room. Because I worked on all the subsystems, that's where I spent most of my time, in the MER with the subsystem managers.

Although APU was the one that seemed to be the most aggravating at the time, there was another subsystem that seemed to occupy a lot of our time and that was the fuel cells. Early on we'd had some fuel cell issues. Those two were the biggies.

WRIGHT: At what point did you learn that you would be assigned to STS-42?

READDY: Well, STS-42 slipped around a bunch, so—gosh, I don't know. There's probably a press release in there someplace. Honestly, I don't recall.

The other job that I had after the subsystem job—one of the outcomes of the Rogers Commission was to build a replacement for *Challenger*, so Bruce [E.] Melnick and I were the two astronaut reps [representatives] to do what became the *Endeavour*. They started building that out of what were known as the structural spares that existed in Downey [California] and Palmdale [California], and then populated with all kinds of other subsystem components.

We were there for all the program reviews and the integration tests, saw it from being built up as a forward fuselage, then an empennage, and a set of wings, to being built and then tested and delivered from Palmdale to the Cape. We were involved in what was originally the OV [Orbiter Vehicle]-105 [*Endeavour*]. That was its name, then I think the schoolchildren of America named it the *Endeavour* with an "o-u-r" after the sailing ship of Captain James Cook.

That spanned that timeframe. We used to spend most of our time out in Downey or Palmdale, but I was back in Houston for something. After one of the Monday morning meetings—I think [Daniel C.] Brandenstein was the chief of the office at the time—he asked

[Stephen S.] Oswald and I to go over to Building 1. At the time there was a project ongoing called the Long Duration Orbiter [LDO]. The idea was to look at all the subsystems and the stowage on the orbiter and see if you could go 14 or 28 days with the existing Space Shuttle.

As I recall, the Space Station plan had been stretching out and stretching out. At this point we hadn't gotten to where Space Station was redesigned and the Russian elements were brought in and Shuttle-Mir started. Oswald was working on one part of that and I was working on the other part of it. We figured for sure we were going over to Building 1 to go present to management over there, and our immediate management over in Building 1 was Mr. [George W.S.] Abbey. Actually, I think the timing was such that it might have been [Donald R.] Puddy who was the FCOD [Flight Crew Operations Directorate] director at the time, about 1990.

Oswald and I are trundling on over to Building 1, have no idea what we're going over there for, and then went up to the FCOD office. They pushed this press release in front of us and said, "You have any problem with that?" I had to read it three or four times before I realized what it was. I saw Oswald's name on there, but my name didn't pop out, and I thought, "Well, congratulations. That's great." "Well buddy, you're going too."

Then we got involved in training, and gosh, we moved from one orbiter to another orbiter to another orbiter. We were on *Columbia* first, then *Atlantis,* and then *Discovery,* and the launch date moved around quite a bit. The silver lining for us, though, was originally it was a due east flight, 28-and-a-half-degree flight, and it was one of the longer laboratory flights. It was the first microgravity laboratory flight with international participation.

On the crew we had a Canadian, Roberta [L.] Bondar, and we had a German, Ulf [D.] Merbold. So we had the Canadian Space Agency, we had ESA [European Space Agency], and we had a whole bunch of experiments from what was NASDA [National Space Development

Agency], became JAXA [Japan Aerospace Exploration Agency], the Japanese space agency. This was before the Russians were onboard. I don't remember any kind of contribution from them.

The flight moved all around. As a result of going from *Columbia*, which was the queen of the fleet, the oldest but also the heaviest, to *Discovery*, we were able to go to an inclined orbit of 57 degrees instead. If you think about what girdles the Earth, it's pretty much water. Right around the equator, plus or minus, there's lots and lots and lots of water. You start to tip that a little bit, you go from 57 degrees north to 57 degrees south every orbit, and you're high enough that you're seeing 1,500 miles either direction.

You're seeing the upper part of Alaska, the Aleutian chain. South you can kind of see the Antarctic. You're going over New Zealand, Australia, all that and well south into South Africa and Tierra del Fuego. From an Earth observation standpoint, it made the flight much, much more interesting. Of course, the downside was you're supposed to spend most of your time in the laboratory, not looking out the window.

It was a great flight, great crew. Worth waiting for, and it kind of spoiled me because we walked out on that January day and waited a little bit for some of the ground fog to clear and launched, which was not to be the case on STS-51.

WRIGHT: But what knowledge you walked out with. You had so many days of seeing the inside of the Shuttle, you knew your spacecraft. And you also went as a mission specialist on your first flight.

READDY: Well, the reason they did that was there were several of us—Don [Donald R.] McMonagle, Ken [Kenneth D.] Bowersox, and I—I guess we were the top three in the class, and they wanted to fly us sooner rather than have to wait. At the time, it looked like the wait was a really big one because they weren't flying any commanders on their second flight. The line was pretty long to get into the pilot's seat, and so they figured we'll kind of jumpstart the process and they started the three of us as mission specialists. Then we got on our crews and started training.

It wasn't too much longer after that they changed the rotation for who got to sit in the commander's seat. That kind of opened up the floodgates, and then a number of my contemporaries wound up getting assigned as pilots on their first flights. The other thing they did—you're the flight engineer but you're also the third pilot. They were 24-hour flights, two-shift flights, and you needed to have a pilot on the other shift. They tended to keep the pilot and the commander on the same shift, so that meant that you had to have somebody else that was schooled in all the orbiter systems and piloting tasks on the other shift. There are no bad flights, there are no bad seats.

WRIGHT: And an interesting crew for this one, because you mentioned the international partners and the micro laboratory.

READDY: Yes. A lot of the science was sponsored by the Canadian Space Agency, so we made a number of trips to Canada, to various laboratories and universities, to try and understand their science. And not just the science—a basic understanding of that, but also being able to take apart the laboratory equipment that was flying with you and reassemble it and fix it if it broke.

That was good training because we had to do a number of that kind of thing while we were up there.

We did one trip over to Noordwijk [the Netherlands], which is where the European Space Agency had their experiment development [European Space Research and Technology Centre (ESTEC)]. Then we went also to Cologne [Germany], where they had their Astronaut Centre. We did quite a bit of traveling, quite a bit of training, and the flight had slipped enough that we had plenty of time to absorb it.

The Spacelab itself was built by the Europeans up in Bremen, Germany, so it was a little different than the Space Shuttle. The systems integrated with the Space Shuttle, but they were different systems. The software architecture was different. The displays were different. A lot of the nomenclature was different. That took a little while to learn, but it was a magnificent facility. Big as a school bus, shirt-sleeve environment, just a fabulous facility.

WRIGHT: As you mentioned, it worked ‘round the clock.

READDY: Yes. We had a couple things that they called middeck experiments—pulled them out of a middeck locker typically, and deploy them and do them there—but the vast majority of things were done back in the laboratory with a couple of the mission specialists and payload specialists. It had a rotating chair and accelerating sled and a whole bunch of other things.

A lot of interest in what happened to the human vestibular system once you got up in orbit. That involves not only the tilt organ, the otolith, but also the semicircular canals. They want to be able to isolate some of those things, so they rotate you very slowly in a chair so that there's equilibrium in those semicircular canals and then they have you tilt your head, move this and move that.

You could do the same kind of thing on the ground except there's always that one vector, the gravity vector, that informs your otolith, the tilt organ, what's going on. So you subtract that. Well, that same organ also gives you linear acceleration. They had a sled, and they would run an astronaut up and down on the sled back and forth. That would give no rotation, just linear acceleration. They turned the chair on the sled sideways, so you could get not only the longitudinal acceleration but also the lateral acceleration. It was very interesting, the whole thing.

You had to learn a little bit about all that, but fortunately we had one physician onboard. Roberta Bondar was a physician as well as a scientist. Ulf Merbold was a German scientist, but his specialization didn't have much to do with the human body. I think he's a physicist. Norm [Norman E.] Thagard was an electrical engineer and medical doctor and a Marine fighter pilot. Dave [David C.] Hilmers was a Marine backseater and all-around smart guy. He could learn anything—and had to because during our training [Manley Lanier] "Sonny" Carter, who was originally a member of the crew, was killed, so Dave Hilmers got tapped to step in and be his replacement. He just never missed a beat. He was amazing. You couldn't throw too much information at him. I mean, the guy's just a sponge and able to absorb it all and then somehow figure out how to process it and spit it back to you. An amazing guy.

WRIGHT: Sounds like a great crew.

READDY: It was. It was a great crew and led by a great guy, Ron [Ronald J.] Grabe, who was really just terrific.

WRIGHT: It's great you had that type of a mission. Within the following year, you were assigned already to another mission to be a pilot.

READDY: That was pretty nice, yes. I had a fairly quick turnaround to STS-51. Also a great crew, very very different mission though. Whereas STS-42 was two-shift, 'round-the-clock science-focused laboratory, STS-51 was very much focused around Shuttle operations. We had an advanced communications satellite to deploy. We had an ultraviolet telescope that we were going to pick up with a robot arm, leave it in space, and come back and get it five days later, called the ORFEUS-SPAS [Orbiting Retrievable Far and Extreme Ultraviolet Spectrometer-Shuttle Pallet Satellite]. It had an IMAX camera on it.

The whole idea was to be able to start developing the rendezvous techniques that we would eventually use for the close approach and then the docking. At this point we were still talking about docking with the Space Station Freedom. The redesign effort hadn't really taken hold yet, and we didn't really have much of an idea of what was going on until after we landed from that flight in September of '93.

I got pulled aside and they said, "We're sending you to Russian language school out in Monterey [Defense Language Institute Foreign Language Center, California]." That's when I really started to learn about the plans that Vice President [Albert A.] Gore had signed up for NASA to do with the Russians, the Gore-Chernomyrdin agreements, that basically set up the International Space Station Phase I Program, which was Shuttle-Mir.

I had no clue about any of that when we launched on [STS]-42 certainly, and on [STS]-51 either. Although on STS-42, on January 24th, 1992—I remember this very vividly—we got a call up from the ground. Typically they would ask you to look at something, "Look down at this, look at that, look at this system." This is window one, two [demonstrates], three is the commander's front window, and as I recall, it was probably window number five. They said, "Look out window number five. What do you see?"

