NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
ORAL HISTORY 2 TRANSCRIPT

ROBERT L. CARLTON
INTERVIEWED BY KEVIN M. RUSNAK
HOUSTON, TEXAS – 10 APRIL 2001

RUSNAK: Today is April [10]th, 2001. This interview with Bob Carlton is being conducted in the offices of the Signal Corporation in Houston, Texas, for the Johnson Space Center Oral History Project. Interviewer is Kevin Rusnak, assisted by Sandra Johnson and Carol Butler.

I'd like to thank you for joining us once again this morning.

CARLTON: It's my pleasure.

RUSNAK: Last time we talked a lot about the Gemini Program, and this time we're going to discuss Apollo. So if you could explain how you made the transition from one program into the other, what sort of differences it meant to mission control, learning these systems for you, creating new mission rules, that sort of thing.

CARLTON: Okay. Pick up at the end of Gemini, and transition through the end of Apollo, and then describe Apollo, I presume.

RUSNAK: Okay.

CARLTON: As we came to the end of the Gemini Program, it had been fast and furious. It was, I guess, a period of learning for most of us newcomers to NASA. We still weren't totally trained and didn't totally understand what this business of flight control was all about, but we were beginning to glean it. We had that team of flight controllers who had now gone through several missions, and a lot of them had been through two programs, had been through the Mercury Program and transitioned into Gemini, and now they were moving on into Apollo.

The team of guys that had been flying missions all this time were too busy up to that time to have even thought about Apollo. In parallel with Gemini, there were other guys who had been working on Apollo all of that time. I'm not sure exactly where it started. We were sort of oblivious to its presence. They were over in another part of the building. The guys in flight control that had been following the Apollo came into it probably in its inception when they first started designing it. They looked over our shoulder, and they were like us in Gemini, newcomers to the game and probably like I was when I first hired into NASA at Gemini. "What is this all about?"

They had been over and sat in some of the missions. You don't really learn it by looking over the shoulder. I can't explain that, but you don't appreciate it until you got in the midst of it. A lot of that stuff just flies over your head and you just don't appreciate what's going on. It's simple. So they had been doing that for several years and mostly, probably, were just totally immersed in trying to watch the Apollo design progress and to influence it so it would be easy to operate.

When we came to the end of the program, there were two or three things that I'd call a transition and in the nature of transition. One thing was that we had been so immersed in Gemini, we didn't even know what the Apollo hardware looked like, or the spacecraft looked like. Occasionally, you'd see a picture on the wall, but it didn't even have a gleam, or inkling, of what was there and how it worked and the systems in it. So there was a brand-new set of spacecraft systems for us to learn.

At the same time, there was a group of people who were our brethren in the flight control game. Maybe you ought to let me diverge on a tangent here just a moment.

There is a rapport among the flight controllers that I'm sure you've observed as you've interviewed them and talked to them, that I suspect is sort of unique. Maybe a few other occupations develop that rapport. I've often wondered about it. It's a sense of—I don't know that "brotherhood" is the right word—"camaraderie" is the right word. I observed it in a few other occupations that maybe talking about it there would give you a better sense of what I'm talking about amongst flight controllers. I notice among policemen, if one is hurt, they all gather and rally around and feel the sense of hurt. I've often wondered about that. I kind of think what it is, is when you face a very strong common adversarial situation, it draws you closer together. I see that same sort of thing exhibited in the combat people that have been in the service and hear them come back and talk about the experiences they went through together and talked about some of the things they did for each other. Some of them would give their lives for each other.

The flight control team, as they're planning a mission and trying to get it all together and accomplish its objectives, you get a sense that we're all doing this and everybody's doing it together. You see it in the football teams here. It's a team effort. That team effort develops a camaraderie that's probably there with them for life, assuming it even stronger when there's an element of risk and danger involved in it. In our case, the danger wasn't to us, but it was with our cohorts, the astronauts, who were in orbit. We felt a tremendous sense of responsibility. It [would have] broke our hearts if one of them had been hurt due to our faults. So there is a common sense that above all else, we must not let a fellow space traveler here be hurt.

