NASA STS Recordation Oral History Project
Edited Oral History Transcript

Alex McCool, Jr.
Interviewed by Rebecca Wright
Huntsville, Alabama – May 11, 2011

WRIGHT: Today is May 11, 2011. This interview is being conducted with Alex McCool, [Jr.] in Huntsville, Alabama, as part of the NASA STS Recordation Oral History Project. Interviewer is Rebecca Wright, assisted by Jennifer Ross-Nazzal.

I want to thank you so much for letting us come into your home this morning and talk with you. We know you began as early as 1954 working with Wernher von Braun during those early days of the Redstone ballistic missile development, and you worked through the Apollo era focusing on propulsion, and into the [Space] Shuttle Program. There you served as Director of the Structures and Propulsion Laboratory at [NASA] Marshall Space Flight Center [Huntsville, Alabama, MSFC]. You led the engineering design of the Shuttle's propulsion elements, and we want to talk to you about that today. We'd like for you to share with us some of those challenges that you experienced during those first days as you and your team members and your colleagues throughout the agency and throughout the Center were trying to formulate what the requirements were going to be for the propulsion system for the Shuttle.

MCCOOL: In 1970 they formed a task team here to do the Phase B studies. That was done in conjunction with JSC [NASA Johnson Space Center, Houston, Texas] and KSC [NASA Kennedy Space Center, Florida] in those days, [NASA] Headquarters [Washington, DC], of course, was involved, but we had contracts. JSC's principal contractors at that time was North American Rockwell and also General Dynamics. Our contractor was McDonnell [Douglas] and

Martin [Marietta Corporation]. We had two competing contracts to look at the configuration, the different systems that came out of Phase A studies.

I spent two years, 1970 to '72, on the task team. They put together a team of folks, and we had a manager. Your [JSC's] manager was Bob [Robert F.] Thompson, and that's the reason today they call J.R. [James R. Thompson] "J.R." instead of "Bob" Thompson. I still call him Bob Thompson, because eventually he got into Shuttle, and that's another story that we can talk about later. But we worked a lot, and very close.

We had the Air Force working very closely with us also in those days, because they had certain requirements in terms of what payloads they wanted to fly, a lot of concern with cross range for landing, emergency, etc. A lot of that work was going on. We had meetings after meetings back and forth. The contracts were a lot of work; a lot of engineering work was going on. There were many, many configurations that came out of those studies. The name "Space Shuttle" came out even before Phase A. Max Akridge came up with that. It was his idea in pre-Phase A to call it Space Shuttle, so I'd like it to be part of the record.

We worked on all these various configurations, and we had engineering groups that worked with various engineering organizations within Marshall and worked very close with the contractors, and we would exchange ideas back and forth with our JSC friends and their contractors. There was a lot of that going on. It was intense, meetings after meetings, presentations, cost studies, you name it. That went on for some two years.

At that time we had what we call a flyback booster. It was going to be another big orbiter, but the [Shuttle] Orbiter sat on top of it. I don't have that model, by the way. There's a lot of them available. We went through all the studies on that thing, and it was going to really be a headache. I remember talking to Max [Maxime A.] Faget, somebody concerned with jet engines, how do you protect them coming back in during reentry. But, the bottom line is, we finally went away from that about 1972 and went to solid rocket boosters [SRBs].

It was a lot simpler and cost-wise probably a lot cheaper. You didn't need to have a crew like we would have on a flyback booster, including the Orbiter. There was a lot of trades that were done that said, "We ought to go to solid rocket boosters." Now, there had been some studies going on, and you're going to find out more about that talking to guys like Gerald [W.] Smith and J.R. Thompson about the different contractors. There were many contractors that could build solid rocket motors.

The background to that, and I need to just mention this, the Air Force had a program called the Titan in those days, and they had a contract with United Technologies, Chemical Systems Division. They're in San Jose, California. They built the Titan rocket, solid rocket motor, and that motor's 10 feet in diameter and wasn't near as big as what we needed. We needed to go 12 feet for us to get the performance in what we wanted to do. Their mission was more or less strap-ons to a large tank that they used for high performance, and of course they used it for missiles. Their background, just like Thiokol, came out of the Air Force program. Thiokol had a lot of experience with Minuteman [rockets], etc., so there was a lot of history with solid rocket motors.

In those days, the Germans that came over were always thinking liquid propellants, which are what we have with Shuttle; in other words, the external tank and the SSME, Space Shuttle main engine. They called them powder rockets in the old days, because they would use them on mortars or bombs, so they didn't particularly like the idea of that. One of the bad features about them is you can't shut them down. With a liquid propulsion engine, you could shut it down and continue to fly. With a solid rocket motor, the way you shut it down, you've got to have some kind of explosive device in the forward end of it to blow it out and neutralize the thrust. That is not easy. In other words, it's complex.

The other thing you like to be able to do is tailor the thrust when you're going uphill, which eventually we did with the solid rocket motors for Shuttle. What you're concerned about is going through maximum dynamic conditions—or what we call max Q—forces; if you can throttle it to get it back down like we do on Space Shuttle main engine during ascent. You could tailor some of that with a solid rocket motor the way you shape the forward segment, which we have what we call a star. The burn rate and the burning area is different up in that area, and it tailored the thrust going uphill to reduce the loads. We throttle down on Space Shuttle main engine, and throttle back up once we get through maximum dynamic pressure, and that's to alleviate the structural loads and concern on the vehicle, particularly the Orbiter.

The solid rocket motor, coming back to about 1972, it looked like that's what we ought to do. We hadn't done a lot of work at that time. We did do a lot of work on Space Shuttle main engine. That started way back in the late sixties, after we'd completed Apollo and had worked on the F-1 engine and also the J-2 engine. Our experience was real good coming from Saturn, using cryogenics. For example, liquid hydrogen as a fuel, liquid oxygen for the oxidizer.

Rocketry 101—I'm going to tell you, and I always do this with young people. In your car, you use gasoline or diesel fuel and air. In the old days you'd mix it in a carburetor, and you'd have a pump to put the gasoline into your cylinder, and you would ignite it with a spark plug. So we had to have a fuel and an oxidizer. We're going up out of the atmosphere. The Germans always pioneered liquid oxygen, liquid oxygen minus-297 Fahrenheit. If you go to liquid hydrogen, you're talking about minus-421. So cryogenics created a lot of problems.

As you know today, at four-dollar a gallon gasoline, you want to get more miles per gallon, and we call that specific impulse, the thrust divided by the mass flow. The higher the specific impulse, the more performance we get. In other words, going with liquid hydrogen, over, for example, kerosene, we get at least 35-40 percent increase in performance. Therefore, we want to stay with liquid hydrogen.

We'd had a lot of experience on the second stage and the third stage of Saturn, a lot of experience there, and we knew what some of the problems were, which we could incorporate with Space Shuttle main engine, and then the same thing with the external tank that was going to carry the propellants. I use the word "propellant" in the case where we're saying gasoline and the air and so forth, because we use, in Space Shuttle main engines, liquid hydrogen, liquid oxygen, which gives us high performance, no question.

The Space Shuttle main engine, today, is the most reliable engine and the most experienced engine and the best engine that anybody on this planet ever built. We've got over a million seconds of test time, including the flights. That was back in 2004. J.R. will tell you about it. J.R. was our manager on the engine, and I probably ought to get to that in a little bit when I start talking about the engine, because we had problems in early years on development of the engine. This is in the early seventies, and we had a lot of problems. We were blowing up the liquid oxygen pumps. Rocketdyne was our contractor, which was part of North American Aviation. Same thing, they built the J-2 engine and the F-1 engines for Saturn, good contractor, excellent people.