"Golly, that's really bright." And it was the Mir Space Station going by. Because the inclination of our flight had changed to 57 degrees, and the Mir flew at 51 degrees, it was just one of those really odd kind of coincidences that we were able to see the Mir. You couldn't see the individual modules or anything, but I mean, it was not a star. It was extremely bright and kind of irregular. That was my first look at the Mir Space Station.

WRIGHT: Do you have any idea if they could see you? Did you ever have a chance to ask anybody?

READDY: You know, I don't even recall who was on the Mir at the time. That would be an interesting thing to go back and look at.

The Shuttle's got lots of windows. It really looks like the bridge of the Starship *Enterprise*. You look out—all those windows there, and then windows there too. The greatest thing in the world is to roll the Shuttle upside down and then point one wing into the velocity vector. You can imagine this.

Here's the Earth down here [demonstrates]. All the windows are facing the Earth, so as you're going across the surface of the Earth you're watching this panorama go by. It's just as amazing in the nighttime as it is in the day because there's nothing to mask the light of all those other stars that we don't see through the atmosphere, and the Milky Way is kind of neon. You can almost read your checklist by it, it's so bright. Plus looking down at the Earth with the lights and moonlight and everything else is really pretty. There's this little kind of glow that is all the stray particles impacting the top part of the atmosphere, so you can kind of see this little bit of Earth glow.

Then on the day side everything looks very very familiar, except there's thousands of times more colors that you can see. It's kind of like a kaleidoscope, because you're going around the Earth once every hour and a half. The Earth is rotating on its own axis, and in an hour and a half it goes 22 and a half degrees. When you look at the map in mission control you see those retreating sine waves. The Shuttle is flying in the same orbital plane the entire time, and the Earth is rotating underneath it, so those sine waves are 22 and a half degrees apart, which is an hour and a half.

You see a different part of the Earth every single orbit. In all those 16 orbits that you do every day, [there are] 16 sunrises, 16 sunsets; 45 minutes of daylight, 45 minutes of being in the Earth's shadow because it's dark. Everywhere it's dark. What you realize in the daytime is if you're not looking at the Earth with all the light being reflected and diffracted—if you look the other direction at the sun, the sun only subtends about a degree of arc.

It's not very big and there's literally nothing between you and the sun, so the light isn't being spread by any kind of atmosphere. If you're not looking within about 20 degrees of the sun, you see all the other stars that are out there. The sun's just the closest one and the brightest one, obviously. You see stars in the daytime if you're looking away from the Earth and not looking directly at the sun.

WRIGHT: That's interesting. I don't think anybody's ever illustrated it that way, so thanks.

READDY: STS-51, getting off the launch pad was kind of a challenge. We had a couple launch slips of our own, but nothing really significant until we actually got to the Cape and strapped in and got ready to go. I think in the countdown we got down to like 19 minutes and everything was going great. Weather is gorgeous, no issues, vehicle is performing fine, and then all of a sudden one of the controllers in Launch Control saw that the pyrotechnics [were armed]. Everything's redundant, so in order to have something detach, let's say to get rid of the solid rocket [boosters] or the external tank or fire the explosive bolts so that the Shuttle lifts off—all those things have two redundant systems that arm and fire them.

There's a pyro [pyrotechnic] initiator charge, PIC. Underneath the Shuttle there is this big huge mobile launch platform, and it looks kind of like being on a Navy ship with all these watertight, airtight doors, sealed cavities, places where they pump nitrogen in there because nitrogen won't support combustion, things like that. One of the boxes in there was the PIC controller. They called it a rack, a PIC rack.

All of a sudden, half of the pyrotechnics armed themselves, and of course that isn't supposed to happen. You don't arm those things until you're just prior to liftoff. For whatever reason, they just armed themselves. Everybody's starting to get a little bit nervous because some of the explosive bolts could fire prematurely. We start going through the scrub checklist, and they want to make sure that that PIC rack was unpowered.

We'd gotten to 19 minutes and finally got the vehicle safed, crawled out, went back to crew quarters. Didn't really have a very good idea of what the problem was and figured that we weren't going to go fly right away. We were right, so we hopped in our T-38s and went back across the Gulf of Mexico and went back into training some more.

[STS]-51 was also a little unusual in that we were scheduled to make the first night landing at the Kennedy Space Center. We were originally supposed to launch back in July, in the summertime. Well, we had to train at night, and in the summertime it doesn't get dark until really late, so we spent most of our time in the crew quarters sleeping during the day and then going out and flying the T-38s and the Shuttle Training Aircraft at night. They spent a lot of time on the night team, so we were already pretty well adapted. We did our Shuttle mission simulators over in Building 5 at night.

And we were just totally, totally rotated off that. We were trained to land at night, but we would still launch in the daytime. So we scrubbed during the daytime, flew home, and now our circadian rhythms are totally out of whack. Lo and behold, they find the problem. There was some kind of temperature issue inside the mobile launch platform that caused the circuit board to warp a little bit and make contact where it shouldn't have. They replaced that and everything's fine, so we polish up a little bit more training, head back to the Cape.

This time get in the count, everything is going great. We get down to 19 seconds, and we scrub because one of those HPUs—one of the things that you want to do is make sure that you've got proper hydraulic pressure, everything's going well—was not behaving normally. It was bogging down. At first they thought, well, we can't go because we launch with all the redundancy. We don't leave some of the redundancy on the launch pad. We make sure everything is working before we'll commit to lifting off. Then, as I recall, they found some kind of line blockage. I don't think it was actually the HPU itself, but something downstream of that, so the pressure didn't make it to the actuator.

So that's 19 seconds. We're getting closer, which is a good thing, but a little disappointed. Frank [L. Culbertson] and I have both flown before, but Carl [E.] Walz and Jim [James H.] Newman and Dan [Daniel W.] Bursch, none of them have flown yet, so they're getting a lot of dress rehearsals here they hadn't planned on.

We go back and go train some more, and they do the troubleshooting and swap out the line and HPU, and we trundle on back. Everything's going great. We get past 19 seconds, which is now a good thing, so we're pretty confident that we just might go fly today. Get down to ten, nine, eight, seven, start the main engines, main engines are coming up.

As the pilot, the engines are my thing, so I'm looking at all the engine gauges. The clock that we use to monitor those things is located on another display. The one that has all the engine parameters and everything else was part of the backup flight software, and the backup flight software clock didn't start until T equals zero, so one of the other indications that you're off and everything is working good is the clock is starting to climb up.

The countdown timer is elsewhere, and I'm looking at the main engines. Mentally I'm going, "Okay, seven, six." I'm seeing the first engines come up, thrust tapes come up. We have status lights for the three main engines, and each one of them had an amber and a red, and I see a red light come on, which is a main engine fault. We had, of course, no idea what's going on. We're at about liftoff—I think it wound up being somewhere around two seconds prior to liftoff—but the engines are still roaring away.

If you've ever watched the Shuttle launch, it's cantilevered off those solid rocket boosters. It's sitting on those solid rocket boosters, and when you start the main engines it tips the stack over a little bit. Doesn't look like very much when you're three miles away, or even on the TV [television] camera, but when you're up in the cockpit at the end of that huge lever arm, when it pushes the stack over, you definitely feel it.

Normally, when that twang is over it goes through the vertical, and that's timed such that that's when the solid rockets fire. You're back into the vertical, and then you fire the explosive bolts, and then away you go. Well, when there was a main engine fault the first thing they do is stop the launch sequence, which de-armed the solid rockets so they wouldn't light up and send us on our way to the first not night landing, but the first return-to-launch-site abort, which it what it would have been.

So as we shut down the main engines, we're still rocking back and forth and back and forth. I'm sitting in a chair right now in the vertical, but imagine now I'm laying on my back and there's the launch pad going back and forth and back and forth. In the meantime, we're talking back and forth to the Launch Control Center, and they're not exactly sure what happened and we're not exactly sure what happened. Then the next thing I see is the water coming down on the cockpit. They start spraying underneath because they were, I guess, concerned about a hydrogen fire.

We go through our safing checklist very expeditiously but very carefully and unstrap, thinking that we might have to go bail out the side and exercise those slide wires. But as it turned out they were happy that they didn't see a fire, and so we were able to egress the vehicle normally instead of having to do the emergency hatch opening. We had the close-out crew come back up and then open the thing and help us get out. By this time, we've now strapped in three times, we're getting ready to go fly and haven't flown at all.

We're now back in those T-38 jets flying across the Gulf. Because Frank and I are the two pilots, we would have one mission specialist in each back seat. We had three mission specialists, so you always need an extra pilot. Well, it turns out flying home that day was Captain John Young, who was the third pilot in the formation, so he's got one of the mission specialists in the back. As we're headed back across the Gulf, as often happened, as soon as you came up on the radio with a NASA call sign they wanted to know what was going on.

"Did y'all hear about the scrub?" Of course, we had heard about it. He said, "Any of y'all astronauts?"

Frank Culbertson, who is the flight leader, says, "Well, yes. Yes, we are."

Says, "Oh, that's great. Any of y'all flown?"

Frank, ever the diplomat, said, "Well, some of us have and some of us are going to fly real soon."

The controller came back with something kind of snide, like, "Well, I guess that makes some of y'all astronauts and some of y'all astronaut-wannabes." There's one potato, two potato, and you could tell everybody in the backseat was not real happy about that. John Young completely broke everybody up. He keyed the mic [microphone] and said to the controller, "You know, and some of us are astronaut has-beens." Oh, to be a has-been like John Young. Isn't that something?

We go back, go back into training, go back into quarantine, go back into the vampire mode of reverse day/night cycle. There was a meteorite shower that delayed it, [the next launch attempt], and then there was some kind of problem with resistors that were in the spacecraft that we were deploying and one thing led to another.

Eventually, on September 12th, 1993, we actually got out there and everything went great and launched and away we went. Things were going pretty smoothly until we lost communications with ground just before we're supposed to deploy this brand-new communications satellite, which is kind of irony itself. You're launching this huge new communications satellite and you lose communications.

We carry something that is just a monstrous volume called the malfunction procedures, and there's checklists that we carry that are abbreviated. Those checklists are for things that you have to take care of within five minutes, typically immediate action things. Those are all in the checklists, and there are also checklists that you use routinely for some operations. Those will be normal procedures and then the emergency procedures. If it's more detailed, then you get into the malfunction book, called the "malf" book.

