NASA MSFC Oral History Interview
Steve Johnson Interviews – Apollo/Saturn Program

Royce Mitchell
Interviewed by Steve Johnson
Huntsville, Alabama – Unknown, Circa 2012

Steve Johnson: I am talking with Royce Mitchell, who worked at Marshall Space Flight Center most of the time between 1963 and 1993. He retired in 1993. Royce, would you talk about your education that prepared you to be in the aerospace program?

Royce Mitchell: My degree from Auburn [University] is in aeronautical engineering. That got me into the aerospace business, but my career caused quite a few branch outs of discipline, primarily having to do with entire systems. I got into the missile and space business out of college with the Boeing Company. I went to Seattle [Washington], worked on a ramjet-powered pilotless interceptor, and part of my job was in the test world to see how this high-speed interceptor reacted with its control system on the ground. That leads you to a lot of disciplines that I did not necessarily specialize in in college. I quickly learned that integrated systems are highly complex, very interesting, and more and more, I got into the integration of large complex systems.

I left Boeing mainly because of the Seattle climate. I moved down to Sunnyvale, California where it never rained and went to work on the Polaris submarine missile system. That was extremely interesting. I got into the systems part of Polaris, control systems, command distribution of functions, and the packaging of these systems within a very limited space. I got into a specialized area also called exploding bridgewire ignition. An exploding bridgewire is a tiny filament, about as big as a course hair, that you passed a lot of electrical energy through suddenly, and it caused that wire to vaporize and explode. This led to, downstream, pyrotechnics that would be touched off by this exploding bridgewire. The units that fired this, put out this high-voltage, high capacitates, were little black boxes connected by cable to these detonators. They were fairly complex, but they were also supposed to be very, very safe.

The opportunity came for an interview with NASA [National Aeronautics and Space Administration] on-site while I was working for Lockheed. It turns out the people who interviewed me happened to be working on exploding bridgewire firing units for the Saturn Program as well as other aspects similar to what I was doing on Polaris. Having grown up as a native of Florence, Alabama, having an opportunity of moving to Huntsville [Alabama] was too good to be true. I was married by then, we came to Huntsville, and we have never regretted it. I enjoyed coming to Huntsville and getting in on the Lunar Landing Program and thinking how lucky I was to have the kind of degree I had, which I was not sure would ever let me be back close to home. It did and that was a good thing.

Johnson: You came to Marshall to work on the ignition system for the Saturn V.

Mitchell: Partially, that was my job. It branched out into such things as the range safety system. I am one of the few people who are extremely proud that the system they worked on so hard never had to be used, and that was the range safety system. The Saturns were so unbelievably good and so reliable that they never had to exercise the destruct system. I worked hard on it, but I was so glad it never had to be used.

Johnson: The ignition system, many people probably think how hard could it be to start a rocket. Was that a problem? Was that a real challenge to figure out the right way to start the rockets?

Mitchell: You put it in a good question. One of the biggest problems in starting a rocket is that you do not want it to start too soon. You want it to start when the time comes, but not start ahead of time, and certainly not late. These exploding bridgewire units, the little black boxes that generated and stored all this high energy just before they were to be used meant that the electrical connection to the detonator was inert. In other words, there was no chance of an early detonation, no chance of a little, simple stray voltage. We even had an air gap within the detonator pins and you had to have enough voltage to jump that air gap, which took many hundreds of volts. The detonators were protected and the exploding bridgewires made it a very safe system so you fired when you needed to and did not fire when you should not fire. That was the critical aspect.

With liquid engines, we did not use these detonators. These detonators were used for the little rocket engines that settle the propellants in orbit, that fired retro motors to slow down, say the first stage after it had been spent. We fired little solid rockets to back that thing away from the rest of the vehicle. The linear shape charges between stages, these detonators were used in a lot of applications. The big liquid engines had what is the equivalent of spark plugs. Of course, there the premature firing is not as important because until you have liquids in there and mixed, you are not going to get any catastrophic problems. The spark plugs inside a liquid engine are another matter. I will talk about that later.

Johnson: Talk about the testing you had to do. Was there a lot of testing?

Mitchell: [There was] a lot of testing for reliability. There is a phenomenon in the electronics world, especially electronics that use high voltage, called the Paschen curve.

Paschen became knowledgeable of the fact that if you get into a rarified atmosphere with high voltage, the air itself becomes a conductor, if the voltage is high enough and the air is at the right, critical density. We spent a lot of time making sure this phenomenon, because we used our systems all up through the atmosphere. We had to do a lot of testing to make sure this effect did not cause stray discharges and stray ignition at the wrong time, in the wrong direction. We did a lot of that testing.