But when you went through trials and stresses and problems like Apollo 13 and others, every mission had a series of little traumas that weren't of the magnitude of the 13, but still had the potential in it before they got corrected, it built a bond that's difficult for me to describe. But I see it even today. I can walk in a room somewhere and see one of my fellow flight controllers, and it don't matter, I'll just automatically be aware of him the instant I walk in, and I'll see his awareness of me.

Sometimes you walk in a meeting, I recall one time walking in a meeting years later, I'd left flight control and was working with the Air Force. The Air Force sent me over to a meeting where a new mission was being reviewed, and [Eugene F.] Kranz and Don [Donald R.] Puddy were sitting up at the table, chairing this meeting. They had a bunch of new flight controllers. A young lady was up there briefing them and going on. I sat down next to Carl [B.] Shelley, who was one of our old flight controllers, and we exchanged greetings. I saw Don and Kranz look at me, and one of them nudged the other one, look back there, and their eyes lit up. We acknowledged each other.

This young lady was going through mission rules, and it took me a while to realize this is a female flight controller. Now, this sounds like a male chauvinistic, so you ladies don't get upset. In our time, there was one female flight controller, Cynthia [F.] Wells. No, it wasn't Cynthia Wells. Cynthia was the second one. There was another one. I forget her name, but she ended up going down to Houston to become a councilman or something like that, had a lot of voters. But most of us were males in that day.

Anyway, when I walked in, this young lady was briefing them, and it was a few instances before I realized, "She's talking like she's a flight controller." I nudged Carl, and I said, "Carl, is she a flight controller?" He grinned. Well, I looked up at the table, and Kranz had nudged Puddy, and they were just laughing. Both of them, they were waiting for me, my reaction, to see what, before I finally woke up to this is a change in the organization, progress. But the camaraderie there is what I was trying to get a handle on.

Now let me come back from that tangent. We were getting ready to go into Apollo. We were not only learning the vehicle. We had a new team of guys that were interleaved. It was a great transition to bring, in our case, in the LM [lunar module], Jim [James E.] Hannigan had a group of guys that had a lot of Air Force troops with him and a lot of contractors with him, Grumman [Aircraft Engineering Corp.] people and a lot of NASA people with him. I forget how many there were, but a pretty good organization of flight control people, who had not been involved in the missions other than just watch it happening.

So the effort was to meld the two teams together, the ones that had been flying that don't know a thing about LM and the ones that knew everything about LM but don't know a thing about flying, and to get them up to speed and weld together a flight control team that would then support the Apollo. So we had a massive reorganization, sprinkling them all together. Jim Hannigan became our branch chief, and we formed a new branch. The ones in the branch, we divided the branch up similar to the way we have the control team in the MOCR [Mission Operations Control Room] and in the Mission Control Center.

Each bird had basically two groups of people following it. We split the bird in two, if you will, systems-wise. Don Puddy was part of Hannigan's group of guys. He was a young Air Force guy that had come out of the Air Force and joined NASA. He ended up with one section in this branch. Jim Hannigan was the branch chief when they worked LM and prior to while we were off in Gemini and he was with the Apollo following the LM. I had the other section, which was the guidance and control.

In his section, we took some of the Gemini electrical people and put them over under Don and sprinkled them in his section. Then Jim sprinkled some of the people who'd been following the guidance control systems into my section. Then I kept some of the guys who had been flying Gemini flights with me, John [A.] Wegener and Hal [Harold A.] Loden and Paul [D.] Nering.

The transition there was kind of rocky when we first started. There was sort of a growing period, I guess you'd say. Part of it was getting to know each other. Part of it was overcoming some psychological barriers that you had naturally built up and you didn't dream were there until you got to working together. One barrier we had to overcome was those who had flight experience on the console sort of disdained the ones who'd been back here on the desk and didn't know a thing about flight controlling. It made me think a little bit of my own experience when I came in as a Gemini flight controller, a newcomer, didn't know a thing about flight controlling.