We ran through the immediate action stuff for loss of com [communication], and it sends us to the malf book, which is about this thick [demonstrates]. I wound up being the coms guy because I'd been the subsystem guy before that, so we start paging through this procedure. It requires you to get into the computer memory, which for the Shuttle era was a hexadecimal, which means zero through nine and then A, B, C, D, E, F. Every one of those has got a value. We reconfigured all the switches, did everything else, and now what we've got to do is get into the memory of the Space Shuttle computer to cause it to switch to an alternate communications frequency.

In the meantime, we're talking to the ground, telling them what's going on, what we're doing, just in case maybe they're hearing us. It turns out they are, and they're following along. We're telling them what step we're on and what page we're on and why we're moving to this. We had downlink. There was no uplink to us until we finally get through the end of this very very very long involved procedure, and lo and behold, the ground's back.

It turns out that as they had assessed the radio telemetry system—the payload interrogator it was called—on the payload interrogator frequency for the ACTS [Advanced Communications

Technology] Satellite, when Carl threw the switch to turn on the payload interrogator, that's what jammed the uplink. We had essentially jammed ourselves. That was supposed to be deconflicted before on the ground. The Shuttle should have been set on the alternate frequency to begin with, but it was one of those escapes that happens occasionally.

In the meantime, as we're walking through this, it's obvious we're not going to make our first deploy window. We know that immediately the ground is going to say, "Well, it's the end of your guys' day. We're going to have to scrub the deploy for the day. We're going to have to move it into tomorrow."

Frank and Carl and Dan and Jim Newman were all talking and saying, "You know, we've got so much adrenalin going here right now, we couldn't go to sleep if we tried." So woven into the commentary as we're walking through the steps in the malfunction book was, "You know, we're feeling really good here. If we can get this thing going, we'd be ready to deploy a rev [revolution] late." Lo and behold, when we got the coms back they said, "We've been following along with you, and we think we could go a rev late. Here's the new time." So we did wind up actually deploying it on day one.

Unbeknownst to us because that was located all the way in the back part of the payload bay, the deploy hadn't gone quite as nominally as we thought. In fact, pyrotechnics had been wired improperly. So when we deployed it, it blew two of the pyrotechnics simultaneously and sent shrapnel into the payload bay and part of the flight support equipment out into outer space. Fortunately, none of it impacted anything critical on the orbiter, and it didn't impact anything critical on the spacecraft. The spacecraft was happy as it soared overhead the flight deck and away it went.

We weren't aware of any of that until it came time to take the robot arm and deploy the ORFEUS-SPAS pallet satellite telescope. As soon as you did that, you looked back and saw the mangled flight support equipment back there, that the explosion had happened and it really did mangle everything. My job at that point was to fly the Shuttle, so I was in the commander's seat doing Shuttle-flying things. I think at the time Dan was the robot arm operator, so he's looking out the window and lifting things up. Slowly lifting it up, you couldn't see anything right away.

Carl was in charge of the ACTS satellite, being from Cleveland [Ohio]. It was a technology development out of the [NASA] Lewis Research Center [in Cleveland], soon to be renamed Glenn [Research Center]. Frank is looking out the window, and he can see what's going on. I can't. I don't think Dan immediately recognized what was unusual about it, and then I hear Frank's voice, "Carl. Carl, get up here." He points it out to Carl and says, "What did you do? What happened? Did you notice anything?"

He put the cameras back on that, and then the ground starts looking at it. Then we've got to start doing a survey of the payload bay and everything else to see if there was any other damage. All the people in the MER get very busy, because they're looking at all their different systems and trying to figure out what happened.

The system included, for redundancy purposes, two firing chains: an A firing chain of pyros and a B firing chain of pyros. The idea is it's two concentric rings, A and B. If the A doesn't work you use the B. Unfortunately, they were wired not as a continuous ring. They were wired as A and B, so two adjacent ones fired simultaneously and destroyed what was supposed to be the containment ring. Fortunately it also fractured the interface, which allowed the spacecraft to depart without any damage, but when those two things fired simultaneously it destroyed the containment ring for the pyros.

Long story short is that's the way it got miswired. Because we had several different contractors involved—I think Orbital Sciences [Corporation] built the TOS, the Transfer Orbit Stage that ACTS was on top of. Lockheed [Corporation] out in Denver [Colorado] was involved, then at the time I think it was Rockwell [International] or Boeing [Company] at the Cape that did payload processing, test, and checkout. So you had three different organizations and several opportunities for the drawings to get misinterpreted.

The oddest part about it was the fact that the pyros had been wired improperly was missed because the test equipment was similarly miswired. So when you did the tests, it showed you that everything was working per print. They were able to test that it was perfectly miswired, but nobody knew that at the time. It was another one of those things that sometimes Murphy gets you.

WRIGHT: Yes, you couldn't have written that one.

READDY: No, never would have happened.

ORFEUS is deployed. ORFEUS also has an IMAX camera on it, so we've got a series of maneuvers that we want to do so that they could capture those. Those wound up being, I think, in the Space Station 3D movie and a couple other movies. Orbit ops and everything else—that was a due east flight, so we saw a lot of ocean. We did some practice rendezvous and then did a rendezvous eventually with the SPAS. Dan picked it up and put it away in the payload bay, and then we headed home for the Cape.

WRIGHT: I think you did some work with some tools, some things that were going to be used for Hubble.

READDY: Oh gosh, the EVA [extravehicular activity]. Yes, I was the IVA, or intravehicular activities person. I got everybody all suited up to go outside and then walked them through the checklist, kind of the coordinator for all that. That was probably one of the real major things that they were looking at is the development and on-orbit test and checkout of the Hubble repair tools, which we brought up there with us.

There were a number of things. There was a special power ratchet tool that was especially designed for Hubble that had a series of tests. We had a couple custom foot restraints that allowed the crew member an awful lot more maneuverability and flexibility, and while they were out there in the payload bay they were also looking for penetrations of the cargo bay liner and things like that. Yes, that's exactly right, the EVA was a big big deal. At the time we weren't doing very many rendezvous and we also weren't doing very many EVAs, so to have both of those on one flight, plus two deploys, one retrieve—it was a very very busy mission.

I think we had some other issues coming home, so we got to spend an extra day, which is always nice because everything's all packed up and you're ready to go home. Somewhere in there I think we had a computer fail, so we had to reboot the computer and restring the computers and do all kinds of other stuff. I think we wound up coming home with one less computer than we started.

WRIGHT: When I was reading about the mission, I thought it was interesting—as a precursor to Space Station operations, it turned off one of the fuel cells and then turned it back on.

READDY: That's right, the fuel cell restart DTO, developmental test objective. I don't think we ever wound up having to use that as much as we thought we would. The fuel cells, like most mechanical technical systems, have an optimum design point. It's not very efficient when it's kind of loafing along, and it gets less efficient when it's at its peak capacity. So rather than have three fuel cells loafing along, you would just as soon have two of them that are producing more towards their optimum. We had never shut down a fuel cell before, so we wanted to make sure that everything worked. The thought was you would get up there, dock to a Space Station—maybe in this Long Duration Orbiter—and shut down a fuel cell or maybe two, use the solar power and batteries off the Space Station to keep the Shuttle happy.

WRIGHT: Then all those times that you got ready for the night landing, it finally came.

READDY: Yes. We had a chance to take a look at the Cape several times before we actually landed there, so we knew that the weather was going to be pretty decent. Both Frank and I were carrier pilots, so we were used to doing a lot of night landings aboard the aircraft carrier. Of course, it's a lot darker out in the middle of the ocean than it is there in the coast of Florida, and the deck of the aircraft carrier's pitching and rolling and moving and fairly tiny, about 600 feet long.

Now we've got three miles of runway in front of us. It's lit, the likes of which you've never seen any runway ever, and it's not going anywhere. We know exactly where it is and we know it's not moving. We had a heads-up display that we were able to use for the night landing, and, really, conditions were ideal. It really was about as benign a set of conditions as you could get, a perfect way to do the first one at the Cape. Frank did a marvelous job. He always did. As I recall, I think we had a drag chute deploy, so he barely even touched the brakes.

But there was one thing that because we were landing in Florida, rather than Edwards—you think about it, what's different? Well, Edwards is a little bit higher, but that's not that much different. But what's the humidity like in the desert and what's the humidity like there at the Cape? One of the APUs—at the base of the tail the exhaust was extremely visible, and at first it looked as though we had a landing light on because it was making an awful lot of visible light. Normally it's just infrared.

When you see infrared views of the Shuttle, you can see the exhaust of the APUs and you can see how hot the brakes get and the tires and everything else. In this case, just the regular television camera is showing the base of the tail, and there's this fire coming out of it. They were anxious for us to get that one shut down expeditiously, but it wasn't any big deal. Just hadn't ever seen that before. That was kind of a normal phenomenon for landing at the Cape at night. Wouldn't ever see that in the daytime and wouldn't see it at night out at Edwards. Very interesting.

WRIGHT: You were talking earlier in our conversation about how as soon as you got back you were requested to go to Monterey, and then of course they had been working on the plans for the Shuttle-Mir International Space Station Phase I project.

READDY: There had been a couple exchanges where we had sent engineers over to Russia and vice versa, so there was kind of the framework of it, but really hadn't done much in terms of developing the operations yet. That was still a ways away. The first part of Shuttle-Mir was train a couple of our astronauts to fly onboard the Mir. The idea was to fly up to the Mir on Soyuz and come back in the Shuttle. Then in the Shuttle would be the replacement crew that would come down in another Soyuz, kind of a daisy chain like that.

The whole Russian experience, I think, was made much easier for us. It wasn't the Cold War anymore, but surprisingly an awful lot of the same people on the Russian side that were involved in Apollo-Soyuz were still over there. Still in the aerospace industry, still in management positions, so we weren't starting completely from scratch even though it was some 20 years later. It was really remarkable how much of a legacy there was from that and what kind of good relations still persisted even with the Cold War intervening, so we weren't starting completely from scratch.

Apollo was one thing, but the Shuttle operation is completely different. We had a whole different generation of NASA people, particularly in the crew office, so we needed to gear up to how we're going to train a lot of people to go do that. And how we're going to train not simply the crew members, but also the people that are going to support the science and the people that are going to support the mission operations.