Reliability, when you use a one-tie use like a detonator, becomes a matter of statistics. I will talk a little about solid rockets later. You are so dependent on processes and skill and inspections because there is no way to test. It is like testing a flashbulb. You tested it, but you do not know whether the next one is going to work or not. Numerically, statistically, it was a tricky business to make sure of the reliability of these. The consequences of unreliability, as you can expect, could be catastrophic. We spent a lot of time on the reliability of these very critical items.

Johnson: With many projects in the Saturn V days, there was somewhat of a time element. Were you under any time constraints? Were they wanting these systems to be readied quickly? Was there some pressure to proceed?

Mitchell: [There was] a lot of pressure. I want to talk about NASA's approach to this timeliness.

Johnson: We are talking during the Saturn years?

Mitchell: During the Saturn. We all know the mandate, or the need, for this country to go to the Moon and return safely to the Earth by the end of this decade. We also knew we were under pressure because of the Russian influence. The Russian influence put as much pressure on Congress as it did on us because they needed to fund us. We went first class. We used to jokingly say we had the big inch pipeline to the Bureau of Engraving and Printing plus the mint. We did not stave for resources, we could take parallel approaches in trying to get these jobs done.

There were some management approaches to getting this job done on time that were remarkable, George Mueller, who was the associate administrator under James Webb, and Deputy Administrator [Robert] Bob Seamans. George Mueller said we were going to go all-up. That was unheard of. It meant that when the first Saturn V, for instance, was launched, it was a complete first stage, it was a complete second stage, it was a complete third stage, the propulsion systems, the engines. That was unprecedented. I know in my experience, if you have a thing like this ramjet booster, it required a rocket motor to get you going fast enough for those ramjets to work. They only work at extremely high dynamic pressures through the atmosphere. You had a booster. You did not put ramjets on the first thing, you shot this booster to see if it would work. After you were satisfied it worked, then you add the rest of the vehicle. Then later you add these kinds of controls. You went at it incrementally. Mueller said, "No, we are going at it full-up, everything, the whole shebang from the first launch." Just about every engineer who had had any kind of experience in this game, their eyes got big.

It did two things. Obviously, if things worked, it cut short verification of a lot of good flight systems. It also changed people's attitudes. Their approach became so focused, so tied to success that there was not going to be any "if this blows up, we will have learned something." No, you wanted everything to work. That was a remarkable stance for Mueller to take.

Johnson: Everything had been tested though. I have heard other people say that this was not really the way the Germans liked to work. They liked to test each thing as you go. This was a change for them too, to speed things up, we did this.

Mitchell: Right. The many unknowns that normally you uncover doing a test program, an incremental test program, you had to do the tests as best you could. The flight dynamic simulations, what happens when you have something over three hundred feet long that starts bending due to dynamic pressure, what kind of interaction between the control system and the vehicle structure, bending and flexing, many, many dynamic things that cannot be fully tested on the ground you had to focus your best, do your damndest, and make sure when you went all-up that everything was ready to go.

Johnson: Was the feeling at Marshall during those years that things were ready to go? Were there some systems where there was some doubt?

Mitchell: There was concern. We had some fine engineers. We did not have the current simulation capability current systems have. We did not model so much of it as current systems do. We did not have computational fluid dynamics that current systems do. There was so much, but no question there was exhaustive testing on every conceivable aspect that you could imagine, sometimes with backups to backups and on and on, trying to make things redundant and trying to make things complete. This all-up idea, again, caused so much focus on so many things and put tremendous pressure on the first article being correct, functioning correctly, and meeting the requirements. It was a remarkable experience.

Johnson: It called for some long work hours, did it not?

Mitchell: (Laughs) It called for unbelievably long hours. Another thing, the Marshall leadership, since we at this juncture just celebrated [Wernher] von Braun's 100th birthday, his leadership, I have never seen anything like it before or since. I have been around some very erudite, smart, and educated people, but von Braun was unbelievable, charismatic, fair. You could tell that one layer down from von Braun, they did not know whether their way would prevail or not, but they knew they would get heard, they knew they would get proper attention. They knew they would not be dismissed. He carefully considered all stories he heard, all facets of a problem he heard. There was no question that once he came to the decision, everyone would abide by it. Everyone felt good that if they had a concern, if they had an approach, if they had an idea, they knew it would get attention, it would get its day. That was important. It was extremely important to the workforce. Morale was wonderful, primarily due to that kind of leadership.

Johnson: Everyone felt like they were part of it.

Mitchell: We are in good hands. We are all in this together. We are a team. We cannot fail. He just had that aura to cause you to think this was going to be successful, we are going to do it, and we are all going to get through this and it is going to be wonderful. And it was.