They built a facility up in Santa Susana. That's in the San Fernando Valley [California]. That's where they used to make westerns in the early days. Now it's all populated. They had a test site up there, and they were designing it to build this facility to test pumps. The pumps have pressures of six and seven thousand pounds per square inch. This was a new thing. They had to build a lot of propellant lines, because they had high pressure systems to carry the propellants. They had to weld those lines and had lots of problems in doing it. In fact, a company in Texas was doing a lot of the welding for Rocketdyne in those days.

They had a big fire up there, and eventually cost overruns and it was really a mess. We didn't get through a lot of testing, and it was thought the best thing was to just test the pumps on the engine, which we would do eventually anyway. So we used the engine as a test bed.

The MSFC Center Director got upset with the manager with NASA and the manager of Rocketdyne, and fired both of them. In 1974, we were going through a reorganization and that's when I was going to be in charge of Structure and Propulsion. J.R. Thompson, worked with us in the lab in Propulsion in those days. I had laid out four divisions, and he was going to be division chief for Propulsion. His deputy was Joe [Joseph] Lombardo. Joe was an MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts] graduate, finally ended up at Thiokol after his NASA retirement. He came here with the Army and came to work with us. Crackerjack Engineer. He was the deputy. I organized three other divisions, but J.R. was going to be my division chief.

The Center Director said he was going to put him as manager of the Space Shuttle main engine, so he was pulled out to do that job. I was glad he could do it and was going to be able to get that challenge, because I'd been involved in propulsion, and, of course, he had too, but he'd been on some other things there, like crew systems interface during Skylab. But, he goes over to take over the engine. We moved Joe Lombardo in as a division chief.

The key is they made a change at Rocketdyne, a fellow named Dominic [J.] Sanchini. He was a lawyer, but also an engineer, and went to Southern Cal [University of Southern California, Los Angeles]. J.R. went to Georgia Tech [Institute of Technology, Atlanta, Georgia] and the University of Alabama [Tuscaloosa]. Where I'm coming to in this was leadership. We got the right kind of leadership, both from the contractor and from the NASA side, and they're the only ones to this day, I believe that could have pulled this off on the Space Shuttle main engine. For everything that we have at Marshall—I don't know a whole lot about the Orbiter, but it was probably not any more complex. I'm going to show you some ball bearings and a few other things from the engine and what that engine had to do. It was a complete new design, and it was far higher performance than what we did previously with the J-2. Without getting too much in detail on that, I'm trying to give credit to J.R. and Sanchini for their leadership.

Then we had leadership in the contractors at the lower level, engineering and so forth, which NASA had also. And involved in all of that, we always had people from JSC and the crew system that would interface and work with us and participate with us, decisions and all the testing. So we kept this testing going on.

In the meantime, we started looking with JSC at what we call the Main Propulsion Test Article, MPTA. This is the flight configuration. If you think about what the Orbiter looks like, think about the propulsion system that goes with it, the feed lines, the pressurization, the tanks, the engine, the manifold, how you fill and drain. That was built and that was tested at our test facility, which is called [NASA] Stennis [Space Center, Mississippi] today. That was a separate test stand, a separate program. JSC participated in it. All this was headed up by Bob [Robert E.] Lindstrom.

He was our first manager when we got into getting the hardware, Bob Lindstrom. In fact, he was J.R.'s boss. His JSC counterpart at that time was Bob Thompson, and the two guys hit it off good. In fact, Bob still calls him to this day asking about his health. One of your questions was how long have we been working together? Well, it started because of these two guys; the two Bobs got their heads together. It's the leadership they had.

Of course, Bob Lindstrom probably told you he had managers for each of the elements, and likewise eventually I had managers when I was in Shuttle. And Gerald Smith ended up being one of the managers. George Hardy was another one. I don't know if he mentioned that to you. There were several of them. There were some military retirees that we had here also working with them, but Bob built a good organization.

They had some tough times out at Canoga Park in California. In fact, J.R. had an office out there. I spent three months out there. J.R. would come out from time to time, and his office was right next to Sanchini's, and we'd come out. I had a team out there. We were trying to get the liquid oxygen pump developed. We'd had all kinds of problems on that, and I had a team with my thermal, stress, hydrodynamics, you name it, and we spent a lot of time there in the plant.

Every afternoon at five o'clock, we'd go in Sanchini's office and get the entire team around the table. J.R. was in there one time. Now, just to show you how it was, one of the engineers had an almond farm and he'd bring almonds in. He'd roast them and bring them in. It was the biggest mess. We'd sit there and peel these things and eat almonds. Then they'd get in some deep technical discussions, and some real knock-downs. This was healthy for the program for discussing issues and coming to consensus.

Rocketdyne had a chief engineer by the name of Matt [Matthew C.] Ek, a big tall guy, about six-four. He'd be in there representing all the engineering, and J.R. and Sanchini would get into it. Then sometimes Sanchini would get into it with engineering, and they'd start cussing. I was in the Navy, I spent four years, and I know every cussword there is, and I'm not proud of that, but they'd get into it and I'd see these guys almost come to fists. And J.R. and Sanchini would get into it. And guess what? That night, right next door to the motel on Ventura Boulevard, here's Sanchini and J.R. eating pizza, drinking beer, like nothing happened, just buddy, buddy!

But I remember that one time going down the hall, Matt Ek put his hand on my shoulder. He said, "Mac, you know, I'm sorry you had to put up with all of this carrying-on, cussing and discussions. You're out here trying to help us." I never will forget he put his hand on my shoulder. It didn't faze me, but he apologized for all this goings-on. What I'm saying is we had an intimate relationship with our contractor and with each other, and you could say what you want and sometimes people maybe had to out-shout the other guy. It was something else, but it worked good, and the leadership was like that.

It was like that all the way to my last days on Shuttle. All these guys that I worked with in the program always encouraged that. We had a lot of good people. We'd have off sites [meetings] from time to time. Wherever it was, we had lots of them. In fact, [Ronald D.] Dittemore, the program manager, liked to play golf. We'd go to these places. I didn't play golf, but I'd enjoy watching it. I'd take my wife a lot of times. It was team building, so I spent a lot of time at this higher level of leadership and people and how it's made with folks.

I think a lot of it comes, really, from Von Braun and our days on the Saturn. He was a hands-on guy. He'd come around and you would see the leaders that way. They were all that way, hands-on people, and they'd always walk around, see what the people, the working troops were doing. They'd go to the shops. Von Braun would come in and look on the drawing board. We had in those days a big drawing board he'd want to look at. "Why don't you do it this way or do it that way?" And they'd say, "Yes, Dr. Von Braun," and they'd do it their own way after he walked off.

I'd go to Rocketdyne a lot of time with Von Braun. They'd say, "Wernher, you think we ought to do it this way or this way?" They'd want to know his input on some new concept or something, get his idea. He was a good engineer.

But he had good leaders. He called it his board of directors of leadership, and they would have these knockdowns in our conference room right here in the tenth floor conference room, and they'd get into some things. I saw him one time—I don't know what kind of cigarettes, a carton, a little box, he threw that thing across the table at one of the other Germans and hit him. Didn't hurt him, but, they'd get into it. He had that way, and we learned from that, the leadership. Getting good people around you, that was the reason they picked J.R., picked Gerald Smith and all those guys. In fact, we all worked together, all in the same place for a long time, and we learned from each other.

Give somebody a task, give them the tools and whatever he needed or she needed, and leave them alone, let them go do it. Let them stub their toe. Let them screw up. When they do a good job, reward them. So I think leadership, we've learned that from them. Shuttle was that way, especially my early days on Shuttle, I saw that. Especially with Bob Thompson from JSC, excellent leader, and then all the other guys, Arnie [Arnold D.] Aldrich and the guys that I worked with over the years, excellent people.

Those early years, at least in Apollo, we had some "hotdogs" in the program. I don't mean just some of the astronauts, but from our own people. "Look at me." When we got into Shuttle, you didn't have any of that. We got away from all the "hotdogs" being number one, and trying to be in the forefront, and I think that's helped.