I didn't speak Russian. I could read the alphabet because I was an engineer and because once upon a time the Russians were our archenemies, so you could read Cyrillic and had some familiarity with how they were organized, but really didn't speak any of the language. I got out to Monterey, and Norm had already been out there for a couple months at that time. This would have been late September, early October of '93. They put together a language program that included three or four Russian language instructors and you, and that was it. You weren't in a class with anybody else. You had a tag team of instructors, one primary instructor and then some others. You listened to Russian radio on tape, and they had Russian TV that they'd recorded.

Then a couple nights during the week—and these were all émigrés who were teaching the language, so they were all native Russian speakers—they would have a social activity out at one of their homes. They would speak Russian, trying to get you used to speaking Russian all the time, hearing Russian all the time—but also trying to give you a little bit more of the cultural dimension to what was going on, as opposed to just the nuts and bolts of the language, and the technical language that was part of the aerospace business and space flight that was a little bit unique.

That went on for many many weeks, and then I got a call. I think it was Mr. Abbey and [Robert L.] "Hoot" Gibson. Hoot Gibson was running the Astronaut Office at the time, and Mr. Abbey was the technical deputy at NASA Headquarters [Washington, D.C.]. They asked me to go over to Russia and do a survey of Star City, the Mission Control Center, and some of the other engineering sites around Moscow and then write up a report on how we would put together our operation to support Shuttle-Mir and the Space Station.

I got the grand tour for about a week of all the different facilities, and then we went down to Baikonur [Cosmodrome, Kazakhstan] and saw a launch and toured those facilities too. I had a chance to calibrate where I was in the Russian language training, and what amazed me is even after only about six weeks' worth of training, I really did feel pretty comfortable and could actually converse with people. Having that experience, when I got back to Monterey and polished up through the Christmastime, knew what I needed to work on. Then, starting January, I went over there quite a bit and then moved over there the following summer to be the operations director in Star City.

WRIGHT: Why were you chosen to do this task?

READDY: Good question, I don't know. George would know, I'm sure.

What's interesting though, is if you look at the crew of STS-51—Frank ran the Shuttle-Mir program for a while after working for Tommy [Thomas W.] Holloway, and then he wound up being a Space Station crewman himself, Space Station commander. Carl Walz and Dan Bursch both again flew. As a matter of fact, Carl flew with me and Dano. So there was this kind of Russian thing that happened. Not only did they wind up flying with the Russians, Jim Newman wound up being the ops director over there in Moscow for a while too. Everybody wound up having a fairly major role in the Shuttle-Mir program, which is kind of odd.

Then again, as the program unfolded there were so many Shuttle-Mir flights and so many station assembly flights, and now [International] Space Station, that just about everybody who was left in the Astronaut Office was going to wind up participating in some form or another. But STS-51 just seemed to be a little bit unusual, particularly that early on.

WRIGHT: Yes, you were at the right place at the right time. Talk about being over in Russia. You said you went several times and then you went in the summer to become the director of operations over there. I think Ken [Kenneth D.] Cameron was there before you?

READDY: Ken Cameron went over there in, I think, January or February. He was an MIT [Massachusetts Institute of Technology, Cambridge] graduate. I think he had some Russian language training before he ever showed up in the Astronaut Office, so he was a logical choice to go over there. They never said so out loud, but I think that also wound up being a little bit of a screen for who was going to be involved as a commander for the [Shuttle-Mir] docking flights.

Hoot Gibson did the first one, but after that there was Ken Cameron and then [Kevin P.] "Chilly" [Chilton] and then me. Then after that, [Michael A.] Mike Baker. There was this succession of folks that went through Star City as the ops director that also wound up being very much involved in the downstream Shuttle-Mir flights as commanders. Charlie [Charles J.] Precourt was Hooter's pilot on STS-71, and he recycled later on and got to be one of the commanders of the docking flight.

WRIGHT: Do you believe that their interaction over at Star City in Russia helped them have more of a bond, as you mentioned earlier about Apollo-Soyuz, that interaction?

READDY: Well, those senior people were still very much involved in the management. Most of the cosmonauts that were involved had retired long ago, same over on this side of the pond. We were dealing with a next generation of cosmonauts. Many of them hadn't flown at all yet and were in training for the Mir, and they didn't realize that the Mir now involved learning how to fly up to the Mir and back on the Shuttle. They were very interested in how that all worked, and there was a lot of cross-pollenization that occurred.

It certainly took us a while to get used to their training regimen, their methodology for teaching. It went back to a chalkboard and posters in a classroom, with the instructor transcribing his notes onto the chalkboard. You transcribed what you saw on the blackboard into your copybook and made your own hand drawings. There were no textbooks, workbooks, videotapes, computer-aided instruction or anything. It was all pretty much one-on-one that way, at least as long as I was over there. Now that the International Space Station is—gosh, we're on Expedition 31. You think about it, we were involved when there wasn't a Space Station to begin with. They were still talking about Expedition 1.

It was a whole different group of cosmonauts. They had to get to know us and vice versa. They train differently than we do, and you don't really fly the Soyuz. When it's a spaceship you do maneuver it and you do docking, but it doesn't have wings so you don't fly it. We spend a lot of time flying airplanes, not only T-38s, but the Shuttle training airplane. The Shuttle is a winged vehicle. It's a rocket ship for 10 minutes and spacecraft for a couple weeks. Then it's this hypersonic reentry vehicle, and then for about five minutes it's a subsonic glider. So we spent a lot of time flying airplanes.

The young cosmonauts didn't necessarily have a lot of flight time. Most of our astronaut pilots had thousands of hours of jet time, and the cosmonauts might have somewhere between 500 and 1,000 hours. Whereas we would fly routinely to the Cape and to Edwards in the Shuttle Training Aircraft, they would fly a training flight maybe every quarter or so, because it just wasn't viewed as being that relevant to their training.

Of course, back then the [Berlin] Wall had just come down and the former Soviet Union was having pretty hard times, so kerosene to put in the jets was a little bit scarce. They were really economizing every place they could, so the Russians had a different training methodology than we did. The one common area, though, was we did lots and lots and lots of simulations. Quite possibly because the Shuttle's a very complicated vehicle and has those different flight regimes, ours always tended to be more aimed at integrated simulations with the Mission Control and everybody involved.

The Russians—it was pretty much the cosmonauts, the simulator, and then the simulator instructor. Only very very occasionally would they actually have something where they would plug in the control center, which was also in another city. Star City is one place, and the Mission Control Center is in what used to be Kaliningrad, now Korolev, another part of the Moscow region.

The Russian roads make it difficult to go back and forth. The Russian organizations that were involved were very different. You had the military that did the Star City, and you had the civilian arm that did the Mission Control Center. They were different organizations, and we found it a little unusual that they didn't train together more often.

When they started training with us, they realized that we trained in an integrated fashion almost all the time. As we got into Shuttle-Mir, we had to plug in the control center over in Korolev with the control center in Houston in order to coordinate all those different things to make sure that the Mir was ready for docking and all the systems were configured correctly, so that the Russians had some insight into how the Shuttle was doing and all those kind of things.

That was something that we had to build up to. It wasn't anything that you could do on day one, it took quite some time to build up to that. I think the first flight where we actually demonstrated that was STS-63, which was *Discovery*. But it didn't have a docking adapter at that point. The docking adapter wasn't ready, so they did a close approach to the Mir and then flew around it and then went home. It took us a while to build up to that.

WRIGHT: Part of that time you were assigned to the [Thomas P.] Stafford Task Force [NASA Advisory Council Task Force on Shuttle-Mir Rendezvous and Docking Missions], is that correct?

READDY: That was one of the things that we thought might be useful, recognizing that all those relationships were still there, and we thought we could shamelessly take advantage. General Stafford, who had very very deep experience doing rendezvous—he and Wally [Walter M.] Schirra did the first space rendezvous in the Gemini program—had developed an awful lot of the techniques that were involved, and he was the commander on the U.S. side for Apollo-Soyuz.

We had NASA and the Russian Space Agency and that relationship. We wanted one that went outside that, that could look over the entire operation, maybe in some cases be a little bit more direct in terms of dealing with issues. The Russians have bureaucracies too, and sometimes the communication wouldn't be as crisp as it could be.

Sometimes we'd have impasses where Stafford and Dr. [Vladimir F.] Utkin didn't have any trouble sorting out the issues and directing people to go off and go do things. It was just a whole lot easier for them. They had a different perspective on it, they had a different range of contacts, and it was just very helpful. When I came back from Star City I got detailed to set that up, so I wound up being involved in that up until the time I got selected to be commander of STS-79.

WRIGHT: Which you found out in a very unique way.

READDY: You know, it seems kind of antiquated. Telecommunications in Russia at the time were fairly old. There weren't a lot of cell [cellular telephone] towers or anything. People would have looked at you crazy if you had even shown them one of those. These were the Motorola [Inc.] things, you remember those big bricks that everybody used to carry around that was a cell phone? There really was no such thing over in Russia. All the phones were landlines, and they were wired up. You had to use their network, and you had to wait to get an outside line. Then you had to attempt to dial the United States, plus the time difference. It was fairly challenging.

One of the things that we brought with us is a satellite terminal, which we put out on the balcony and aimed at the satellite. That caused a huge stir there in the Star City because it was still a secret military zone and here we had this satellite communications link. We had a lot of visitors, a lot of attention, when we first set that thing up. As it turns out, the satellite link was only marginally useful.

If you think about what an email is and all the different things that are involved in the header and the addresses and everything else, when we would try and attempt to use the satellite link for email, you get about halfway through the address list on an incoming email, and that's when it would drop sync and you'd start all over again. So it was marginally useful, which drove us to using faxes for everything. Faxes worked fine in the Russian phone lines, which were, for ordinary purposes, very slow. They're analog lines and they worked great, so everything was done with faxes. Faxes, faxes, faxes.

I roll into my job one morning—and because of the time difference, you would typically show up and there would be all this rolled-up fax paper on the floor. The first thing you'd do is collect it all up and try and straighten the fax paper and put it on a clipboard. You're going to start routing it around to everybody in the office. And lo and behold, there's this fax that says that I've been assigned to a mission.

WRIGHT: As the commander.

READDY: As the commander.

READDY: What was interesting is the Russians knew before I did. Maybe the Russians read our faxes or they had their own sources, but that made for a very nice day in the Star City for me. It was remarkable though, how many Russians already knew that day. Good news travels fast, right?

WRIGHT: That will be another one of those mysteries, how did they know? You came from a couple of good missions that gave you some good experience as well as all the time that you were over. Share with us what it was like being a commander and working with your crew and getting trained to go visit the Mir.