Von Braun had to be convinced on a couple of things. One was how do we get to the Moon. James Webb, the administrator, did a wonderful job of keeping Congress on his side, keeping the funding coming, doing all the right political things as well as technical things. James Webb, and for a while von Braun, wanted to go directly to the Moon, it was called direct ascent. It meant the rocket would take off from the Moon, land with enough fuel to come back. If you think about that, that is a heck of a thing. The resulting vehicle is monstrous. A direct ascent, even though it was studied and even though James Webb at first thought that was it, and von Braun supported it, he had another approach. He wanted to do Earth orbit rendezvous. He wanted to take Saturns that would have been smaller than the Saturn V but still fairly large, and launch pieces of this lunar trip vehicle and assemble it all in Earth orbit. That reduced the size and complexity of the launch vehicles from Earth but still required quite a vehicle to go on to the Moon, again, carrying enough to come back to Earth.

There was a guy up at Langley [Research Center] named [John] Houbolt, and he was kind of a voice in the wilderness. He kept petitioning NASA Headquarters and Seamans Committee and the people who were trying to make this configuration decision. They had ground ruled out what he was interested in. What he was interested in was what eventually became implemented, the lunar orbit option. You landed on the Moon with the least amount to bring back. It required another vehicle with another life support system to land on the Moon, then come back, and then do the lunar orbit to get ready to come home. It was not planned for that purpose, but having a second life support system, I am sure, was welcome by [James] Jim Lovell and the people on Apollo 13 when they were able to use the Lunar Module to survive when the Service Module blew on the way to the Moon.

The direct ascent was too big, too hard to do, too huge a vehicle. Earth orbit was better but still required a large vehicle to go to the Moon and back. Lunar orbit meant going to the vicinity of the Moon with a fairly small vehicle and going down to the surface of the Moon with an even smaller vehicle, a subset of that, and then coming home with the absolute minimum of hardware and, therefore, propulsion requirements. Some of the people began to see some of the advantages of the lunar even though it was more complicated and probably, from a reliability of so many more parts having to work, more risky. If we were going to get to the Moon reasonably and within the schedule the nation had committed to, the lunar orbit rendezvous of Houbolt was the best way to go. Once von Braun recognized that, he jumped on it fully and said that is the way we ought to go. It took him a while to come around, but he was the second guy to recognize that. He brought along, eventually, the rest of the agency.

There was another aspect he was a little resistant about. General [Samuel C.] Sam Phillips, he was a major general in the Air Force that had impressed George Mueller. George Mueller, again, is the guy who dictated we will go all-up on every flight. Mueller had been impressed by Sam Phillips on the Minuteman Program and how he was able to orchestrate all the elements of the Minuteman Program and bring it along with rigor, with discipline, with good management. Mueller put Sam Phillips in charge of the Apollo Program from Washington [District of Columbia] and Sam Phillips started implementing his management systems on the centers. He got some pushback form Marshall, but after they saw the light, they embraced it. The management system at Marshall was probably superior once they embraced the idea of having this kind of interaction.

Instead of having everybody working on tweezers, valves, springs, and rockets, to work on program requirements and schedules and making sure things got done. Otherwise, you do not make it, no matter how good your technology is. You have to have good management. Von Braun saw that and embraced it. That is the way he was. If he did not think of it, he tested the idea. Once he was convinced, you had better get out of his way because things were going to be good.

Johnson: When all these things were happening, let us talk more about what you were doing. These things were happening, you were working at Marshall, you obviously loved the atmosphere, even the long work hours. During these times, you started out working on ignition systems, but you later went into the Integration Group.

Mitchell: The ignition system was part of the Integration Group because getting things ready to move and then making them move was part of it. Part of Sam Phillips' management requirements was there would be well-disciplined project offices. We formed project offices within the laboratories that could integrate the activities of the laboratories and have everything function in a well-oiled management structure. I became a project engineer on the Instrument Unit for the Saturns. IBM [International Business Machines] was brought in to produce, test, and manufacture these Instrument Units. They are a ring the full size of the Saturn where they sat. They were only a little over three feet in length like a donut sitting at the top of the big Saturn V and issuing all these commands. The stable platform that kept up with where you are in space, the flight control computer that took the commands and converted them into things the Saturn needed to do to follow its flight program, all this was part of the Instrument Unit

Project Office, where I was. That became even more a part of my job, the integration of guidance, flight control, commands, power distributions, ignitions, timing, all the many things it took to make the Saturn work became part of the Instrument unit, which I worked on. [It was] a very satisfying job to work on the brains of the Saturn V.

Johnson: Knowing that it was going to have to work.

Mitchell: Knowing it was going to have to work.

Johnson: Were you able to test all the parts enough to feel comfortable that it would work?

Mitchell: Yes, we built up Instrument Units. We had one that was fully stocked with all the flight-type hardware connected to monitoring computers, monitoring consoles. We could put the Instrument Unit through its paces, check all the timing, all the dynamics, all the flight control commands, all that. We felt very confident that the Instrument Unit would work.