Some of the guys that worked with me, Ed [Edward L.] Dunbar [Jr.], I remember, was one that worked with us. He was a Philco troop that had been back in Mercury. Their favorite expression was "Well, now back in Mercury, we did so and so." The implication is, "You just don't know a thing about how this works." I got so sick of hearing that. [Laughter] I can remember some of the guys telling Ed, "Ed, we don't give a crap what you did back in Mercury. This is a new program." Well, I'm sure the LM troops felt the same way about us. "In Gemini, now we did—"

But as we worked together trying to plan the new missions together, the new perspective evolved us, and they challenged us, "Why are you doing it this way?" Well, even though you were impatient with them for saying that, we've done it and this is best, still they say why, you've got to stop and think, "Now, why are we?" Or if they say, "Why don't you do it this way?" you've got to answer the question. In answering the question, you begin to realize there's a different way. We done it one way, but there's another. So we had, I guess, you'd say an evolution take place as the new blood poured into our outfit.

We had a different psychological barrier or hurdle we had to overcome. The guys that had been on the LM and understood the LM and been in the design of it, if we came in and looked at something and criticized "Why did you let them design it this way?" Well, there was that same defensiveness. But they had to answer the question. They were the experts on the LM. We were the experts on flight controlling. Each one felt like, a little bit, "This is my turf. You do it like I say." So they had to kind of get over that.

Another thing they had to get over, and this was most especially difficult for the Grumman [Aircraft Engineering Corp.], the contractors, the way they had worked, prior to coming into our outfit, was here's the LM being built. Grumman had sent this team of guys down to assist the young NASA green-bean troops, who were younger than the contractors, [the] old mature guys. Really old, they were in their early thirties. The NASA guys were young. They were in their twenties. The contractors were the experts on the systems, so they had a sort of a relationship with these green-bean NASA troops. "I'm a senior engineer and understand. You come to me. I understand the whole thing."

Well, when they came to us, we didn't work that way. We expected every flight controller to be intimately familiar with his spacecraft. More than that, they weren't dealing with a young NASA twenty-year-old when they came in to us. I was more mature, like I say, I was essentially their own age and pretty domineering in the way I run the outfit. That gave them a lot of heartburn. Though when I asked them to do that, I accept them as flight controllers and determined to make flight controllers out of them, and I didn't realize their ignorance in flight controlling. I acknowledged their expertise in their knowledge of the LM, but they were ignorant in flight controlling. But they hated to take on this role of ignorance.

So it was a transition for them, to suddenly not be the all-knowing senior person in the outfit. It also was a transition for them to have to be completely under the authority of a young NASA troop. Even though I was approximately their age, I was still. So we went through a lot of growing pains there.

But, gradually, as we kept our focus on “Here’s what we’re trying to do and here’s the mission,” that teamwork came to the forefront and they evolved into a close-knit team. Even today they are part of the flight control team.

We had a mixture of people, contractors that came from Grumman, we had Philco contractors, like Dunbar and some of the others, that went out to the remote sites. Ed [Edward I.] Fendell, there was just a raft of them. They were good people. We had Air Force and other servicemen that came in and joined with us. Then we had the NASA corps. I don’t know what the ratio of people would be. I would guess NASA people were no more than a third of the total team.

One unique thing about it was they all worked together close as a team. There was a teamwork there that took place that you just sort of before you knew it, you were doing it. It made you sort of subvert this human tendency to, “I’m the hero.” It was, “Boy, if we don’t all do our job together, this is not going to work.”

When you listen to the tape later and you hear the mission taking place, you can perceive that. If you’re listening to what’s happening, you’ll hear one guy say here’s so-and-so and so-and-so, and another guy from another organization, “I got that, Flight.” He’s waiting on the information, and the teamwork back and forth between them all and the way they work together as a team will come through to you, I think.