READDY: Well, the commander's job is mostly stay out of the way and let everybody do what they do best, and try and keep up with everybody. I just had an embarrassment of talent on the crew. Terry [Terrence W.] Wilcutt was ready to be a commander. He didn't need another trip in the right seat, I don't think. He was ready and a very very very capable guy, very good pilot. The flight engineer was Tom [Thomas D.] Akers, another guy who was just spectacular.

Jay Apt, he was remarkable. He was just so versatile, he could do anything. Among other things, he is really a world-class photographer. Published a couple books of photography with, I think, [M.] Justin Wilkinson and Roger Ressmeyer, both also very famous Earth ops photographers. And Carl Walz, who I had a chance to fly with before. That was great, that was a nice treat. Then John [E.] Blaha, who was mostly over in Russia training for his flight. He was

Shannon [W.] Lucid's numerical replacement [aboard Mir]. Shannon, of course, hadn't planned on staying up there quite as long as she did.

We got to a couple months before flight, and Ken [Kenneth D.] Cockrell was the commander. I think the flight just before us, they had found some kind of delamination problem with the solid rocket booster seals, and they were concerned enough about it that they had to de-stack our mission and put it all back together again. That gave Shannon the opportunity to set the world's record at the time for endurance on the Mir, and John got a little extra training out of the deal, and a little bit more time over in Houston with his family before he had to go off and fly. John had been a Shuttle commander before, so he probably knew more about it than I did, but he was very very gracious about it. It was great to have him on the crew.

WRIGHT: I didn't think about that. You had him as a passenger.

READDY: Well, we wanted to make sure he felt like more than a passenger. He's certainly an integral part of the crew. Of course we had to train without Shannon. Before she launched on her flight with Kevin Chilton on STS-76 we had gone over there to make sure that we had a chance to talk to her about operations and what was going on, but really at that point we didn't have much communication.

Matter of fact, the communication we had was in the ham [amateur] radio shack out there near the Gilruth Center in Houston. We'd figure out when the Mir was flying over, and we'd go out there with a ham radio. Jay was a ham radio operator, and Ellen [S.] Baker was usually out there. We'd have a chance to talk for literally just a couple minutes as the Mir was going past and talk to Shannon, see how things were doing. Like I say, she got to spend a little bit more time than she had planned up there.

WRIGHT: I guess the weather helped her stay a little bit. You had a couple hurricane issues.

READDY: Oh gosh, yes. But that was a great, great crew. It was a very involved mission, a lot of things going on. A very narrow launch window and then a very intricate series of burns in order to get phased properly, the whole choreography that was involved. At the time you had to perform the docking within a very tight tolerance so that it could occur over a Russian ground station, so that they could monitor the Mir station during the docking. I don't think that's true anymore for International Space Station because we have relay satellites, but at the time the Russians wanted to monitor all those things. They didn't have a relay satellite to use, so they had the docking occur over one of their ground stations.

You had a number of different constraints. One was to align the Shuttle within about an inch in any axis, and then orientation such that it was less than a degree offset in any axis. The contact velocity was basically about an inch per second, tenth of a foot per second, and a fairly tight tolerance around there. Then you add the time constraint. That's an awful lot of things to keep all balanced up, and we arrived at a couple of procedures that allowed us to do that.

We would constrain it so that you would arrive at 10 meters away, and you would park there while everybody was deciding that everything was go. Then you would push off at exactly the right time so that if you flew the normal approach, contact would occur within that window and the contact velocity would be right. We spent a long time developing those things, and also the visualization tools that allowed you to fly in a very precise corridor so that the reaction control jets that you're firing on the Space Shuttle didn't impinge on the solar arrays of the Russian station for example, things like that.

You also wanted to be very conservative in how you used the fuel on the Space Shuttle. That required an awful lot of simulation, awful lot of practice. A lot of people involved in the flight deck, because you needed somebody who had a laser gun they were shining out the window in order to get very precisely how far away you were and feed that into your calculus of what was going on.

Jay Apt had the master checklist, and he would have been what I'd describe as the concertmaster. He was making sure everybody did their particular part, and he kept track of that master checklist. He was just great at that. Terry was up in the commander's seat up front, and he was typing in the different data entries into the computer. I was looking out the overhead window and flying the Shuttle, and off to the right was Carl, who was primarily focusing the cameras and making sure that everything was working in the docking adapter. Tom Akers was the flight engineer. He got to see all the mechanical-type things that were going on. These guys, it didn't make any difference what the simulator crew threw at them, it was no big deal. They were really terrific.

WRIGHT: And it worked well when you got there.

READDY: Yes. You think about it after the fact, and if you don't dock successfully there is no mission. So I guess in retrospect there is a little bit of pressure on getting the docking right, but you've practiced so many many times before that when they aren't throwing malfunctions at you all the time, then it's really quite simple, smooth, quiet. If you listen to the tapes of the flight deck, mostly what you hear is the noise from the avionics fans. You can talk in this tone of voice on the flight deck and everybody knows what their role is and when they're supposed to do this and do that. It's just very matter-of-fact.

WRIGHT: As you were approaching Mir, could you see that light that you had seen one time before?

READDY: Well, the light was just the reflection. When you start to get close to the Mir you do use the overhead, it looks like a gun sight. It's an optical reticle with crosshairs in it, and you can see it. As it gets closer, it all of sudden goes from being just a very, very bright kind of irregular shape into something that's got modules and then something that's got solar arrays. It's amazing.

We took a whole series of pictures. The book *Dragonfly* [*An Epic Adventure of Survival in Outer Space* by Bryan Burrough]—when they put all the modules on the Mir, it really did look kind of like a dragonfly with the arrays going off at different angles. It was really pretty too. It's something about the insulation that they use that's got a little bit of a gold color to it, and within the solar arrays there's almost kind of a purple hue to some of it. You've got orange and bright white and purple and gold—it's really very pretty. Then you have the Earth in the background, which is just spectacular.

You've seen the pictures that were taken as they did a little fly-around with the Shuttle, STS-71 docked to the Mir Space Station?

WRIGHT: Yes.

READDY: The Shuttle weighs about 100 tons and the Mir weighed about 120 tons. You look at it, and the Russian Space Station and the Shuttle are about the same size. Very irregularly shaped versus something that's very compact, but they really are almost the same size. Now, if you look at the Space Shuttle against the backdrop of the International Space Station, it gets lost. The Shuttle is so tiny. The Shuttle is 100 tons, and Space Station is 500 tons. The solar arrays weigh next to nothing, but they're huge in terms of acreage. It winds up really causing the Space Shuttle to get lost in all that.

I remember the Mir looked really really remarkable. You see something that grows from the brightest star in the sky, then it gets bigger and it takes form, and then at that point you can't look at the station anymore. You have to look at the docking adapter, and then more narrowly the target on the docking adapter. The rest of the Space Station is just way out of your peripheral vision. You can't even look at it, you've got to really focus on the task at hand.

WRIGHT: It's an interesting thought that you're actually docking to an outpost. There are people that are on the other side of the hatch, and Shannon was very glad to see you there.

READDY: Once the docking has taken place and you've brought the two vehicles together and the latches are all fired and you've made sure there's no leaks, you could hear people talking on the other side of the hatch. You could have a conversation. You don't need to be talking on the radio anymore. It's just like this room. There's air on this side and there's air in that room over there. You can close the door and we can still talk to each other, and the same is true there. It took a little while for us to get the hatch open because we had to wait for Houston and Moscow to agree that it was time, but you could talk back and forth across the hatch.

Shannon was really anxious to see John, and we were anxious to see her and Valery [G. Korzun] and [Alexander Y.] "Sasha" [Kaleri], good bunch. Then you get very very very busy. We had a double laboratory that was full of all kinds of different equipment, storage batteries, gyrodynes. You name it, all kinds of equipment that needed to go over to the Mir. Then did some joint experiments, brought a number of things back with us, got those all stowed.

As the commander I would always sleep in the Shuttle, but I let other crew members go find someplace that they wanted to go sleep. A number of them found a little cubbyhole in the Mir someplace just to say they'd done it.

WRIGHT: Did you have everybody over to eat in the Shuttle?

READDY: We did, yes. As soon as the hatch opens, there was this smell coming from the Russian [side], and it's not what you think. The Mir at that time, everything worked. There was no odor or anything else; everything worked. The smell was the kitchen smell. We were all really really hungry at the end of a long day, and they had already started dinner. As soon as we got the hatch open we went over there to the base block, the crew module, and we had supper.

We had asked the crew kitchen down in Houston to prepare a couple of special meals for the Russians when we invited them over. We had Pe-Te's Cajun Barbecue and strawberry shortcake and iced tea, and I think also we had a couple small jugs of barbecue sauce that we brought along with us.

It's interesting how your tastes change when you get up in space. Anything here on Earth that's sweet is not appealing at all up there. Things that you crave up in space are things that are salty, things that are spicy. You'd eat a cardboard box if it had barbecue sauce on it, so we left the barbecue sauce when we departed at the end of the mission. They came aboard and they had a grand old time, really really enjoyed it.

WRIGHT: It was interesting that you were also doing some, as you mentioned, pre-Station maneuvers about transferring equipment and supplies.

READDY: Yes. The trajectory that we used and the fly-around that we did, all those kinds of things were aimed at being preparatory for International Space Station. The docked operations predominantly seemed to be caught up with logistics transfer. We had a number of experiments on the Shuttle side that needed to be done too, but it seemed like there was just an incredible amount of logistics back and forth.

Tom Akers was amazing. In addition to being the flight engineer, he also wound up being kind of the loadmaster. He coordinated all the transfer operations. This is before a little handheld device and barcode scanners. He had just reams of checklists, making sure that all got transmitted to the ground, and the ground kept track of what was on which side of the hatch. It was just a remarkable remarkable feat, and also pointed for opportunities to improve when we were going to step up to doing something much much much bigger on the Space Station.

One thing I never worried about for a second, though—when it came time to close the hatch and go home, I knew which side of the hatch Shannon was going to be on. I wasn't quite so sure about John there for a while. But Shannon, I knew Shannon was going to be on the proper side of the hatch when the time came. She was ready to come home.

WRIGHT: I'll bet she was. That's a long time up there. When you came home, you shifted gears again and went to the Space Shuttle Program Development Office.