Johnson: How did you feel when we got to the point where the first Saturn V flew? Were you standing there wondering if enough testing had been done to go all-up? How did you feel?

Mitchell: It was awesome. I went to the Cape [Canaveral, Florida] for the first Saturn V launch. If you have ever been out to the Davidson Center here in Huntsville and seen that Saturn V, the immensity of it, my thought was how is that thing going to get up to 4,000 miles an hour on the first stage alone. Then it is going to have to hold together, be at the right attitude, be at the right altitude. When that Saturn first stage, the S-IC stage with those five monstrous engines, separates at 4,000 miles an hour, will there be anything left after that event. I could not get that idea out of my mind. Here is something thirty stories tall that is going to be going through the air at over 4,000 miles an hour. Of course, that is just the start as far as velocity is concerned. Other stages were going to take over and do the higher velocities.

Johnson: You were not convinced, it sounds like. There was some doubt that things would work like they were supposed to.

Mitchell: There are always the unknown unknowns. You hope you have covered everything, you hope you have tested everything and put in design margins to take care of the unknowns. Until you fly it, until you make it happen, there is that queasy "what did it not do."

Johnson: But it flew, it worked.

Mitchell: It flew, it worked. People think of the Saturn as being "perfect." Not quite. The second Saturn V launch, Apollo 6, I believe, was the nomenclature. We used the Saturn Is and IBs for Apollo jobs in between the Saturn Vs. The second Saturn V we launched developed what is called pogo. If you think of a pogo stick jumping up and down with a kid on it, the Saturn began to pulsate, its propulsion system pulsated. What happens when that develops, or what causes it, is that you have a vibration start in the vehicle and the lines and tubes feeding propellant to the engines pick up this vibration and they start shaking. Within those pipes, the propellant surges with each vibration. In other words, you get a chug, chug, chug effect and it runs away.

When you have propellant entering the engine in pulses, the engine chug, chug, chugs and makes bigger vibrations. The second Saturn V called 502 almost shook itself to pieces. Fortunately, it held together for those F-1s even though they had developed the pogo. There was a successful separation, a successful second stage aft skirt separation, another use for the exploding bridgewires. When you see the old TV [Television] images of a kind of circular ring falling away, you are looking back and that ring falls away, that is the skirt of the second stage falling away. If you look at it, you can see as it tumbles, it looks like it is trying to burst into flame. What it has done, it is being bombarded by the superheated steam of those hydrogen, oxygen engines of the second stage, there were five of them, each one about 200,000 pounds of thrust. You have 1,000,000 pounds of thrust hitting that skirt.

We get through that and then the second stage, we later learned, had suffered some damage due to the first stage pogo and it began to develop pogo. An auxiliary propellant line had been damaged, which caused instable combustion in the engine and began to shake and have problems. The engine had a monitor on itself that if you got into really rough combustion, it would shut itself down. There were also accelerometers that sent signals up to the brains that said we have an engine acting up and you need to shut that engine down. The engine that was acting up shut itself down. The brains up front said I will send a signal to shut it down. It did except there had been a wiring mistake, and that signal shut a second engine down. On the second Saturn V, it almost shook itself to pieces and then it violated a flight rule when two engines shut down on the second stage.

The guy sitting at the console was a friend of mine at Marshall, his name was Bob Wolf. He was on the console at flight control as the booster representative. In other words, the rocket representative. The flight controller said it is your call, booster. Bob started looking at his data because he had had some sporadic data and was not sure if two engines had really shut down. The flight rules say if you lose two engines on the second stage, it is an abort. You destruct the vehicle and it will not fly. By the time he had satisfied himself that we really had lost two engines, the simulations had said by that time the vehicle should be doing figure eights over Cuba or some wild maneuver and was going to crash anyway. You aborted. It had righted itself, it was humming on down the road.

We had the capability if you lost an engine, the other engines burned longer. It did not have a whole lot of effect on the mission. He said to let her go. Do not destruct. The flight controller took his lead. The vehicle went on and made it safely into orbit. There were some people who said that action made it possible for us to make it to the Moon in 1969, which was the target year. Otherwise, with an abort, with a destruction of a stage, we would have stood down, we would have had failure investigations. It is interesting how things.

Johnson: How long did it take to fix these things, the problems you had?

Mitchell: That is part of the story. What do you do? On the S-IC stage, the big, huge F-1, million and half pounds each, five of them on there, in the propellant lines, they added accumulators, kind of like shock absorbers. They were little chambers filled with helium. If you started getting the propellant surging, it would hit these pockets of helium and would damp out. In other works, the helium would allow the propellant to smooth out, it was a smoothing effect. It was an anti-pogo fix. They tested it on the ground. Likewise, they made sure the S-II engines, the problem there, had really been associated with the first stage's pogo.