So we were transitioning and getting ready to go into Apollo. At that time, also the Mission Control Center was still transitioning. It had a brand-new system to support Apollo. In the early missions, that thing was still growing, and it had some horrible bugs. Every time you sat down to do a simulation, they'd have improved it a whole lot since the last time, so the improvements just made it difficult to keep up with what the ground system was. It was growing and changing. Each mission, we put in requirements and said, "Now, this is what we'd like to have. This is the way we want the displays to look, and here's the way we want the event lights to be driven, and here's the parameters. We want a strip chart recorder, and here's the data rate we want coming in the door."

They'd say, "We just can't get it. We can give you this much." So every time you sat down on the console, you didn't know what you had. Sometimes they'd work themselves to the bone, and you'd have something you didn't expect. Other times, you was expecting something that wasn't there. "That'll be the next mission."

Later on, it was a chore. You'd sit down and you'd have a configuration. Mostly it was software. You'd have a configuration that supported this mission, but when you reached a point of maturity and they had tested it, then they didn't want to change it anymore. You had it verified and it was supporting the mission, you don't want people in there messing with it or they might put a bug in it that will mess you up in the flight.

So you reached a point where you froze this configuration, but you also, at the same time, you would be training for the next mission, running simulations on it. So you'd go in and with this mission's configuration and train today, and tomorrow you might run a sim on the next mission's configuration and had a bunch of improvements. Then you'd get back the next day to this mission, and your brain would get mixed up. "Now is this event light working or not working? Is this display? What are these parameters on here? Oh, that's the next mission. Oh, I didn't think they'd get that to two more missions." It was hard to keep up with, and it was frustrating. That was a big frustration. Toward the end of Apollo, that settled down and we began to settle down, steady state, and then there were more incremental changes. But in the front end of the program, there were some just massive changes taking place.

Another thing that took place was the transition as we, somewhere along the time, and I forget what mission it was, we suddenly had all the data flowing in to the control center. We got a taste of that when the bird left in the lunar missions. As the bird left the Earth and went toward the Moon, it was continuous contact with it. We had these big antennas that could see to the Moon and all the way, and the bird was somewhere between here and there. No matter how the Earth rotated around, one of these three big antennas could see it.

They could flow real time, what we call real time, data to the control center. By "real time," I mean like it's the total data stream flowing to you—not actually the total, because it flowed through a bottleneck. The data lines that came from those sites were one or two kilobits of data. The data coming out of the bird was probably a hundred times, I don't know exactly, maybe a thousand times more than that, so you had to select the particular parameters.

For example, the thruster firings, an RCS [reaction control system] thruster that controlled attitude, the thruster could fire for about ten milliseconds, a minimum burst. If you just had a small amount of error, you… want to turn a thruster on that small amount of time. If you had a big torque you was counteracting, or the astronaut was doing a maneuver, then you'd turn a thruster on, and this was automatic in the system, of course. But you'd turn it on for a bigger period of time, maybe a two-second burn. Well, to get those teeny-weeny burns, you had the telemetry downlink that parameter showing you thrust chamber and RCS thruster at maybe a hundred times a second. But when it got to the ground, you couldn't flow that much data to the control center, so you repacked that information and you put that bit in there and you turned it on. If the thruster had fired in the last two seconds, it turned the bit on and it stayed on. At the end of two seconds, it turned it off, and they sampled the bird again, the data stream, and if it was still on, they reset the bit and you got another. It showed it.

So what came down at a hundred times a second I saw on the console as once every two seconds. Sometimes that took a lot of planning to know which parameters didn't make any difference and which parameters is important to have a higher sample rate done. We went through a lot of learning on that.

Some parameters like the temperature in a tank is a very slow-moving thing. You get in the sunshine, and the sun warms it up, and it begins to creep upwards. Well, once a second, you can go once every five minutes and keep up with that temperature. You get a thruster firing every ten milliseconds, and you've got to have it fast. That bit, we had some learning and a learning curve there, too, learn how to live with this choke-down data flow coming from the remote sites to the control center.

Then we had limitations in the control center on the TV. It updated once a second. So it didn't matter how fast it come into the control center, it was going to get updated one sample per second on your TV monitor. To get around that, some parameters like the RCS thruster firings, we'd put them on an event light. They had drivers downstairs, and it would drive that event light at whatever sample rate it came in off the pipe. This data flow coming in, I call it the pipe.