READDY: Right. I came back and went to work for Tommy Holloway, who was the Space Shuttle program manager at the time. This was a time when we were looking at what to do to improve the safety and reliability of the Space Shuttle. Maybe because I'd spent so much time working in the subsystems areas, and working with the Rockwell folks on the build of the *Endeavour*, maybe that's why I got fingered to do that job. That was probably from '96 to '98. Then in '98 I came up here to Headquarters to be the deputy in the Office of Space Flight, and then after that to be the associate administrator [of the Space Operations Mission Directorate].

WRIGHT: Can you talk some about the modifications that were made for safety and reliability while you were in that position?

READDY: Oh, gosh. There were just more than I can count, and the same thing happened after *Challenger* [STS 51-L accident]. This was a continuation of those modifications. We looked at the systems that were critical to being able to conduct rendezvous, docking and assembly, and we wanted to make sure that those were the areas that we focused on. You didn't want a fuel cell quitting that would compromise the mission; you'd have to come home early. You couldn't continue the Space Station mission, for example.

There was another whole branch that Don McMonagle ran at the time that was set up to do the EVA improvements that were required. We were only doing occasional EVAs, and all of a sudden there was this wall of EVA that was required in order to build the Space Station. They estimated the number of hours. Well how are we going to do that? Do we have enough hardware, is the hardware reliable enough? Is the training pipeline for the crew members robust enough to be able to handle that many crew members? A whole number of things.

So it wasn't uniquely the orbiter that we were looking at, it was the entire system. For us, it was the mobile launch platforms too. That whole Space Shuttle development was across the entire system. You often think of the Space Shuttle as the orbiter. That's certainly the JSC part, but it also included SRBs, main engines, external tank, mobile launch platforms. The work that was done in the new flight control center there—all the control center modernization and the glass, replacing all those old 60s-era CRTs [cathode ray tubes] and things like that.

Pointing to any one of those, we had scores of them going on at any one time. Probably one of the most involved was upgrading the Shuttle main engines and the Shuttle main engine controllers. We never had an engine shut down. We never had an issue with the Space Shuttle main engine, and that's remarkable. Nobody has ever built a reusable main engine before or since, and of course the consequences of having a bad day with a main engine is something that we desperately wanted to avoid. If you were to ask anybody, I think they would have said that's probably the weakest link in the Shuttle system, the main engine, because it's so complicated. Turbo pumps and things like that, everything in the main propulsion system we spent a lot of time on.

Solid rocket booster—there were tweaks to it, but I think after the redesign on the *Challenger*, it got to be the RSRM [reusable solid rocket motor], is what they called it. It got to be, I think, a very mature design. There were a couple things they did to redesign the seals very slightly to make it even more robust, and there were some slight material changes they made to it.

The external tank, we were always working on the external tank. We changed the parent material to aluminum lithium, which was much lighter weight, much much tougher than the previous tank. That was so that we could accommodate the additional performance we needed. This is a little bit complicated. Space Station Freedom was intended to be launched due east out of the Cape. Well, we were doing an International Space Station with the Russians. The Russians launch all their hardware to 51 degrees inclination, which meant that we had to launch all our hardware to 51 degrees inclination.

We launch due east because we want to take advantage of the Earth's rotation; the maximum advantage you take of the Earth's rotation is to launch due east. So now instead of launching due east out of the Cape—the latitude of the Cape is 28 and a half degrees, which gives you the 28 and a half degrees north, and on the flipside of the orbit is 28 and a half degrees south. That's the inclination that you launch to. We would have to launch up the East Coast to 51.6 degrees to match the inclination that the Russians launch their hardware to. If you look at the angle, the amount of the Earth's rotation you're able to use to get you into space is somewhat less.

That meant that you needed to somehow get better performance out of the Shuttle system, so you had to take weight out, you had to increase the thrust of the main engines. I think the biggest thing that we did in one fell swoop was changing the material of the external tank. We had this Super Lightweight Tank, I think about 7,500 pounds. It was huge. Then you eat the elephant one bite at a time. If you want to reduce a bunch of weight, you start reducing small things and then add them all up. That was one of the big areas that we spent time on, reducing the weight of the different systems, improving their reliability and safety.

After the tour working for Tommy, then I came up here to Headquarters and the portfolio changed a little bit. It was not just Shuttle anymore. It was now Shuttle, Station, launch vehicles and space communications. I got to learn a little bit on the job there, some different things. One of the first things that I was confronted with when I arrived had nothing to do with Shuttle or Station though, had nothing to do with launch vehicles.

It had to do with the Tracking and Data Relay Satellite System [TDRSS]. The very first one that we had launched, which was called TDRS [Tracking and Data Relay Satellite] F1, had been launched in 1983. This is now 1998, so it had been around for a while. It was aging.

We had a bunch of other TDRS satellites, so they came with the plan to retire the satellite, to put it into what they call a super-synchronous orbit. Get it out of the geostationary belt and turn it off, basically. Put it in a junkyard-type orbit away from everything and turn it off. I heard from the advocates for doing that, and we did have plenty of capacity. Then we asked what other agencies might be interested in using that capacity, because all the transponders, all the radios were still working. The satellite itself was still functional, except we didn't have station-keeping fuel so it would oscillate north and south of the equator, less than 10 degrees I think.

Oddly enough, the National Science Foundation comes up and says, "You know, our polar programs office could really use this kind of exquisite high bandwidth communications." So rather than turn it off, we started providing data services for the National Science Foundation, in particular in the Antarctic. If you think about the geometry, the South Pole is at 90 South, and if I'm looking at the equator, that means I have to be looking which direction? Kind of down like that [demonstrates]. Well, I can't use conventional communication satellites, but I could use this TDRS satellite, at least for four hours a day, which is a lot better than anything they'd ever seen before.

So fast-forward to the following summer for us, winter for them. The [medical] doctor that was wintering over at the South Pole was Jerri [L.] Nielsen, who diagnosed herself with breast cancer. We were able to use the TDRS to do telemedicine and then also to get a rescue flight in to go get her. That was one of the first things that I got to do at Headquarters, and we only turned it off, I think, in 2010.

You think about the lifetime that that satellite had—Dr. Nielsen was just the first of many that were able to use the telemedicine and were able to be extracted out of the South Pole in what would normally inaccessible. Plus all the science that you could do. Instead of flying all these mag [magnetic] tapes on a [Lockheed] C-130 [Hercules aircraft] to the Pole—putting all your data, six months, on the mag tapes, flying all those tapes out—they could actually collaborate with their co-investigators around the world throughout the winter over a period.

It was a diverse portfolio, a very different kind of a job up here inside the Beltway than down at the Johnson Space Center, I'll tell you that. It was a very interesting time to be up here. We were very very busy, and big flight rate, and lots of interesting things to do.

WRIGHT: Station was really taking off, wasn't it?

READDY: Station was about to get cranked up. Our first Station flight was in 2000 with Bill [William M.] Shepherd as the commander and Sergei [K.] Krikalev and [Yuri P. Gidzenko]. Getting the Space Station going, the Shuttle was just doing a terrific job. You think about all the different missions it was flying. Of course, the one that everybody noticed probably wasn't building the Space Station. It was probably repairing the Hubble Space Telescope, which we got to do more times than anybody would have ever expected.

WRIGHT: Would you like to talk about some of that? One of the things I wanted to talk to you about was some of the legislative work that your job also involved, talking to Capitol Hill and explaining the science, the Hubble.

READDY: Hubble is obviously still a very high-profile telescope. NASA has lots of telescopes in orbit, but that's the one that seems to get the most attention still, and I think deservedly so. It's a remarkable testament to the foresight of the people that designed the telescope that it could be serviced on orbit. That's one remarkable thing. Fortunately it was, because that allowed them to design the COSTAR [Corrective Optics Space Telescope Axial Replacement] instrument to correct the flaw in the optics, and that totally changed the fate of the telescope. Not that it wasn't doing science before, it just wasn't doing the science that they promised. That allowed them to fulfill the promise of the Hubble. The very first servicing mission happened around Christmastime in '93. That was the first visit to Hubble, and that was the one that corrected the optics and really got them going.

Then early on while I was at Headquarters there was a fairly immediate need to go visit the Hubble. We had actually planned the Shuttle radar topography mission, and we wound up putting that off for some period of time so that we could go to the Hubble sooner. I think it was a matter of gyro [gyroscope] failure. We were going to replace gyros, and we also replaced solar arrays and things like that.

That was kind of a repeating theme. Because they could service it, they kept coming up with great enhancements to the telescope optics and systems, which just made it better and better and better over time. That's fortunate, because we're still a couple years away from launching the James Webb Space Telescope, which was intended to be its replacement. That was back in 2005 or 2006 or 2007, so it's great that the Hubble continues to soldier on the way it has.

One of the interesting sidelights—the last Shuttle visit to Hubble, some of the work they were able to do was made possible because we didn't think we were going to be able to do it with the Shuttle. Frank [J.] Cepollina and his servicing team out of [NASA] Goddard [Space Flight Center, Greenbelt, Maryland], faced with the prospect that we couldn't fly the Shuttle anymore, had developed a number of tools that a robot could have used to remove a whole bunch of fasteners and replace different things. We used a human instead of the robot, but the techniques and the tools that were developed for robotic use were what was used on the last servicing mission.

WRIGHT: You had some controversy surrounding that one because it had been cancelled and then resurrected.

READDY: Yes. If you think about the timing, the [*Columbia* STS-107] accident happened February first [2003]. During the summer, Admiral [Harold W. "Hal"] Gehman and his team [*Columbia* Accident Investigation Board] were still completing their fact-finding, and it wasn't until early in the summer that we actually found the pieces of the wing leading edge and parts of the wing that allowed us to conclusively determine that's what caused the accident. Up to that point there were still several different theories, but that allowed us to really know what happened precisely. It wasn't until probably August or so that we got their final report and knew what we really needed to do to return to flight.

We had some ideas what that might be and scoped how long it was going to take us to do that, and at the time there were a number of competing things. One was the folks at Goddard had said, "On Hubble we've got battery problems. They won't last long enough to make servicing feasible." If return to flight takes this amount of time, the batteries won't last. If the batteries don't last, then the heaters don't work on the structure, the structure deforms. As soon as the structure deforms on a telescope, there's no way that you'll ever be able to get it back in alignment so that it would be useful. That was one of the issues, and I think there was something else again with gyros.