Now, that's talking about the people. What I've seen, too, is more and more once I got into Shuttle and when I came over there and took over—I wasn't the first guy. Bob Lindstrom was the first guy that organized it, and there was two or three before me, [Gene] Porter Bridwell, Bob Marshall. They had a lot of gals working, particularly in the business world. But we had duties, program operating plans. Now, I'm not exaggerating. Those gals would put together notebooks that were several inches thick doing the cost and projection for the fiscal year to put it all together. Now, I can't think of Jim's last name. He was the cost guy that worked for Dittemore. We would work with him. They would come up, and he would help us. Each one of our projects had a business office.

I probably ought to stop right there and tell you how we were organized in the project. I had a deputy, and then each project was autonomous. I had four projects: external tank, solid rocket booster, solid rocket motor, Space Shuttle main engine. It's an outgrowth of what Lindstrom had, it came down that way, and each project had its own chief engineer. Each project had its own business office. Then they had their own staff to help them. In other words, chief engineer has a group, the guys who work in turbo machinery, guys that work combustion, working nozzles, somebody works with getting all the hardware systems together.

In addition, each project had its own resident office, wherever it is. For example, Martin Marietta was in New Orleans [Louisiana]. We had a resident office there, full-time, that reported back to the tank manager. Same thing at Rocketdyne; we had a resident office in Canoga Park. In addition, we had a resident office in Stennis to work with our contractor down there, plus the NASA people. And it's the same thing on the other projects. The SRB finally moved from here [Huntsville] to KSC, and we had a project office down there. In addition, we had another project office that reported to me, that supported everything else going on down there beside SRB. ETs [external tanks] in New Orleans, SSME in Canoga Park, Thiokol out in Ogden, Utah, Wasatch, we had a team out there. Each one was autonomous.

When I talk about the program operating plan, when I first went, four of them were managed by women, and I'd go to Washington with these folks, and, I'm telling you, they'd go toe-to-toe with those people up there in defending their budget, and what they needed. They had spent weeks and weeks and weeks on that plan, and they knew it better than anybody. I was really proud of them. My background had been more in engineering rather than all the cost and business aspects, so I depended heavily on them. I did have a business guy on my staff that worked with me, but I was really impressed with the way the women could do these things. I had one gal on the tank, she had a Ph.D. working for her, and he came over from the Army. I think he's still working on the tank.

I think today, when I look back and I see, I think the lord made women stronger than men. I know you appreciate that, but look at it from another way. I think women can do things that men can't do. Well, for sure, bearing babies and all that. That's part of it, but I think it's another thing, that women are far, far better equipped. When you think about it, you go in where they're doing PC [personal computer] boards in some of these factories, it's women everywhere. Why? Because they're good at details. My mother used to knit. She got so bad with arthritis she had to quit, but women can do things like that, and they're good at it. I think it's the same thing in business aspects.

When I say they're stronger, I mean spiritually, mentally, almost physically. I don't mean I can't pick up as much as you, or you can't pick up as much as me. I'm talking about how many do you know, the husband's left, she's got one or two kids, but she's able to raise those kids and live through life. Think about how many men have had to do that. Probably ten or twenty women compared to one man. So women can do things, I think, and I've learned that. I've learned that about the women, and I learned a lot, I guess, when I was in engineering.

Jan Davis, I don't know if you know Jan Davis, our astronaut. She worked in stress in my lab. In fact, I hired her, and actually I helped her get into flying and scuba diving and getting her doctorate to get into the Astronaut Corps. I was glad for her. When I see that, and I see how good she's done, and I get a blessing out of it. I really enjoy seeing how young people learn from their professional experience and how you've helped them develop, and I guess that's been my best thing I've enjoyed the most. I've been there, done that, I'm not looking for this, or any more things. I could take you upstairs and show you my study; all the walls are covered. I've been there, done that, but where I really get my jollies is when I see somebody do a good job.

And that's the way it used to be when we'd go to Washington for the business review. Our gals, they'd get up there and they'd present, and they'd spend hours. We spent hours up there.

A guy from Headquarters got into it with one of our managers, Cary [H.] Rutland. He was a solid rocket booster guy. It almost got personal, and then they finally ended up apologizing to each other. Some of these things can get out of hand, but the gals seem to be always cool, not like the guys. I've never seen any of the gals lose their cool and just go toe-to-toe, because they'd done their homework, smooth. I think it helped us, too, with the program. They'd go back to the program, they'd get support. I don't know. I think we men, we're just puppy dogs around the gals, I guess, we want to help them, and they could do things.

We had cost problems, no question, but they were able to get through that working with the program. The program was, of course, JSC after it was moved back to Houston from Washington, and they always were able to work and get what we wanted. We were always well off there and worked together because of the team. I don't ever remember interviewing or having to go to [Tommy W.] Holloway or Brewster [H.] Shaw or one of those guys for something in terms of business or cost, because they had done their homework and worked it out at a lower level, which is probably good. They had more important headaches to worry about, rather than me talking to them about that.

Then we get into the technical and start doing a lot of development. First, it was solid rocket motor, a lot of testing going on out there at Utah, full-scale tests. We didn't do much here in terms of testing until later, and it's the same thing as on the pumps. We didn't do much here other than components.

You asked the question about testing, so let me touch on that, because I think that's important. If you look at the German team, that's what they really emphasize, and they brought that to us to this country. Testing was important, most important, because there's only so much—now, you've got to think, back in those days, the same way in our early days in Saturn, we didn't have all the nice computers we have today, high speed. We didn't even have these little handheld things. In fact, we used slide rules in the early days on Saturn and graduated to Marchant mechanical calculators and Fridens and eventually got the IBMs. Besides that, we didn't have the tools, the analytical tools that we have today, so you can only do so much when you calculate or do predictions.

For example, I know in the early years on the tank, the tank was designed for around 76,000 pounds, I believe it was, but we used a safety factor of 1.4 to be sure, thinking you'd know all of what you had predicted on the loads, etc. Then we went back and said, "We need more performance," so they were able to go back and look at a lot of areas for well-defined loads, and they could reduce the safety factor in those areas to 1.25, which saved weight. Every pound of weight on the tank is another pound they get for the payload. That was done in the early days, and that was what they called the lightweight tank [66,800 pounds].

Eventually, we went for the high inclination for the Russians going to the Space Station, which is 51 degrees. We needed more performance, so they started looking at what we call a super lightweight tank, which used aluminum lithium, much lighter weight and higher strength, and was able to save some more weight, which is what we fly today, aluminum lithium [58,500 pounds]. Now, for a while we had headaches. They, in fact, almost lost the recipe for making this stuff, Reynolds aluminum, and they had to go back through our materials people and with the contractor, and finally worked that out, and that's helped. We didn't have a lot of the tools in those days, but we wanted to test.

You'd test on a component. For example, you build a valve. You'd like to know how that valve works. You test it in water, but if it's in cryogenics, you've got to put it in cryogenics, not just liquid oxygen. Most of the time they use liquid nitrogen, which is minus-300-something, but you like to test in liquid hydrogen if you can, because we got burned in Saturn on one of the missions.

This is before we flew Apollo 8, we learned this. I think it was Apollo 6. It was unmanned, one of the first Apollo missions, first stage, and we were going uphill. We had longitudinal oscillations; we called it pogo. We were able to identify what it was and we had discussions and we were able to replicate that. Then in a full-scale test, we had pre-valves very similar to what we have on the Shuttle, we had a cavity there, and we could put gas and gas pocket to attenuate or dampen that oscillation, and was able to prove that in Mississippi tests on a hot firing. So we convinced ourselves that's okay.