We had a lot of arguments about that. We had two pipes. That was a big, big battle that took place in the early part. The sample rate just was not sufficient with one. I forget how much flow was in one, 1-point-something kilobits, and we filed for a second line, data line, and it got us up to 2-point-something kilobits. Today, that's teletype counting data flow.

But it was expensive to bring that second data line in. We had a big, big battle over that, and finally John [D.] Hodge, our chief of Flight Control Division, was the one that made the decision, finally. But it was a big strong battle. He didn't want to buy the extra cost it took to have that line brought in. But finally he acquiesced and did.

So as we went through those growing pains, we got ourselves prepared and began to do simulations. The simulator itself, that's a complex system. I hope you talk to some simulator guys. They'll tell you that was not a simple thing. I mean, they had to simulate this vehicle, LM vehicle, that looked to us on the console just like the real LM, and they did a fantastic job of it. Had to simulate the dynamics of it going to the Moon, and if we did a burn, it had to transition itself into the dynamics that we saw changed the thrust vectors and changed the flight vectors of the ephemeris, and they had to do it in such a way that it looked real to us. And it did. It looked so real, that after you got through and thought back on the mission, it was difficult to separate in your mind what happened in sims and the real mission, with the exception of a few.

The Apollo landings stuck in your mind pretty strong. But most of your sims, the on-orbit stuff, you get it confused. You think back and you'll remember something, "That was a sim. That didn't happen." Some of the little incidents with people doing things, that was a sim that didn't really happen.

The one example of an incident, and actually this was back in Gemini, but it's an incident that illustrates that point. It seems like a real mission to me, but I think it was in a sim. I know it was in a sim. We were going to do a burn, and we did that manually controlled from the ground. It's a very, very short burn, like at one-and-a-half seconds or something like that. And we did it on time. Started a stopwatch.

So when we did the burn, I had the stopwatch in my hand. I got one button on the engine and one button to fire the engine, one button to stop the engine. So the sequence has got to be fast, and it's got to be right. Now, what am I going to do? I'm going to arm and I'm going to fire and start the stopwatch at the same time. Then after so many seconds, I'm going to stop the stopwatch and punch the stop button. Well, I got mixed up. Arm, fire, and instead of starting the stopwatch, I hit the stop.

Well, there was a little light come on. The command's received by the bird. I hit arm, and that light went up. I hit the fire, and that light went up. About the time I hit that, I realized I done a wrong thing. I thought maybe it didn't take. Ten eternities later, that big light came on. Engine stopped. I thought, "Oh, what have I done? I don't know what I did."

About that time my SSR [Staff Support Room], I hear it in my ear, "Bob, the engine shut off." He couldn't see that I'd sent the command.

Shortly after that, the FIDO [Flight Dynamics Officer] down there says, I hear him tell flight, he says, "Flight," he says, "we don't indicate that we're burning." He's watching the acceleration. John Hodge was flight director. I just took my headset off, I laid it on the console, and laid my head down there. I thought, oh, god. Even today if we get together, some of them will start reminding me, "Oh, Commander Carlton, you know, we got to teach him how to command."

A few weeks later, Kranz came over and handed me a little ballpoint pencil, pen. He said, "Bob, you can have this."

I said, "What do you mean? It's no good."

He said, "This is a memento from me to you." He said, "I was going to start my stopwatch, and I had it in my left hand. I was writing with my right hand and instead of pushing a button, I just shoved that pencil in and just splintered the end of it." Anyway, those little things.

Now let me come back to our—we were ready for Apollo. Those were some human things. That's the frailness of the human being, and humans make mistakes. In Apollo we tried to have a flight control team and everything set up so as to be able to minimize the human mistakes. I think I mentioned to you before when we were talking about Gemini, we have a dichotomy when you talk about man in the loop. On one hand, man is prone to error. I think I mentioned to you that if you look at aircraft accidents, 90-plus percent of them are caused by human error.