This is a tribute to our management, to our forceful, competent, and aggressive management, after the second Saturn V almost shook itself to death, the third Saturn V, the next launch, took [Frank] Borman, [Jim] Lovell, and [William] Anders around the Moon.

Johnson: We did not have a bunch of test flights?

Mitchell: We did not have test flights. We went from that near catastrophe to putting men all the way around and in orbit around the Moon. Of course, they did not land, but that shows you the tremendous capability, the tremendous spirit of can-do. The things that were done were done a t Marshall and it is awesome to think about.

Johnson: When you look back at that, it almost seems like they what?

Mitchell: Right. Who would have thought. Every generation has their own arrogance. I think people today would not do or could not do that kind of step. They would be so cautious. That is probably not true. Today's generation, when you put them on the spot, they produce. There was no question. That group of engineers at Marshall, I was glad to be a part of that whole shebang. Something like that is incredible.

This was more of a design remarkable thing that came up early in the program. We at Marshall, von Braun, of course, was instrumental, had an agreement with the Houston [Texas] people. It was not called Johnson Space Center at that time. It was called the Manned Spacecraft Center. It was later named for President [Lyndon Baines] Johnson. The people at Houston, we had an agreement with them. Marshall would produce 60,000 pounds of payload to Earth orbit and then they would take over, living within that constraint, and do the Command and Service Module and the Lunar Excursion Module. That was the interface agreement, if you will.

Early in the program, Houston realized they were not going to be able to make it on 60,000 pounds. There was a big get-together and von Braun, the sly dog, said how about 90,000 pounds? How about a fifty percent increase that you can use for your spacecraft to the Moon. He had foreseen something like this probably happening. He had put in the margins and his whole staff knew that capability was there. It was hardly a bump in the road. Everybody thought maybe that would be the end of things for a long time. We were able to offer Houston 90,000 pounds instead of 60,000 pounds. It was all because of von Braun.

Johnson: Because he had anticipated.

Mitchell: He had it up his sleeve.

Johnson: Did you know during these times that you were making history?

Mitchell: You know, I did. I appreciate it more now than I did then. It was almost like every historic thing was just another day at work, but we were conscious. We had a leader, his name escapes me right now, but we were in a meeting that was breaking up and we were talking about how great this is, how wonderful that test went, and how wonderful this structure is. He said, "And to think we are just in the T [Test] model stage. It is historic, but we are just in the T model stage. There is more history to come. Make no question about it, we are doing some groundbreaking work here." Of course, the press, they would underscore some of these events, some of these accomplishments, some of these breakthroughs. We all knew, we all had this sense of this is great. We are really doing something unbelievable here.

Johnson: Let us jump ahead. The Apollo Program is over, or is ending. We are still doing some Saturn applications, but we are trying to decide what a space shuttle will be. Talk about figuring out what a space shuttle will be. You were involved with the conceptual design of the shuttle.

Mitchell: Yes, I was on what was called the Space Shuttle Task Team. There was an Electra commuter plane that flew between Marshall and Houston virtually every day. The Marshall people went to Houston, Houston people would come to Marshall. We would spend a lot of time arguing over what a shuttle should look like. The politics and the budget, that honeymoon was over. Washington was looking at how much money the space program needed. The [Richard] Nixon Administration was struggling with that. The Apollo Program had cost, in those years, not in today's dollars, back in the 1960s and 1970s, on the order of $24,000,000,000. It was really a large funding phenomenon. That was not going to happen again. We were going to keep funding at what we thought were unbelievably low rates.

We went from having a fully reusable shuttle that people really wanted. The booster was to fly back and land like an airplane. The orbiter was to be totally self-contained and go into orbit on its own fuel and propulsion system. You had two stages to orbit and you were supposed to have this huge payload bay. The results in development costs were astronomical. People began to scratch their heads thinking what can we do to reduce costs. Little by little, by trying various configurations within the fiscal constraints, the guidelines had been given, we eventually came up with what was first called the rocket-assisted takeoff shuttle. When you think about it, that is really what we eventually had evolve.

It was a spaceship with these solid rockets attached to it. The spaceship would light up with its engines and the rockets would boost for the first couple of minutes to get it up and going. To keep the size of the orbiter, the shuttle craft, from being unbelievably large, it was decided that the tank would become external and would be discarded every flight. It was a sacrifice of operational costs to stay within the development ceilings. That is where the term External Tank came from.

Johnson: I want to stop you here. When we were first talking shuttle, that huge tank would be inside the orbiter?