Second stage, we had an inadvertent shutdown on an engine. This was before Apollo 8. So we start doing some testing, had a lot of measurements of instrumentation, and bottom line, what finally happened was a flex line, it's a bellows line, and it was oscillating. It was oscillating in flight. When you go up in flight, there's no ice buildup like you'd had when you're testing on the ground. Liquid nitrogen builds up from the air on the outside of the line and that attenuates or dampened the flow and that line failed. A hydrogen line that failed spewed liquid hydrogen. The engine shut down going uphill. To finish that story on second stage, the pre-valves were crisscrossed inadvertently and it shut another engine down also, so two engines shut down.

The third stage, which had one engine, went into parking orbit, shut down, tried to restart, and it failed. The line had no dampening because of the ice buildup. We proved that here in a vacuum chamber, testing. We didn't know that at that time, in terms of testing, but we were able to test that and predict that's going to happen. We found a way to first replicate it and find a redesign to preclude that.

Before we leave that, Apollo 8 was coming up. George [M.] Low decided, "Hey, the Russians are getting close. Maybe we ought to go circumlunar." They had a come-to-Jesus party out here. Donald [W.] Douglas was there, and the only time I ever saw this guy. Von Braun was there. I was present there in that meeting. All the leaders, [Robert R.] Gilruth, all of them were here, George [E.] Mueller and his whole team, Sam [Samuel C.] Phillips, and they were here to discuss our problems and were we ready to go fly Apollo 8. We went through all the stuff in terms of understanding the problem, how we fixed the problem, how we replicate it, and how we proved that the new design was okay. They all signed up to it, and that's how we flew Apollo 8. They made the decision. Of course, that was 1968.

But, people don't realize today that Apollo 8 was critical for Apollo 11, when you think about it, but it gets back to testing, and there's only so much you can test on the ground. When you're going uphill, there's a lot of the aerodynamics—you say wind tunnel, but some of that you can't test. You do the best you can, but testing is very important. You do it at the component level, you do at the subsystem level, you do it at the system level. Now, some you can't do, then you instrument it when you're flying, so you get some learning. That's why we put in cameras, to fly and look at thermal protection coming off.

Testing is very important, and we learned that from the Germans. That was their philosophy and their theory, always test, test the way you fly if you can. Again, there's some things that we just can't test till you fly, but then you try to cover, in terms of safety factor or redundancy or putting in systems to preclude any kind of bad failure. The thermal protection system, that was [Space Shuttle] *Columbia* [STS-107 accident], you had that problem. Now, we tested in wind tunnels, lots of times, things that we did at Tullahoma [Tennessee]. So testing's important, very important.

I think another thing, too, that maybe I went over too fast, when we got into Shuttle we had a lot of new analytical programs that we were able to share with JSC and our contractors, ourselves, in terms of design. They came up with a lot of what we call finite element modeling, doing two-dimension and three-dimensional analysis on structures. Since I've left there, they've come up with, in terms of fluid dynamics, computation fluid dynamics [CFD].

NACA [National Advisory Committee for Aeronautics], the precursor of NASA, did a lot of those research things in the early days, and so we have those tools today. In fact, here in Huntsville, we have several companies that do CFD analysis for companies they started. Some of the guys that worked for NASA went off and started their companies. But we have a lot of new tools, analytical tools, that we didn't have in early years for sure, in Saturn, Apollo, even Gemini, or in early days on Shuttle. What you did is try to provide enough safety factors, and provide enough redundancy.

When I went to safety and mission assurance, J.R. was our Center Director, and that was in September 1986. We didn't have a good safety organization in those days. In fact, the safety guy had retired, and we didn't even have a safety officer at the Center, and I was ready for a change to get out of engineering. I'd been there, I think, 12 years, had been looking for a change, and I could see the need. So he said, yes, he wanted me to. We got two or three people that could help me, somebody that'd worked more in the avionics and electrical field. I had a quality guy that had been there before, and then some other folks, but then they were able to help me.

The first thing I do, I get on the phone talking to my JSC buddy. I need a crew rep [representative]. Mr. Charlie [F.] Bolden [current NASA Administrator] was my man. He was my crew rep in those days, and I really appreciate that Charlie was able to help us on some things. We got into a lot of risk-assessment stuff, and then—who's Code Q now?

WRIGHT: Bryan [D.] O'Connor?

MCCOOL: Bryan O'Connor.

WRIGHT: I think they've changed the names, but he is the Chief of Safety and Mission Assurance [S&MA].

MCCOOL: Before that George [A.] Rodney was [Associate Administrator for Safety, Reliability and Quality Assurance]. He's an old pilot himself, and he'd tell me the story about when he worked at Martin years ago, when engineering would say, "Hey, it's ready to go fly," and he'd say, "Okay, come on, get in." He was the test pilot, but he wanted the engineer sitting in there with him. He was Code Q during my days when I was in S&MA. His deputy was from MSFC, Jim [James H.] Ehl. He's still here. I still see him from time to time out at the gym. He went to Headquarters and then came back, in fact, he took my place when I left S&MA. Jim Ehl, a good, solid guy.

He helped us put in what we called risk management, and a lot of analysis went into looking at failure effects and how you manage these things, and do you have enough redundancy. This was after [Space Shuttle] *Challenger* [STS 51-L accident]; a lot of emphasis on safety, reviews after reviews after reviews, checks and balances. We tried to do that here at Marshall, reinvigorate what our safety and mission assurance was, put in a lot of this risk-assessment stuff, put in things like we did at Thiokol, what we called fingerprinting. They had a system for their materials. All their receiving would come in, now what does that equipment look like? What is it you buy? They used a lot of epoxies and a lot of material things. How do you know that's the right stuff? What is the shelf life? When the materials would come in, they had a database and they put a lot of procedures in place, things to make sure that you know what you got and what you're using. The same thing when you get ready to use it, if the guy on the floor has got to have quality there, and the shelf life on this material that he's using.

WRIGHT: Now, was this quite a bit different from what you prepared for STS-1, the things that you're talking about?

MCCOOL: Yes, this was all after *Challenger*, a lot of other things that we put in place. There was a lot of reviews, too, and we'd have some knockdowns in engineering. They'd say, "Here comes the quality guy. Look out." I tried to get our folks to understand, "Look," I said, "we want you to be a part of the team and not going around playing 'Gotcha'. You're not doing that. Tell them what it is when you find it and see what you can do to make it better in the process." It all boils down to processes and with people, people trusting each other. In other words, teamwork. This is at the floor level, not going around playing "Gotcha." And they had a little of that type of thinking, some of the quality people in the early years. A lot of that changed after *Challenger*.

We had had a flight in early January [1986], and there was some kind of payload on there. I don't even know what it was. They landed at Edwards [Air Force Base, California], and they brought it back, and it was at the Cape [Canaveral, Florida]. They said, "Hey, McCool, we want a senior guy. You pull together a team and go down there, look at this hardware and figure out where it was." They were always setting up teams to do stuff like that.

We fly down on our little King Air the day before they were supposed to fly *Challenger*. We go to the O&C [Operations and Checkout Building] and there's the hardware. We look at it, get a plan, start figuring out what we're going to do and work with the KSC guys. Whoever the payload manager was at that time, met us down there to see what we were going to do.

The next day is the *Challenger* launch. I was not involved in the discussion prior to launch. Of course, it's January 28, 1986. They have some boxcars across from the LCC [Launch Control Center], and I go over there to stand up on the boxcars, and I have some binoculars, and I'm going to watch the launch. That's where I was for *Challenger*. I looked—

Rebecca, I'm getting goose bumps. Really, I cannot believe. I thought a LOX pump, liquid oxygen pump, had blown up, because I'd seen them happen just like that. It happens instantaneous and it wipes out everything. Man, it's kind of weird thinking about that, but when I saw it, that's really what I thought had happened. Next thing I see, I see the motors doing something like that, crossing [demonstrates].

Well, everybody's in shock and we go back and we meet in the LCC, all of us over there, the leadership. I go over there, and everybody's in the room, and I think it was midnight before we got away from there to come back home. Everybody's thinking that it was the engine that had blown up. In fact, the guy that was the manager on the tank, he worked for Lindstrom, he wanted to buy drinks on the plane for the engine guys when we were coming back. I came back with them. We had the system set up with the contingency teams to investigate the accident.