So, on one hand, you want man in the loop because he has the flexibility to work around problems that occur. On the other hand, when you give him the total operation, he's prone to make mistakes. I'm a firm proponent of man in the loop. I think that we probably wouldn't have done 10 percent of what we did if we'd had it all automated. I doubt that we would have had a single successful mission of landing on the Moon.

If you look at some of the problems we worked around and corrected, almost every mission had some unforeseen problem that would have put us dead in the water. But once you recognized it and had men in the loop, we got turnaround, and we could get it to work again. We'd figure out a way to work around it.

But the stuff that was automated, it don't make mistakes, provided that it don't run into a failure or unforeseen situation. So how you do that, well, that caused us a lot—we had a lot of learning to do there in how to do that. We went through a tremendous amount of procedural things that we did to try to circumvent this idea of man making mistakes.

One thing we did was we always had two people looking at a function. We probably had three because Kranz was a fantastic systems flight controller himself. He understood systems. He looked over our shoulder a lot and would ask questions, how's this and that and the other. A lot of times that was very beneficial and helpful, made us look at it from a different setup, different perspective.

But we always tried to plan things so that we had two different people correcting each other. In SSR, we had a guy that was looking at propulsion systems. That was his responsibility and he made the calls. He looked at the systems and he diagnosed and recognized when problems were happening. He should have seen them first always. But the guy on the MOCR [Mission Operations Control Room], we insisted that he know the systems to the level to be able to troubleshoot it and operate it by himself without an SSR. So he was a double check on the guy on the SSR doing their job right.

Likewise, the guy in the front room, if he made errors, the guy in the back is the double check. So they worked together. There's the checks and the balances there to keep either one of them from making a mistake, and that saved our bacon. There's a lot of times that that would come to the forefront and you got to where, time allowed, you tried to confirm with each other, but you also got, if you listened to the tapes, you'll think that was not happening. But when you work with somebody for a long period of time, you almost know what each other's thinking.

A lot of the procedures, the guy in the back room reports something and the guy in the front room won't even acknowledge it. He'll just report it to whoever it needs to be forwarded to. So it wasn't that he failed to coordinate with the guy in the back room. He knew the guy in the back room was expecting him to go that next step, and he would hear him make a response. So there was a coordination between them going on there, but it might not be apparent to you if you weren't intimately familiar with what they were doing.

You'll see that come to the forefront in one of these tapes, and it will almost be invisible to you. We had [an indication that] a thruster failed on. If you're listening to that, there's some other voices going on at the time, you probably won't hear my voice, but Bill [William E.] Sturm, that was in his area. He should have recognized it first and called it to my attention. But somebody had shoved a book up over his event light, and he hadn't noticed it. When it came on, it had an event light that come on that showed you the thruster was on, an indication of a failed thruster. All you'll hear on the loop, and it's so short and terse that you won't even notice it. In fact, as I listened for it, if I didn't know where it was, I couldn't have told it. I said, "Bill, ignore the event light. It's telemetry. The RCS failed event light is telemetry."

Bill said, "Roger." And that's the only thing he said. There was a human error corrected by having two sets of eyeballs. There was also the working relationship so close that you didn't need any further discussion. The teams worked that way, and that saved us from making mistakes. You really had a third set of eyeballs looking at things: the flight crew. We didn't make the switch position changes and so forth. The flight crew flew the LM. We diagnosed the problem, and if it had to have corrective action, we would relay that to Flight and say, "Tell the crew do this." The Capcom is listening and I'd said okay, the Capcom would voice it up and the crew would do the action. If they didn't like it, they'd question it. "Why're you doing that?" So you really had three sets.

If I add Kranz to it, I had four. Not all flight directors could be counted on to be the fourth set. It had varying proficiencies among flight directors. Some of them were very concentrated in their knowledge of trajectory kind of things and had not had the long systems expertise in exposure and others. Wherever their strengths were is how much some of them would reinforce different groups of guys. Kranz happened to reinforce, he was a systems-oriented guy, so he reinforced us. We had four sets of systems.