Faced with the fact that return to flight was going to take much longer than the estimated life of the telescope, Ed [Edward J.] Weiler and others decided that in the risk trade it wasn't worth trying to accelerate return to flight. It wasn't worth adding additional risk to the Shuttle crew members to do a servicing mission, so for some time there, a number of months, the mission was cancelled officially.

Then the people out at Goddard starting working on the systems of the telescope. They managed the batteries differently so you got more battery life. They came up with a couple degraded modes that would enable the telescope to continue to perform on orbit with less than three gyroscopes; they had a single gyroscope science package. That had previously been a topic that could not be discussed. "Impossible, can't do it." Well, what happens if you had to do it? "Well, we could get some science. It wouldn't be the science we want, but we could get some."

You start to peel back the different layers and you realize that, yes, we can make the telescope last longer. As soon as you make the telescope last longer, all of a sudden it fits within the return to flight envelope. Fortunately, many of us felt that we would not want to preclude doing a Hubble repair mission, so we made sure that all the things that we did in return to flight would accommodate self-inspection of the Space Shuttle and other things that would allow you to go refurbish the telescope one last time.

We accommodated all those things into the return to flight package, and then we got our external reviewers to go off and look at the different trades. For example, if you launched [and flew to] the Hubble Space Telescope, there is no safe haven. One of the prerequisites for us going back to flight was a safe haven aboard the International Space Station. The crew's got to have some place to hang out for a while until we can get another Shuttle up there, until we can arrange for rescue on the Soyuzes, or whatever. Obviously that possibility doesn't exist at the telescope, so you need to be able to inspect yourself.

You need to do a whole number of other things. If you launch due east, we no longer had any transatlantic abort sites due east. Banjul [International Airport, Gambia] had been shut down and so had our site in Ben Guerir, Morocco. Fortuitously the Shuttle, when it goes up to Hubble, is on a very high performance trajectory, and also the Shuttle is very very lightweight. So very shortly after you lift off, you can lose an engine and still make it to orbit. You didn't need an overseas landing site for ascent coverage anyhow.

You start to knock down all those different constraints, and then it comes down to benefits versus the risks, and I think the science community overwhelmingly supported doing that. Whereas before some of them had been probably of a mind the money would be better spent trying to accelerate the James Webb Telescope, I think ultimately the science community all rallied around the Hubble and flying another Hubble repair mission.

If maybe some of them were a little bit late arriving at that conclusion or deciding to support that, the American public was behind the Hubble repair mission from the very beginning. I don't think we ever got so much mail as the day after the announcement from OMB [Office of Management and Budget] leaked out that we weren't going to do a Hubble repair mission. We got more mail than we'd ever seen, and it all had to do with the Hubble.

I think without some 20/20 hindsight, NASA also got an awful lot of mail when Hubble was first deployed and they realized that they had a flaw in the optics. It was $2 billion of space junk and all that. It is kind of interesting. You turn it from the sow's ear into the silk purse, and now you're going to abandon that? You couldn't possibly do that. And rightly so, because it still obviously has got plenty of life left in it, and it would have been a shame not to have done that mission.

WRIGHT: You had quite a diversity of challenges as associate administrator at NASA Headquarters. You had a lot of history with the Russians. How were you able to apply that experience into working with some of the International Space Station negotiations and requirements that you were using for the build-out?

READDY: Fortunately I had a couple of people that were very skilled at that, that had a very long history working for Space Station Freedom, and then the redesign, the International Space Station. I had a deputy for Space Station, who was Mike Hawes, William Michael Hawes. He was just exceptional at dealing with the Russians.

One of the smartest things I did was when I became the associate administrator—I needed a deputy to do my old job, and I split it up. Mike [Michael C.] Kostelnik came in and ran herd on Shuttle and Station, predominantly Shuttle. Then I needed another deputy, so we hired Lynn Cline, who had previously been in the office of international relations. She had spent her entire career working with the U.N. [United Nations], working with the Russians, working with the Japanese and everybody else. So we had a team that was already very experienced working on all those issues, and I think they brought that experience to bear.

We had rough spots. We would disagree about EVA protocols or the number of crew members. It used to come down to the safety community didn't like the way the Russians had certified the batteries. There would be these little brushfires that would occur from time to time, but I think in aggregate we got along very well.

I have to say that in the aftermath of *Columbia* the Russians were terrific partners. They lived up to every agreement that they'd ever signed with us, they provided the progresses on the Soyuzes on time. And the same with the other international partners too, the Europeans and the Japanese and the Canadians. They really all rallied around NASA during return to flight, and I think the Space Station partnership got a lot stronger for it.

WRIGHT: After the loss of the Space Shuttle *Columbia* you were serving as a chair of the Space Flight Leadership Council. Can you talk a little bit about those responsibilities?

READDY: Mike Haas was extremely helpful there. First thing we did is we went back and reread the Rogers Commission Report and looked at the implementation and said, "How are we going to structure how we respond to Admiral Gehman?" That's where the Stafford-[Richard O.] Covey [Return to Flight Task Group] external review came into being. They had the Gehman Report on one side and they had NASA's submittals for closure on the other side, and they refereed whether we had complied with the letter and the intent of the Gehman recommendations.

The Space Flight Leadership Council that we put up was a little bit of a hybrid from what had been done previously in return to flight. I think the one significant difference was I wanted to make sure that the contractors had seats at the table. Typically, and maybe even during the *Challenger*, the contractor reports up through their NASA manager, and the NASA manager sits at the table. So the information winds up getting filtered a number of times. One of the things that *Columbia* Accident Investigation Board said was there was an issue with communications, so I figured that one of the ways was to get them at the table. We rotated. It wasn't everybody come up to Headquarters. We moved it from site to site, from field center to contractor site, to field center, to contractor site, to make sure that it was very inclusive.

The other thing where I got tremendous leadership and support from Sean O'Keefe as the [NASA] administrator—the way NASA was organized at the time, Office of Space Flight had four field centers that reported to it: Johnson, Marshall [Space Flight Center, Huntsville, Alabama], Kennedy, and Stennis [Space Center, Mississippi], and then some of the test activities. Earth science had Goddard, and space science had JPL [Jet Propulsion Laboratory, Pasadena, California]. Aeronautics had Lewis, Ames [Research Center, Moffett Field, California], Dryden [Flight Research Center, Edwards, California], and Langley [Research Center, Hampton, Virginia].

The way the field centers were organized, they ran up through a mission directorate and they reported to the associate administrator. There was a thought that *Columbia* was obviously a Shuttle problem, Office of Space Flight responsibility. Briefly there was the notion that Langley would not be involved in return to flight, nor would Lewis, nor would Ames. Why would Goddard be involved, why would JPL be involved?

One of the things that we realized immediately is everybody's got a role to play. I mean, there's tremendous wealth of expertise in all those field centers. They can all do something on return to flight, and I think that's where Sean was just critical. We would have a Monday morning Headquarters tag-up. It was either a telecon [telephone conference] or a VTC [video teleconference], and everybody is reporting on what's going on in their center this week and what they accomplished last week.

Sean said, "Okay, what did you do for return to flight this week?"

They went, "Huh, what do you mean? That's space flight stuff."

He said, "Well, no. What did you do for return to flight? This is a NASA problem, this is NASA return to flight."

It didn't last more than seconds, and then everybody got in step. I think some of the really clever solutions that we got came from the aeronautic centers. For example, who knew that one of the problems we were going to have had to do with lubricants in the space environment? Lubricants for mechanical systems like the rudder, the speed brake, doors that opened and closed—well, who has expertise in lubricants? Turns out NASA Glenn does. NASA Glenn has the world's foremost tribologists—tribologists, the science of lubrication—they had the answers. If you want somebody in mechanical systems, it might not be at the Johnson Space Center or KSC.

I think working together we got an awful lot more brain power focused on some of the really vexing problems. Some of the things that I remember seeing in the Gehman Report initially were really mission impossible. There was just no way we could figure out how to do that, and we did it.

WRIGHT: Your decision to leave NASA was also in 2005.

READDY: It was, it was. When Mike [Michael D.] Griffin showed up as the [NASA] administrator in April, we had a series of discussions about the trajectory of human space flight. What that meant for Shuttle, what that meant for Station, and other parts of my portfolio that at the time were still launch vehicles, space coms and the four field centers.

I had two things that I wanted to get accomplished before I considered doing anything else: return to flight, which was in July of ’05, and the Mars Reconnaissance Orbiter, which was [August]. Those were the two major things. The other milestones in the Space Station were all sorted out. The launches that we had, the replenishing the TDRS constellation were done. I thought that was a good break point.

I’d been up at Headquarters for a long time and during some fairly trying circumstances, so I thought that would be a good time to try something else. I thought briefly about staying at NASA, but I was eligible to retire at that point, and I hadn’t seen my family in a long time and I had some other things that I wanted to go accomplish. It seemed to be the right breakpoint, and I think I made the right decision at the right time.

WRIGHT: You ventured off into your own business, is that correct?

READDY: Yes, different parts of the aerospace business. Not government work, not NASA work, but challenging, new, different. The other thing is as a government person, and in particular in the senior executive [service] ranks, you can't do pro bono philanthropic things, and that was something that I had wanted to do for a while. So shortly after I left, I joined the board of the *Challenger* Center [for Space Science Education] and a couple other nonprofits. A little bit of business, a little bit of nonprofit, a lot of family. A different balance.

WRIGHT: And a very robust legacy, you established a lot there. I have one other question we always like to ask the people. You've met so many people, you've left with so many friends. Do you still have established relationships with the people that you worked with?

READDY: Oh yes, absolutely. I really always enjoyed doing Silver Snoopys and spending time out with the troops. To the general public, it's just awesome watching the Shuttle launch, watching it come home. It's overwhelming, particularly the folks that actually get to go and see it. But it's not about the smoke and noise. That's the part that captures everybody's imagination, but you realize that the vehicle didn't integrate itself, didn't motivate itself to the launch pad.

The mission didn't plan itself, and everybody that's involved in all those different steps, hundreds of thousands of different steps in order to get to the point where all that works, that's what you come away with. We just have such an incredible wealth of talent. It's amazing what you can do when people are motivated by a common sense of mission. Everything else kind of goes by the wayside. And it's that sense of mission that allows somebody on third shift to make the right decision without somebody looking over their shoulder. That's what I think is so different about what we do, people really feel very personally involved in what they do.