The next morning, my team—I was the inertial upper-stage [IUS] team. That's the Air Force, and we had two solid rocket motors with a payload in there, and it was a TDRSS [tracking and data relay satellite system]. I was the team leader, and I had to get all the team together, plus the Air Force, plus their contractor, Aerospace, all of them had come in, because we thought maybe one of those motors blew up. We had two solid rocket motors in the payload bay, and we had to exonerate those. We did that in about five days. The guys came and we worked around the clock to get them, and we settled that.

February 9, [Robert L.] Crippen called. He was down at KSC and in that area, and they wanted to set up a team to work with the Navy, identifying the hardware. The Navy was already out there doing bottom searches. I get on the plane, go back down there to the Cape and plan to stay. I had, I guess, five, six people I took with me.

We didn't get involved in anything with the Orbiter. They recovered the engines. We went over and looked at them, but we started working with the Navy. They set up shop on the Air Force side. I can't remember the Navy Captain's name, but he was the superintendent of salvage. I really looked up to him. He was tough as nails, and he knew what he was doing. He had a contractor. In fact, the contractor works in Houston [Steadfast Engineering].

The ships were already out there doing side scan sonar, back and forth, and they would take these traces and they'd send them in by courier, and their contractor could look on there and identify certain things. They had the *USS Hyman G. Rickover* nuclear research sub [submarine], 118 feet long, and it had cameras. He could stay under water for two weeks. We had another one called a Johnson Sea Link [submersible] out of Fort Pierce, Florida. That's Johnson & Johnson Pharmaceutical. They do hydrographic research studies; very good, excellent cameras, just like a helicopter bubble, and it carries a crew of three. One of my guys would go with them, and they'd identify a certain area where a piece of something, the solid rocket motor is. Remember, they blew it up. It was all fragmented from the range safety system, and here we're trying to find the hardware that caused the problem.

They would see something and they'd send the ship down, and he had underwater photography. Then they'd send these images in. We had about six TVs up there to review, and I had my people sitting there to identify what you could see. Another thing we were concerned about was hazards, because we had hypergolic fuel in the aft skirt, and we had range safety [explosives], so you had to tell them if there was anything safety-wise for them. We'd try to identify [debris]. I'd say, "What about this? What about that? Do we want that?" They started picking up [debris] for us. I guess we were doing that maybe at the end of February.

I get a call seven o'clock in the morning from KSC, and they said they believe they have found the piece and recovered it. They had a North Sea salvage ship, it was out about forty miles, with a hundred-ton crane. I said, "Yeah, let's go." So they lined us up to go out on a Coast Guard cutter, another person and myself, just the two of us, that Sunday morning.

We go to Port Canaveral to get on the boat, and one of the crew said, "Hey, it's going to be rough out there today."

I said, "You got anything to put on the back of my ear [patch for sea sickness]?"

"No," he said, "but I can give you a Band-aid to make you think you got something." [laughter] So we go to the drugstore and get some Dramamine.

We go out there and there's this big derrick on this salvage ship. The next thing I know, they're putting out a twelve-foot Zodiac [rigid inflatable boat] with an outboard motor, and this coxswain gets on his rain suit and life jacket, and I'm about to wet my britches, I'm telling you, golly. We get in that pontoon boat and go over to the ship, and I look up and here's this Jacob's ladder hanging out the side. He said, "Grab a hold of that thing. Climb up."

I'm hanging on, and I'm the first one. When you make it to the steps, it's just two ropes hanging down. I said, "Leon, hold that bottom ladder down. Hold that board, it's twisting on me," and I'm so nervous. Then I get up to the top—it looked like a hundred feet up there; it wasn't that far; thirty feet or whatever—these arms grabbed me and lifted me over the rail. First thing I say, "Where's the head?" In the Navy that's a restroom, so they take me there.

We go down on deck and there's that big chunk of steel, and it was the forward part of the motor, and you could see where the 5,000 degrees—remember, now, inside that motor it's 5,000 degrees, and it's chafing that metal, cutting that metal—and you could see where it was. We had cameras, started taking a lot of pictures, and then we tried to take some measurements.

We had a tape measure and got a big piece of cardboard, and we just traced what it was and then took all that back. We spent about an hour on the boat, and then the coxswain came back to retrieve us.

He got sick as a dog, Leon did, my buddy. I didn't get sick, but the captain told us to go stay in his cabin—he had TV. I didn't even want to watch TV. We got back about midnight to the port, and I told Leon, "We're going to have to be there early in the morning." Because all those guys, J.R., Bob Crippen, all of them, they wanted to see. They told the ship to bring that in, and in the meantime, they developed the pictures, the film. Sure enough, it was the part that failed!

We located it over on the Air Force side. They set up a separate hangar for us, because a lot of times you have propellant still there and it has saltwater on it, it can leach out and it can be hazardous. Some of the Rogers Commission [presidential commission investigating the accident] came over to look at it, I remember that, and we spent a lot of time with them.

Then after that, I left, came back, and that's another story, but the Air Force blew up a Titan in California, and I went out to that. In the meantime, all our folks started doing redesign, and we can talk a little bit about that if you want to.

This is an O-ring [demonstrating]. That's the O-ring, and it's a Viton [fluoroelastomer]. You can pinch it. See how hard it is? Now imagine in the wintertime, cold, cold weather. You don't have that problem in Houston like we do. Your car has been sitting outside, it got down low temperature, and your tires get real hard, and that's what happened with the rubber. Well, that thing goes around, and it's 12 feet in diameter, remember. Multiply that times pi to get the length. Let me first show you what we got here. This is the way the design is. This is actual size and everything. This is where the pin goes. Look good. You can see the O-ring. See the O-ring?

WRIGHT: Yes.

MCCOOL: That's the O-ring. Now visualize, this is the tank coming around. This is just a slice out of that tank. It's 12 feet in diameter, and that's from here over there. That's the diameter. This goes all the way around, and that little O-ring is to keep the hot gas—inside it's 5,000 degrees temperature. What is the propellant burning? Let me back up just a second.

You got a big igniter on top of this thing. It's another solid rocket motor, and it's like a doughnut. Visualize a hole in a doughnut. There's a hole in the middle, and here's this hot gas coming down, igniting all this propellant, so it burns from the inside to the outside, 5,000 degrees. Now, there's insulation inside the tank, but it doesn't take long if you get past all this.

What happened, if you remember, on Shuttle, T minus six minutes, we light off the SSME and the whole vehicle does this [demonstrates shifting movement]. Have you seen it? See where the engine's on the rear? They're asymmetrical to the center line of the Orbiter, so the vehicle rotates over twenty-one inches right at ignition, T minus six seconds, it does this. When it did that, it unseated one of these O-rings. "Pfft." Here comes the hot gas, spews on the hydrogen tanks. It started the failure. Now, the reason I know that, we have film now to prove that. They saw the flame impinge on the tank, actually. That was after the fact that they developed that, so that was the problem.

For redesign, they went to something called—the same thing that I was showing you there, and it has three O-rings. It's triple redundant. In fact, on the first test, what we did at

Thiokol, we agreed, let's score this seal. In other words, just put a scratch on it and see if the hot gas can get past it. J.R. was there, and a group of us went out and we had to climb up this ladder, put your hand up on the motor case after the firing to see if it was hot, or if it was warm. When they disassembled the hardware, sure enough, it still worked good. So that's the way we've been flying.

Now you say why did you design it this way originally? That's the way the Titan did. That was our experience in those days, so we went to something like this. There's four segments that you put together. There are no welds in these cylinders, about a half inch thick, and you can almost see it there, the thickness. High-strength steel. The chamber pressure is about 1,000 psi, 1,000 pounds per square inch inside. You got high pressure. This is the pin [demonstrates]. You put it together. Now this was a Titan pin. This is what our pin looks like—it's an inch in diameter; larger than the Titan, and they tap them in with a mallet. There's many hundred to go around the circumference of the segments.