Mitchell: Inside the orbiter. You can imagine what kind of booster it would take to put that up. Then the orbiter engines would not necessarily be burning at that time. You had the booster doing all the work, the orbiter propelling itself into orbit, and carrying its tank with it. It was a big vehicle, big booster, big orbiter. Making the tank disposable moved it outside the orbiter. That is where the name External Tank comes from. I am surprised I do not get asked more often why do you call it an External Tank. Because at one time, it was going to be internal. It was going to be part of the orbiter. That was how we eventually settled on it. That was how the shuttle came to be.

Johnson: Looking back on how the shuttle was finally conceived, it seems awfully complicated. I have had one NASA veteran say to me before that he thought it was needlessly complicated. That was just one guy. The Saturn V, although it was incredibly complex, seemed almost simple compared to the shuttle.

Mitchell: The shuttle had to do things the Saturn V did not. You have this large delta wing craft up there. It had to have a life support system for a larger crew than Apollo had. It had to have systems to support whatever is in the payload bay, fuel cells. The orbiter is an unbelievably complex vehicle. Getting it to orbit is not all that complicated an idea. The Solid Rocket Motors, they were scaled up Titan solids. As a matter of fact, the Titan vehicle was begun when I was still a college student. I remember thinking they are going to put a giant rocket together in pieces, a solid rocket motor joined with joints. I said that sounds dangerous to me. Little did I know that some years later the shuttle would suffer because of that business of stacking pieces of solid rocket together.

Be that as it may, solid rockets are inherently simple. You pour them full of propellant in the proper shape and consistency and you ignite them. There is no whirling turbomachinery. There are no vents, explosive atmospheres generated in pockets and inner stages. Solid rockets are pretty simple. The Space Shuttle Main Engine, because of its extremely high performance is complicated, but when you consider Saturn V with the many, many engines it had, it had five engines on the first stage, five engines on the second stage, a restartable engine on the third stage. It was complicated, more complicated than you might imagine. What we asked the shuttle to do, and with it cantilevered off the side of the stack the way it is, it is complicated. It had to be complicated for what we were asking it to do.

Johnson: Did you have the same feeling when the shuttle flew successfully as you did when the Saturn V flew successfully?

Mitchell: Yes, I was close enough to the Houston people. I remember being in Houston, working hard on the orbiter contract proposal evaluation phase the day George Wallace was shot. I was concerned. I was not concerned about the Space Shuttle Main Engines, although I thought if we had a failure it would come from the Space Shuttle Main Engines. I was concerned about the orbiter reentering. When we launched the first shuttle, it got into orbit and everybody thought that was wonderful. All I could think about was they had to come back. They had to reenter with a system that has been tested, but they had to maneuver, a lot of the Houston simulations had the orbiter running out of its attitude control fuel before it touched down. It was a really tricky thing to have to have that orbiter survive reentry and everything work.

I was a lot more relieved when the shuttle came back, after they went through the reentry phase that causes the plasma when you cannot talk to them. When they came out of that plasma reentry area and we could hear them talking and see the data, I was really relieved. [I was] a lot more concerned about the shuttle reentering than I was about getting it into orbit. Bob Crippen and John Young have to be two of the bravest astronauts, bravest people, that have ever lived. It is astounding what it was like on that first shuttle launch.

Johnson: Let us skip ahead to something you have already alluded to, and that was the *Challenger* disaster when there was a problem with the solid rocket motor. After the disaster, you were put in charge of the Solid Rocket Motor, to bring it and the entire Shuttle Program back to flight. What was the chief challenge for you in doing that?

Mitchell: It was convincing the world that we knew what we were doing. Technically, there was not an element of the Solid Rocket Motor that we did not change. We changed the nozzle seals. We changed the ignitor up front, its seals. We changed everything. Of course, the focus was on the joints between those segments. We did two major things to those joints. We put a metal lip that kept the joints more stable. I really need to talk about the failure of the *Challenger*.

Everybody talks about how the O-rings failed. It might come as a surprise to people to know that the same O-rings were kept. God knows we tested every other possible material for the O-rings. And we kept the same type of O-ring that was on *Challenger* for the rest of the shuttle flights. It was not the O-rings themselves that failed, it was the fact that that joint flexed and tried to pry itself open when in that high pressure. That over 1,000 psi [Pounds per Square Inch] pressure inside that motor tried to flex and move and move relative to each other. On that cold day that we tried to launch *Challenger*, the O-rings got stiff and could not keep up with that flexure, that movement of those sealing surfaces. That was what caused the problem. You can say O-ring failure, but inherently, those O-rings could not do what they had been asked to do. The blame was on the fact that that joint flexed.