Tom [Thomas K. "Ken"] Mattingly used to tell the story—he didn't get to fly on Apollo 13, but he got to fly later. He was nosing around the Saturn V [rocket] the night before launch, and they noticed he was the only guy not in a bunny suit. He was in the area in between the stages, where the inertial measurement unit was, and there was this technician in there. T.K. started talking to him, asked him what he was doing, and then the technician said, "Mr. Mattingly, I don't know if you're going to make it to the Moon or not."

He says, "This is awfully complicated stuff and I don't know about anything but this here, but I'll guarantee you if you don't get to the Moon, it's not going to be because of me and my stuff." That's the kind of ownership, that's the kind of sense of purpose and sense of mission that was just spread throughout the contractor and NASA civil service team that allowed us to be so successful for so long.

WRIGHT: It was an amazing amazing legacy for the Shuttle. Any thoughts on its program closeout?

READDY: That was one of the things that I got involved in in the summer. Actually we'd started work on it before *Columbia* happened, but we got to work really hard. Simultaneously with the accident investigation return to flight, we were also working on the Vision for Space Exploration. We'd read all the previous reports and everything going back to the [Wernher] von Braun era. We wanted to make it simple and, we thought, compelling.

First was obviously return to flight, second was complete the International Space Station. Third—you're going to think that coming from a Shuttle guy, probably a Shuttle hugger and that this doesn't make any sense—the third one was make LEO, low-Earth orbit, the domain of commerce. Basically the thought was leave LEO behind so that you can continue exploring. Go back to the Moon and explore beyond. Moon, Mars, beyond—that was the Vision for Space Exploration in a nutshell.

Built into that was the notion that we're going to retire the Shuttle at some point. At that point, the Office of Management and Budget hadn't inserted the 10-year horizon in there, 2010 retire the Shuttle. We wanted to make it milestone-dependent, like when you're done with the International Space Station assembly and logistics, then you retire the Shuttle.

Well, got Shuttle retirement a little bit premature maybe, but you are going to retire the Shuttle. The thing is, if you want to explore beyond low-Earth orbit, wings and a tail are weight and complexity you don't need. If you're coming back from the Moon, you're going so fast, that kind of heat shield isn't ideal for being able to do that. If you're going to routinely go back and forth to the Moon, then maybe you're going to have something that goes back and forth to a Space Station for example, and then something that goes from the Space Station to the Moon and never goes into an atmosphere. So it's a very very different vehicle than the one that has to go through this 1-G soupy atmosphere, then go up into space and return through that same atmosphere going a couple, three thousand degrees. It enables you to look at space travel and space exploration in a completely different way.

Of course, the Moon is part of the Earth. I can challenge you to go out in the evening sky and show me where Mars is or Jupiter, and you might be able to pull it off. But I'll guarantee you anybody could go out in the backyard and point at the Moon. It is part of the Earth, and it is the perfect space port. It has one-sixth gravity, no atmosphere, abundant materials that you could use to make fuel and structures. You put a magnetic catapult on the surface of the Moon—abundant solar energy, you don't need a first stage. The Moon is your first stage.

Robert [A.] Heinlein said the Moon is halfway to anywhere in the solar system. Energy-wise, he's right. You use the Moon as your first stage, you can go back and forth to the Moon. You don't need to make it aerodynamic. The first stage can literally be the Moon with some kind of mag lev [magnetic levitation] or some other kind of device. Then if you want to get around the solar system, you probably want electrical or nuclear power, and you can leave all those main engines behind.

I think that if we ever want to aspire to go beyond lunar space, that's the way to do it. Developing the propulsion mechanisms to go to Mars—instead of in eight months, in maybe eight weeks. All of a sudden, the size of the mission gets way way down. The reliability of the systems goes way way down. The amount of food—it's the difference between packing for an overnight or packing for the whole summer when you realize you can't buy anything. If you didn't bring it, you don't have it.

It changes that. It becomes a very very different mission. I think we're right now in an era of consolidation. We're getting our feet back underneath us here in the Space Station. We'll learn a lot from Space Station, and we'll use that as the stepping stone to the next phase of human exploration.

WRIGHT: Sounds good, thank you. Jennifer, do you have a question?

ROSS-NAZZAL: I just have a couple of questions based on what you had said about the SCA. You seemed to indicate that you were looking at planes other than the 747.

READDY: We had to look at other planes. We were required to by the folks on the Hill and OMB. Fortunately, Rockwell had done a fairly extensive study years and years and years ago, before they selected the 747 in the first place. They had looked at the [Lockheed] C-5 Galaxy and at a number of other aircraft. At the time, believe it or not, even though we already had the engineering design for the 747, there were a number of folks that were trying to sell [McDonnell Douglas] DC-10s.

There were a lot of DC-10s available and they were very inexpensive, so we had to prove that the DC-10 was not a suitable aircraft. In your mind's eye, think of where you mount the Space Shuttle on the 747. The DC-10 had a center-mounted engine, which would have been immediately behind it. The other thing is the consequence of losing an engine when you've got three engines and a big draggy, heavy spacecraft on top.

We had to do some trade studies. We had to at least show that we had considered alternatives, and quite frankly, because we already had the experience with the other aircraft, the maintenance manuals for the other aircraft, we had people trained to maintain it—the whole operation was geared around the 747. We went out to look for an airplane that was as close to the one we had as possible, and turns out there were a number of used 747s on the market. American Airlines 747-123 was the first one we had, so we went out looking for a 747-100 Series.

We got one from Japan Airlines [Co., Ltd.], then fortuitously, about that same period of time Qantas Airlines [Limited], I think the largest operator of 747s at the time, decided they wanted to re-engine their airplanes from Pratt & Whitney engines to Rolls-Royce engines. They had a whole bunch of pristine jet engines that would be upgrades from what we had been flying, so we were able to work a deal with Qantas and got engines that had higher reliability, more thrust. Both of the Shuttle Carrier Aircraft got modified with JT9D-7Gs or -7Js. It was the best engine Pratt & Whitney made, and we were able to get that from Qantas.

ROSS-NAZZAL: What were some of the other mods [modifications], besides the engines? Were there structural modifications made to the vehicle?

READDY: No, it was pretty well over-engineered from that standpoint. One thing we did consider early on was eliminating the tip fins, those big huge end plates on the horizontal tail. We had a lot of experience flying the Shuttle-747 combination, and by that time there were aircraft that had active yaw stability augmentation systems. You could have put in place an active rudder, a rudder that was constantly correcting, rather than one that was static, and probably had equivalent stability to the airplane with those end plates by removing them.

We thought about doing that because it would have saved a bunch of weight and complexity, but then we got into the dissimilarities between the aircraft and the certification of a new aircraft and the new system. By the time we got done with that, it was just simpler to go ahead and build a couple more and bolt them on, and that’s what we did.

I think we did all the mods—the tires, wheels, the brakes—and then we incorporated whatever bulletins that Boeing recommended for the fleet operators that were flying 747s. Even though we weren’t flying 14 hours every day with our airplane, all the structural bulletins and things like that, we went ahead and put into our airplane. To my knowledge, we never missed a sortie with either airplane.

There was one other thing that cropped up, and it cropped up a couple times. Remember the Rogers Commission talking about having all your eggs in one basket? Well, we also decided that you probably didn't want to park the two 747s next to each other or anywhere close to each other. We had to have another base for the 747s. We had one out at El Paso [Texas] at Biggs Army Airfield, and we had one out at NASA Dryden, just to keep them away from one another. No one tornado is going to get both airplanes, no one fire, whatever act of god.

ROSS-NAZZAL: You had also mentioned at one point you actually lost an engine. Can you tell us about that?

READDY: I wasn't flying when that happened. I think Jack [A.] Nickel was flying when that happened. They were departing out of Edwards on a ferry mission and lost an engine, but had plenty of performance to power out of it and make a safe landing.

I remember looking at the performance of the Shuttle Carrier Aircraft when I first started getting involved with it. There was only one airplane that had worse engine-out performance than the Shuttle carrier airplane, and that was the original KC-135 tanker, which after the original version had undergone several different engine upgrades. So I was pretty intent on making sure that we upgraded the engines, because I'd flown the KC-135 and it was pretty anemic.

The places where we fly, out of Edwards in particular, is already 2,800 or 2,300 feet. It's already high. You go through El Paso, that's 4,000 feet. You operate under some fairly severe circumstances, so you just want to give yourself whatever margin you possibly can. That was one of the things that turns out was pretty easy to do, thanks to Qantas deciding that they wanted Rolls engines in their airplanes.

ROSS-NAZZAL: You mentioned you were working on the OV-105. I was curious, was *Columbia* up there for an OMDP [orbiter maintenance down period] at that point while you were working there? I thought I'd seen pictures.

READDY: No, it was all alone out there. *Discovery* and *Atlantis* were built side by side, and they're about identical. [OV]-103 [*Discovery*] rolled out first, then [OV]-104 [*Atlantis*]. 105, we had a number of thoughts. 105 could have been the first-glass cockpit, the first with GPS [global positioning system], the first with a number of things, but again, it's kind of like the SCA decision. We already had the drawings, we already had the engineering, we already had everything that we needed from 103, 104, and it just made not a lot of sense to change the configuration on 105.

At the time we were still considering doing a 106, so there was a 106 project going on. The idea was not unlike how Endeavour got built. *Endeavour* was built out of structural spares, so the idea was do you need another structural spares program or not? The decision was "not." We have plenty of spacecraft right now, given the flight rates that we're flying. They're going to be gently used, so there wasn't really any point. I don't know if anybody actually sat down and said, "We could lose one, and we could still continue." To my knowledge, nobody ever had that kind of explicit discussion about it, but certainly in the aftermath of *Columbia* would say that we had enough capacity to do the missions that we needed to.

ROSS-NAZZAL: Just one other question. As Rebecca mentioned, you flew as a mission specialist before you flew as a pilot. Were you ever approached by any of the other pilots in the office who had followed that same path, like Steve [Steven R.] Nagel?

READDY: Oh, yes. I think it might have even been Steve Nagel that said, “There’s no bad missions and there’s no bad seats.” And he was right, he was right.

ROSS-NAZZAL: Well, I’m sure I could continue asking you questions, but I think those are all the major ones.

READDY: Okay.

[End of interview]