See how they put it together? Now, they got a crane; it's actually suspended there, and it takes it around there and they tap these in, and that's where the pin is. That pin I just showed you is right there.

That was the design. They experimented with different kinds of rubber for the O-ring. It was almost two years before we got back to flying because of the redesign and testing, and then we had to convince ourselves that we'd done the right thing. Now, lots of testing was done to go back and prove that the design's going to work.

STS-26 is the first time we flew the redesign. That was in September 1988. I never will forget, my wife—that's going to stay in my mind—found out she had ovarian cancer, and we took the family and went out for that launch. It was going back to flying in 1988. We were down there for that, and everything turned out good after we saw the hardware. Then she went in and had her operation and had to have chemo. She's cured, 1988, from those days. I never will forget that. That was our flight, 1988, September.

It was traumatic for me when you see what happened. It was just something else. Golly. I think at first it was a bad decision. They shouldn't have tried to push to fly. We had flown earlier, a few weeks earlier in January 1986.

Let me back up just a second. In January of '85, we had a DoD [Department of Defense] mission, STS 51-C. I didn't tell you all about that. It was a DoD mission and it was successful, but we had ice out there. We stayed at a motel there in Cocoa Beach [Florida]. My wife and I went down. They had water sprinklers for the grass and they were all just solid ice. It was January of '85. *Challenger*, in January 1986, was just as bad. We didn't have any problems on STS 51-C.

WRIGHT: What was one of the biggest things that you had to overcome? And maybe discuss some of the evolution of the propulsion system from when you first were putting the requirements together until you left the program. What were some of the major changes that occurred through there?

MCCOOL: The one we talked about was the redesign on solid rocket motor, putting those changes in for that, that was a big challenge for us there. Space Shuttle main engine, we had a lot to do there, because you asked about upgrades and the safety. We spent a lot of time and a lot of money and a lot of effort with Rocketdyne, first on looking at how we change the engine, make it safer. Now, again, I can't overemphasize when you take a pump, rev it up to 35,000 revs, that fuel pump develops over 70,000 horsepower. You think about horsepower for your car, or how many railroad engines or how many Hoover Dams and those kinds of mechanical systems.

Here was a big challenge, to say can you make it safer. There's several ways that we looked at. If you take just the nozzle, if we opened up the throat—now, appreciate you have the combustion chamber—the higher the chamber pressure, the better performance. Then you think about a molecule up there where you're burning, come to the throat, and it's doing Mach 1, and then it goes supersonic as it gives up temperature and gains velocity. You want that. Well, we looked at opening up the throat to reduce the pressures in the system. Now, you lose a little performance, some of the miles per gallon I was talking about.

We were able to do that and open the throat up. What you're trying to do, ease up on some of the systems so they're not operating at their higher pressures and higher temperatures. That was one that was done and it was done successfully, we've been flying.

Another one, and I cannot remember the Administrator's name. He was the administrator during the *Challenger* time.

WRIGHT: Jim [James M.] Beggs.

MCCOOL: Thank you. Beggs. I couldn't remember that.

I was in his conference room and one of our people that was there making a presentation, but he was really making a point, and I don't know what it was. He wanted to try to get Pratt & Whitney. Pratt & Whitney has always been involved, and I knew them in World War II, in engines, then they were in jet engines. Good at rotating machinery. He wanted to get them under contract. Of course, Rocketdyne had the contract, but he told us, “You guys see what you can do to get what we call alternate turbo pumps.”

Now, think for a moment. Here you got a contractor, i.e., Rocketdyne, he’s built this complete system. You say, “Wait a minute. Time out. We want to put some other pump. We got this other contractor.” Just think about that for a moment. First you had to deal with the psychology of this thing. He didn’t like it, and we, of course, were a little bit concerned ourselves. You got all the interfaces you had to deal with. Pratt and Whitney, if you go back and look at history, they protested when Rocketdyne got the original contract for the Phase C D, and held it up being able to start work.

We got going with them, and was able to work all these interfaces with both of them, and they had a lot of new ideas. If you take the fuel pump that Rocketdyne had, the way they fabricated it, they had a lot of welds. Some of the welds were even difficult to inspect. You do x-ray and nondestructive evaluation to look at the welds. You always worried about one of the welds coming loose. You have high pressure inside, 7000 psi inside. What’s going to happen? Just like that it’s gone. They came up with precision castings; a new idea, new concept. How’d they know? They’d been working casting for turbine blades for years and years. They had new concepts. That was going to be a big gain in terms of reliability and safety. So that was the first one, was for the fuel pump, the casting.

Another big one that they pioneered, and I’ve got a little example I’ll show you here, was using bearings inside the pump. This is a roller bearing [demonstrating]. It’s made out of steel. It’s called 440-C steel. Feel this one. That’s a silicon nitride. It’s a ceramic bearing. That’s a roller bearing. This is a ball bearing. Take a hammer, you can’t even break that with a hammer. It doesn’t care anything about the temperature of loading.

What we used to do in the early days, we had to take the pumps off. We'd fly the first test, take the pumps off, put new bearings in, and have to overhaul the pumps. We just worried. With the alternate turbo pump with Pratt & Whitney, and our folks did a lot of work in developing this technology here, this silicon nitride bearing is very expensive. In fact, I went to a couple of companies in Germany where they make these and they showed us how they do it. You wonder how they make a round ball, and you have two plates. These are diamond wheels. They use industrial diamonds and grind them between, and that's how they make them round. Of course, it's a very precision operation.

I'll show you one problem. Feel this one. That's steel. Feel this one. This is a round one like that too. That's a ceramic bearing. They use them in chemical processes like acids. If you put acid on this steel, it'd eat it up, so we had those bearings and we've been flying those. Our folks did a lot of work out here at our material testing, bearing testing here at Marshall to support Pratt & Whitney on this new technology. That's helped us. That was a big change when we put both pumps on.

We've been flying several years now with the pumps, with the bearings and the new turbo pumps. The Space Shuttle main engine today flies with the Pratt & Whitney pumps. That doesn't matter, because they bought Rocketdyne, by the way. Boeing didn't want Rocketdyne, so that's part of the same company. We've been flying for many years now the fuel pump, we started earlier on it. Then we went to the LOX pump after that.

J.R. can give you all that background about the alternate turbo pump, but it's worked out better. It was a big challenge. I spent a lot of time on the engine. I think the engine really was probably the hardest thing for all of us in terms of technology and technological advancement.

If you look at another one that I hadn't talked to you about, but if you just take the J-2 engine, that's what we flew on Saturn. You had an oxidizer pump and a fuel pump, and both of them had propellants that came to one combustor. That's just a combustion chamber. Hot gas comes out, drives a turbine that drives the pumps and takes the propellants from the tank, forces it in the combustion chamber. You ignite it with a spark plug, like your car. It's a more exotic spark plug and exciter, and the pump will start going. You bring propellants in there to do that.

The Space Shuttle's main engine is what we call stage combustion, a complete new cycle. In the past (J-2) from that turbine I told you about, combustor and everything, you discharge all that gas overboard, so you didn't get the performance that you could have. In stage combustion, each pump has its own combustion chamber or what we call a pre-burner. You bring the two propellants into it, and each one operates individually its own pump, stage combustion. It goes in the main combustion chamber, and those exhaust gases come in there also. You don't waste anything and you get the additional performance. A big change in technology to go to that. The temperatures are higher. You worry about the loads on the turbine blades. You think about a little old turbine blade has got like seven and a half tons' load on it, with centrifugal forces.