To return to flight, we put a third metal lip in that joint that cut that flexure down significantly to near zero. We also added heaters to the joints, all the way around each joint of all the boosters. That heat would keep the O-rings more flexible, just having a belt and suspenders on this safety problem. That was what we did. People might be surprised to know that we had boosters on the pad out at Vandenberg Air Force Base that had that extra lip. The boosters at Vandenberg were not steel cases. They were composite, filament wound cases for lightness. The Vandenberg launches were going to go into polar orbit, and we needed payload out of Vandenberg because we did not get the benefit of the Earth's rotation. We launch out of the Cape because the Earth is moving in the direction we want to go and it helps us get into orbit. Out of Vandenberg, we were going to launch spy satellites over polar orbits, over the poles, and therefore over Russia, with each revolution, so we needed more payload.

Those boosters out at Vandenberg had joints that had that lip to keep them from flexing as much. We knew what we needed to do. You asked me the problem of bringing the program back online. We knew what we needed to do, but we had to convince the oversight committee, the Rogers Commission, rules and recommendations had been sent down. Guyford Stever, who was Nixon's scientific advisor, he had been put in charge of a committee to oversee what we were doing. We made presentations to the Rogers Commission enforcement people, the National Research Council, that yes we know what we are doing and here is where we are going to test it. We had oversight committees from the Astronaut Corps and we had to convince them we knew what we were doing. We had Congressional oversight committees. We had visiting congressmen and we had to convince them we knew what we were doing. Technically, the job was, relatively speaking, a lot more simple than convincing people we knew what we were doing. We had one congressman who stood up at the plant out at Thiokol and said, "Guys, you have to realize that I am here to posture. I am here to show that I am keeping on top of things. That is why I am here." He said that off record, but everybody knew that is what was going on.

Johnson: Was there any pressure that you had best not screw up, you had better get it right the first time?

Mitchell: We thought it would be the end of the space program if not the end of the agency. If we do not get this right, the consequences are unacceptable, unbelievable. It will be a national disaster. We have to get it right.

Johnson: Did that make you proceed with a lot of caution?

Mitchell: Yes, but mainly a lot of testing, a lot of verification. The Thiokol people, there was a guy out there by the name of [Allan] Al McDonald. He had been in on the night before the *Challenger* launch. He estimated that our test program for the rocket motor was six times more extensive than the first time through. I had written a paper some time before that said I thought it was about five times more extensive than the test program. The main thing we realized was that because the solid rockets had originally been modeled after scaling up a Titan solid rocket, we did not have to characterize it so much, same propellants, same D-6 AC steel cases. We did add the second O-ring. The Titan, believe it or not, only had one O-ring at each joint. We added another one for "redundancy." It turns out that solid rockets were not characterized as much as they perhaps should have been. That was another reason they were chosen, to save costs. Here is an existing technology. We do not have to spend all that money on some far out, high performance program.

Johnson: When you say characterization, what do you mean?

Mitchell: Understanding the behavior, characterizing that joint, its flexure, the structural integrity of it, the bonds of the nearby items such as the insulation that protects the case from propellant. On and on and on. Do we fully understand where there is circumferential flow inside that motor? That is hard to model and hard to test for.

Johnson: Should some of this have been done before the shuttle ever flew?

Mitchell: Yes. It is easy to say that after a disaster. You look back and ask what were we thinking.

Johnson: Was there a little previous success?

Mitchell: There may have been some arrogance there. I recall the awful Apollo 1 fire when Gus Grissom and [Roger] Chaffee and those guys were killed. The feeling was that was another center, that was Houston, that was their problem. Could Marshall ever allow something like that to happen? Even on Apollo when we had Apollo 13, that was Houston's problem, even though, a lot of people do not realize this, but that pogo thing I talked about at some length earlier, there was pogo in the Saturn V when Apollo 13 went up. All it did was shut down one engine on the second stage and it went on into orbit with no effect on the mission to speak of. The Apollo 1 fire and the Apollo 13 explosion, that was another center. I think there was an arrogance that may have crept in.

Johnson: That Marshall would not let anything like this happen.

Mitchell: While we are on this track, I find it incredible to think that it was the two simplest propulsion elements that caused both disasters. The Solid Rocket Motor, some people kiddingly called them those giant firecrackers. We had one of those fail and kill the crew. Then we had the External Tank shed the foam, hit the orbiter, and kill the crew.

Johnson: You are talking about the *Columbia* disaster.

Mitchell: Here at the Marshall Space Flight Center, we had three major elements. We had the External Tank, we had the Rocket Motor, and we had the Space Shuttle Main Engines. It was not the unbelievably complicated, high performance, high pressure, high efficiency, high rotating machinery Main Engines that caused the problem. Everybody said if we ever have a problem it will be those unbelievably high performance Main Engines. They worked fine. The External Tank may have a valve or two, virtually no moving part, yet it killed the crew. The dark days at Marshall, it is hard to think back to the Apollo days and think how did this happen. The second one, *Columbia*, the shedding of foam, here again we have a problem that has been seen before, it has repeated. Has the problem been bounded? How do we know how much foam can come off? How do we know what bad effects it may have? Yet, we continued to fly and we had another disaster.