Really, the engine, I think, was the biggest technological issue that we had to deal with and getting to where it is. Here we've been flying all these years and the engine's been wonderful, and today it's the most reliable system that we've got on Shuttle, and I don't know why we're not continuing to use it for whatever new vehicles we're looking at. That was probably the biggest one, using the pumps and then doing some of the other mods [modifications] that we did on the engine.

There were some other changes we made. We have a computer on the engine, a controller, we call it. It's the controller that has all the intelligence to operate the valves, sequence the valves, and get the propellants at the right time at the right place, all the components on there. It's the brain, if you will, of the engine. We modified it a couple of times, increased the memory and what it can do in terms of making measurements and getting information for us.

In addition, we've gone to what we call a health monitoring system that's a part of that. It takes instrumentation temperature and accelerometer, particularly accelerometer, measures vibration, and it has built inside—we've been flying this, by the way, for safety, and it can shut itself down just like that if they see certain critical levels. That's what our advanced health monitoring system did for us. When you ask what upgrades have been made for safety, that's probably the biggest one, particularly on the engine. And it's been working well. We haven't had any problem with it, reliability .999, way up there. The Russians never built anything on that.

The one downside, on the nozzle we have tubes coming down that are cooled by liquid hydrogen and come down to a manifold down below and turns and goes up another tube, and into the chamber. These tubes are put in together, and they're tapered. There's about a thousand of them, and the worker has to assemble them precisely. We talked to the Russians, how do they do it, and they had a large manifold on the outside. The tooling they have is as big as this room to make this equipment. They don't use tubes like we do.

Tubes are lightweight, a lighter weight than what they use, but they have huge castings, and then they weld these things together. We looked at their technology a few years ago, went over to see if that was something we want to do here. They wanted to sell it to us, and it is just a nightmare, a mess for the tooling, and so we never pursued it. It wasn't going to pay off. It would cost so much just for that. They were willing to sell us that technology.

By the way, you know, the Atlas V uses their engine. We use Russian engines today. I don't know if NASA uses them. The Air Force is using it, the two RD-180s, I think it is, their two engines for the first stage on their upgraded Atlas. The upper stage is liquid hydrogen.

The engine, I think, is the key; it was our most technological system that we had, and we just were lucky with all the testing that had been done for years and years and years. In 1977, I used to be a runner, and I learned how to run in 1977. That's during Easter. We went to Mississippi for tests. We weren't getting there. Congress and OMB [Office of Management and Budget] was holding our feet to the fire to be able to test at rated power level for sixty seconds, and we just had all kinds of problems. McCool's back down there for months with a team, and J.R. was the boss then. In fact, Rocketdyne sent their boss down there with us to get that test off, and they finally got to that milestone to be able to do that. We'd been having problems with the hardware components, working close with them, and they finally were able to get to it, and we were a part of that, being help for whatever we can to do that because that was difficult.

We stayed in a motel, Ramada Motel, so that's when I started running and had sneakers, 1977. In 1994, I quit running because I had surgery in both knees from all my running. I kept a diary and I got up 10,000 miles in those days. When we'd go out to Canoga, and I'd take my shoes, and I'd go with Sanchini and some of the guys at lunchtime—I can't think of the college there. They had a track, and we'd get out there and run. Of course, we could take a shower there. Every time I'd go to the Cape, I'd always take my shoes with me, run on the beach, but at my age I had to slow down, so I just bike.

WRIGHT: You talked to us about your involvement after *Challenger*. Were you also involved during the time of the *Columbia* accident?

MCCOOL: Yes. That's another story, and I need to share that with you a little bit. That's another bad one. We had had reviews, and it's kind of touchy. You asked about the readiness reviews. We had gone through all that, and we'd had problems with the thermal protection system, and we'd had reviews ourselves with our contractor and with the program. Then we went to the Cape and had the big one with all the Center Directors and the board. We went through the FRR [flight readiness review], and we'd convinced ourselves we're about ready to go, and then we all come back home and get ready for the launch, and I go back down there for the L-minus two.

This is kind of a personal thing I'm sharing with you. I go over to the health club, it was in O&C, and I do my two miles or whatever on the treadmill, and I notice my badge is expired. So I asked the attendant, I said, "What do I need to do to get a new badge here?"

He said, "Well, sit down. Let me take your blood pressure." He said, "You've got a problem." He takes it again. He has a gal come out and take it. And everybody, "Oh, we got to send you to the Med Center." Two days, L-minus two.

I get kind of worried and I'm uptight. The reason I'm uptight, my engine manager, who worked for J.R., but he worked in my shop, he had had a problem down there, his heart was speeding up quite some time before that, and he goes to the same family doctor I go, and I call him, "What do we do?"

"Take him to the emergency room." So I did. I took him to Cape Canaveral, put him in a hospital for five days, and I stayed down there with him.

I'm thinking the same thing, "McCool, if you've got a problem, you need to go home." This is a true story. I called the crew that flew us down on our plane, and they were going to

Washington the next day to get somebody to bring them down. I said, "You mind dropping me off at Huntsville?"

"Yeah, we'll do that." So they dropped me off. I didn't go back for the launch, L-minus one, and I wasn't there for the launch, but I was up there watching it on TV the next day. I forgot when the launch was now, because the seventh was when I went in and I had four bypasses. I had major blockage, I found out.

Well, I didn't give you the whole story, part of it. My family doctor sent me to a doctor at Mayo [Clinic] in Jacksonville [Florida], a cardiologist, with the records, and he recommended I go in and have the bypass. High blood pressure. It was major with four bypasses. But I was not there for the launch [January 16, 2003], but I was here and I saw it.

I missed that and got involved in all the subsequent investigation and after that with our people. In fact, there was a [William C.] McCool, Willie McCool [no relation], I never met him, that was on the flight, the pilot. I didn't meet any of the crewmembers there. That's a whole other heartache I'd hate to deal with. I just wish I could have done or known something, and not say, "Let's go fly." Just say, "Time out." Because you could do that. You could do it in FRR. You don't want to wait that late. You could do it at the launch, sitting in the LCC. I always had to give them my okay, but I was not there for that one, for the launch.

I was in the FRR and the board had heard from everybody, including our people, our contractor, my project manager, Jerry [W.] Smelser. It was a thermal protection problem, stuff peeled away and it hit the Orbiter, and then that was—I just—I don't know. I tried to do what I could, that was to try to get back to flying, but it was just the next year, January 2004, when I retired.

I don't know if you ever been to Michoud [Assembly Facility, New Orleans, Louisiana] where the external tank is manufactured. They have robotics in this chamber and they spray in thermal protection system. That stuff's pretty thick on there, and you need that to preclude the boil-off of liquid hydrogen, and that part works out good. They were able to develop all the procedures, which was not easy, and our materials processing people really helped us on that and developed a lot of the techniques to do that here at Marshall. In fact, Martin people came here for that. Then the close-outs, where the liquid oxygen line runs down the side, that's all applied hand-done and is where they had problems, where you had close-outs and where you had penetrations coming through the thing.

I remember climbing up on the tank. They had tanks all around the place in the factory there. You go up and look and see what they're doing, and they'd have their bunny suits on, their masks and gloves. I always worried about that since then. While we have been flying, I worry, because we have cameras now looking at particles coming off. You don't want it to come off, hit that fragile tile on the Orbiter. That was another thing I just have to carry to the grave with me, that and *Challenger*, the bad, bad experiences of my life when I look back, and I just ask myself and think about it.

I didn't tell you about a good friend of mine. He was a launch director down there. You ought to get his input. Gene [James A.] Thomas. Do you know Gene?

WRIGHT: No, but we certainly would like to talk to him.

MCCOOL: He was a launch director on *Challenger*. I met him when I transferred into S&MA, a very deep, spiritual person, and I developed a real close relationship with him. What a wonderful person. General Forrest [S.] McCartney was the KSC Center Director, and I still call him General. A lot of guys call him Forrest. He's named after Nathan Bedford Forrest, the Confederate general. He told me, "I had to find another job for Gene." He put him chief of safety at KSC. He was the launch director on *Challenger*. He really got close to the crew and emotionally torn up. He's written a book. I can show you the book if you want to get a copy of it, and he tells about what he did and what he went through. He talks about a lot of spiritual things. We had a close spiritual relationship.

I remember when we got ready to fly in '88, Gene said, "We were holding hands, and you and I were praying. You and I were praying," and he's right. I look at people like him and I look at the crew guys that I've known over the years, and they inspire me. Like John Glenn. He's just my hero, a lot of others, though, being close to Brewster Shaw. When I see what they go through and then what Gene went through, and I think, well, maybe that was my scar I had to carry, like Paul the Apostle. We don't know what his pain in the side was. Maybe those two losses—I don't know, losing the *Columbia* after *Challenger*, thinking we were all fat and happy!

It's probably good. The hardware is telling us something. It's a little bit like your body. You know, your body tells you when you start getting an ache here, an ache there, and you need to slow down or change something you're doing. There's no question after this many years, it's getting tired. Maybe it is, it's nostalgic to me, to have to retire and live all that. I wish they could continue. Enough's enough, probably.

WRIGHT: You were involved with the propulsion system for a lot of the Shuttle missions.

MCCOOL: Yes.

WRIGHT: I know you talked about the success of the engine, but what do you feel overall has been the most significant accomplishment from the Shuttle Program, especially at the beginning when you were trying to put out the expectations of the vehicle?

MCCOOL: The first, the hardware. Just take the hardware, and being able to fly that many times over and over and over. Recall, now, after Saturn everything went in the water. We wanted to have a reusable vehicle, which we did, not the tank, and we knew that was going to be a headache, but still it turned out everything else worked well, worked exceptionally well. You look at how many hundreds and hundreds of people that's been involved in this over the years, how many crewmembers, not just our country, foreigners, been involved in space. I look up there, it's coming over every ninety minutes, Space Station, just look and think about how you were a part of all that, of history, and what it's done.

When I look at that and see the satisfaction, and the one, this picture right here, it's flat on this wall here, was *Endeavor* in 1992, 500 years after Columbus discovered America, getting ready to fly its maiden flight. Every time I see that picture now, I say, "Hey, Mac, maybe we're going to get it. We're going to make it. The *Endeavor*'s going to make it next week." That was its maiden voyage.

Rick [Charles Richard] Chappell, Dr. Chappell, worked with us out here, good friend, and he got me to meet Walter Cronkite when he came here for a von Braun ceremony one time. He found out the three ships were down off the Florida coast down there. He organized and tried to get them to come by the Cape. When I see here's the launch complex, rotating structures pulled back, and that lightning tower, and there she's sitting, getting ready to fly, maiden voyage, and here's going to be the next to last one. Now, to me, man, that is something!

Now, another good one, because I told you about John Glenn—can I talk about Apollo for a minute?

WRIGHT: Sure.

MCCOOL: All right. Let me go back. I'm digressing, but where I'm coming to is John Glenn. That's when I first met him, after his flight in 1962. In those days, after the Russians had already put up [Yuri] Gagarin, and here we were playing tail-end Charlie. [President John F.] Kennedy was on the hot seat, so far as his problems with the Russians, the Cubans, the Cuban Missile Crisis, etc., and von Braun had an input to that. I can show you a letter I have a copy of that I got years ago. He had an input about going to the Moon.

So Al [Alan B.] Shepard goes and flies up and down, suborbital, May 5th, 1961. Kennedy talks May 25th, the State of the Union, and commits to go to the Moon. Now come along to when John Glenn goes. We had nothing to do with that. That's all JSC and Air Force hardware, Atlas. We didn't know how we were going to go to the Moon. Von Braun's team wanted to go—there's three ways you can go to the Moon: build a rocket big enough, launch it and go straight to the Moon; have another one and go Earth orbit rendezvous; or the last one go lunar orbit rendezvous. So they were going back and forth.

Von Braun's team, the Germans, said, "Let's go Earth orbit." They'd done a lot of orbital mechanics. So he's going to go to Houston. At that time, there wasn't a JSC; still the Space Task Group. Gilruth and a few of his key people that had gone down to a motel they'd rented in Houston. I don't even know where. I couldn't take you there if you give me a million dollars. I don't know where it was. In those days we didn't have the jetport you came in on. There's a place called Airport Road, it's right in town in here. That's where the airport was in '62, in those days. Somebody had a B-26, an Army B-26, that they leased for us to go. Von Braun and two other guys and myself go down. He lets us read his speech going down on the plane. He proposed to team up with Bob Gilruth and get Headquarters and all these science committees to go LOR [lunar orbit rendezvous]. John [C.] Houbolt, from Langley, is the guy that came up with the concept of lunar orbit rendezvous.

We go down there and talk about some studies first. I covered the propulsion stuff. My boss, Dr. [William H.] Mrazek covered all the structure and the vehicle. Ludie [G.] Richards covered the avionics. Von Braun got up and gave his speech. When he got through, all I remember is that this dining room, everybody's clapping, because he wanted to team up with Gilruth. Once the two leaders agreed, it wasn't much longer that NASA Headquarters science committees made the decision to fly lunar orbit.

Sitting next to me at the table is John Glenn, and I'm awe of him. I'm getting goosebumps right now thinking about it. I'm just in awe of this guy. I'm coming back to the other thing, but in 1998, he flies on STS-95 as the oldest astronaut. I always wished he'd been able to fly on the Apollo. He probably would have liked to, but it's like the military does with a fighter pilot. They did this in World War II. After a guy has been shot down so many times, they'd put him back as an instructor, take him back, sell war bonds. They figured next time that he's going to—and that'd be a worse thing. It could have been the same thing with John. I don't know that. That's just my own theory.

He's flown now, that's enough. But then he gets his way to fly on Shuttle, which he did, and in fact, I know the [Shuttle] commander was a little upset about that, because he's getting all the limelight instead of the crew. He didn't want that, but he wanted to fly. John [W.] Young told me one time that John Glenn's the only guy he ever saw could do a one-arm pushup. Think about that. My buddy John Young. That kind of thing is to me just a personal thing. When I see he was able to fly the second time, then a Senator, still dedicated and married to Annie [Glenn]. Read his autobiography sometime when he talks about it.

WRIGHT: I have.

MCCOOL: Have you read it? Especially he's talking about the other guys, the hotdogs down at KSC with their Corvettes, and why he didn't get to fly on the first mission of Mercury, but he did fly the first time in orbit, not suborbital.

Another thing, too, I think as a people, of what it's made, it's done so much for the people. Everybody, all of us, we've been a part of history. It's an inspiration to the young people. I've been going to the Space and Rocket Center. I don't know if you have been there, this one, the one we have here. When I talk to them, I give them talks there, and every year I would do a thing, what the Germans called the von Braun Forum. All the Germans died on me. I'm down to three, so we haven't done this since 2009, but I talked to them Monday, and I'm going back Friday and see what else I can do just to inspire the kids, because young people come there, come there in schools. We bring them in school buses, all over the country. We've got the [US Space and Rocket] Center, and it's probably a little larger than the one you have next to your Center [Space Center Houston].

I did get a chance to go to that one time for an award. That's where I met the President George H. W. [Bush], or the boss. I got his autograph. John Young was the emcee. John introduced the president. The president, I think, got some kind of recognition, too, but he wasn't the president at the time. He was being recognized. Of course, he lives in Houston, unlike Sonny [George W. Bush], who lives in Dallas.

WRIGHT: Yes, he lives in Dallas.

I think we've covered most of what we wanted to ask, because we talked about the components and talked about Challenger and Columbia, evolution of the propulsion system, and that's what we wanted to hit on. You talked about safety. You studied pretty hard before we got here. I think you did it.

MCCOOL: Yes.

[End of interview]