The O-rings, we had seen O-ring damage before *Challenger* and we lulled ourselves into thinking this was the norm, we can accept this, it has been seen before. It is "within family." We had not bounded the problem. We had not said what is the worst that it can become. We had not analyzed and then anchored those analyses with hard empirical testing to say we know we have bounded the problem, we know the problem is not going to lead to catastrophic failure. In both cases, we repeated with the External Tank. I find that hard to take on reflection, that my center, the Marshall Center, somehow allowed that to happen.

Johnson: Let us go back to the Solid Rocket Motor.

Mitchell: I have not told you about something else. I said we did two major things to the joints. The second thing was a concept promoted by Dr. Joseph Pelham. He was originally from New York. He attended the University of Alabama. I think maybe he was down here as a soldier and fell in love with a Southern belle. He went to the University of Alabama. He was at Thiokol out in Utah and he was very instrumental. He came up with great testing systems and ways to test this joint, part of that five, six times testing. We characterized the joint. We actually reproduced the *Challenger* failure with one of his test rigs.

The second major thing he did, he invented a sealed insulation. In other words, when you brought these booster segments together, the insulation met and sealed. We had a non-curing adhesive. If you struggle with the idea of what is an adhesive that does not cure up, think about at Post-It note. You have an adhesive on the back of a Post-It note that stays gummy through its life. We put some non-curing adhesive on the insulation parts. He conceptualized having this insulation that would meet from segment to segment at the joint and the flames would never even approach the O-rings. The O-rings were there, but this sealed insulation did the job. The astronauts, they loved that.

Johnson: That was a redundancy they could handle.

Mitchell: Like most good things, it was elegant, simple, classic, just a magnificent design. I was later made manager of what was to be an Advanced Solid Rocket Motor. We were going to build it in an abandoned nuclear reactor site over in Iuka, Mississippi, Yellow Creek was the name of the site. We were going to put a rocket motor plant there and we were going to build this advance Solid Rocket Motor. It was going to have a different type of joint, a joint that actually, due to its geometry and fashioning configuration, would close under pressure. I thought that was great. I presented to the astronauts and said we had a joint that will close. The sealing surfaces over the O-rings will actually get tighter. They asked if it was going to have that sealed insulation. We said yes and they said that was all they wanted to hear.

Johnson: I want to get your feeling after you have done the work on the Solid Rocket Motor after *Challenger*. It is time to fly again. You talked about your fear all the way back to Saturn that there was concern with the first shuttle flight. What was it like returning to flight? You have done the redesign. You have tested. You feel good about it, but I have to believe that was a good day for anxiety.

Mitchell: It was, anxiety was very high, but I had an ace in the hole. We had done something unprecedented in the test program, back to characterizing everything, testing the hell out of it. We had done something that had never been done before. After we redesigned the joint and had run the static test as the last thing we did, we said we were going to take a motor and deliberately ding it up. We were going to put surface blemishes on the sealing surfaces. We were going to cut holes through this wonderful new sealing insulation. We were going to damage virtually every joint on that motor and test it on the stand. And we did. People told us we were crazy. Dr. [James] Fletcher, the NASA administrator at the time, said we could test it that way, but we were not to take that motor apart until after we fly the shuttle again. Somebody will find something and we will spend two years analyzing that. Test it. If it holds together, fine. Let us go fly.

That test, that one test was kind of the culmination of all the other testing, all the other measurements, all the other process verification, all the work we did around the clock. That one test did more to let me feel confident. The intensity was there. The concern was there. The acknowledgement of what failure would mean was there. That one test successfully done, where we damaged those rocket motor joints and they still worked fine, what a relief that was. I cannot tell you how much that took a lot of the load off all those concerns. Again, there is always the unknown unknowns, the who would have thought of that. That is always there. That one test probably generated more hours of sleep for me than any other thing we did.

Johnson: We return to flight, have a successful flight, you had your ace in the hole, the test. Looking back, working on the Saturn V, the work you did there, helping come up with the conception for the shuttle, getting the shuttle back into space after a terrible disaster, when you look back at your career, which one of those do you remember most?

Mitchell: That is easy. As we left the firing room after STS-26, the first flight after *Challenger*, I turned to a colleague and said, “It is a hell of a note to realize that everything in the future is going to be downhill from this one evening.” We launched that thing, everything was great. That launch, the STS-26 launch, was the highlight by far of my whole career.

Johnson: Coming back from disaster.

Mitchell: I had plenty of exhilarating successes before and after, but nothing compares with walking out of that firing room at the Cape with that satisfied feeling. As I said, it is tough to think that everything else will pale in my career in the future.