Well, as we went ahead, then, getting ready for Apollo, the new guys also learned this, just as we did, this system and what we're doing in this game of flight control and by the exercising of mission rules and the onboard procedures and the malfunction procedures and the preparation of the drawings that we used. Those were instruments—and I can't recall if we discussed this in the Gemini conversation or not—those were all instruments that I think were just critical to making the program run as smoothly as it did. They were a means and a mechanism for the program management people to have their desires carried down to the very lowest echelon.

For example, the program management might say once we've landed on the Moon, the primary objective is to gather some rocks. Well, we also had cameras to take pictures, and we had all kind of instruments they took out and planted on the Moon. But they set the priorities for everything we did. The first priority is to land on the Moon. The second priority is to do this and that and another and another.

But once we knew what was important to them, we planned our reaction to any unforeseen problems in such a way that we maximized the return according to the priorities they had assigned stuff. We wrote that down in mission rules and reviewed it with them. We'd tell the manager, "Now, if we have this failure, this knocks out this system. It don't work anymore and we can't do this. But we have a limited ability to do this and this, and we're going to do them in this order." He would look at that and see what we're trying to get done. "Here's the priorities you gave us."

If he disagreed with us, you'd say, "No, I'd rather do this." So it'd give him opportunity to see how we were following through on his overall programmatic priorities. There were times when we didn't give him a vote. If crew safety was concerned, it didn't matter what he wanted, we were going to bring the crew back. But that's where we overrule with the flight control priority. But he knew that. We reviewed that with him, too, so it was a means of communicating from the top to the bottom.

I think another thing that made the program a great success was there was a philosophy, a programmatic philosophy, that was, I think, unique in NASA. I had never run across it before anywhere in my experience in the military or in industry. That philosophy was that there was always an open ear at all levels of management to a concern of any person in the chain of the team.

It didn't matter how low he was. When we had reviews of spacecraft, they would encourage—it didn't matter where you worked, who you was or what his level was or what his boss thought, he could write up what we call a RID [Review Item Disposition] discrepancy report on "I think this is wrong with the system, the design is flawed," or whatever.

That got bumped up the chain, and top management would finally look at it, and they would make a ruling. Whoever that impacted had opportunity to argue the case. "Well, he's off base." But the fact that the little guy, no matter where he was, he was a part of the team and his voice got heard, I think that was the very heart and soul and strength of why the program was so successful. That weeded out a lot of problems that could have come to the forefront and bit you later on. It was a very conscious thing, part of the NASA management philosophy to do that. That impressed me at the time, and I think it was unique to NASA.

I doubt that it happens even today. Usually, the boss don't want the problems that's under his command to be aired to the upper echelon. You don't go around the boss. So the effect of that is to mute any dissent about what's going on, and upper management only then sees what the next level below wants them to see. Therefore, they don't always have full visibility. NASA didn't work that way. Considering as much as was at stake, it probably was a very good thing that they didn't. It caused probably a lot of extra wheel-spinning. They worked problems that the majority of the problems this little guy thought was insurmountable or big, the upper chain knew about it already and had made a decision we were going to live with it for one way or to work around. So that was sort of a uniqueness of the program.

I think there was another thing that was unique to the program and made it a success, was the way in which the NASA management worked with this gigantic team. It's hard even today talking about it, to comprehend how many people were involved in that Apollo Program. You had several spacecraft with the manufacturers scattered all over the United States. If you went to KSC [Kennedy Space Center, Florida], they were simultaneously building the KSC facilities with a complex of contractors went every which way.

The NASA program management, trying to get all of these diverse people to work together so when the hardware got together it worked together. You had a booster sitting on a booster sitting on a booster sitting on a booster, each one of them built by a separate contractor, and yet they had to talk to each other through their interface. As it went into orbit, the mechanical strength of the interface had to work. It interfaced to the Cape. As it was sitting on the pad, it interfaced to the Cape. When it got into orbit, it interfaced to the control center via the telemetry link. It's mind-boggling to see how many different things had to work together.

Then all of those contractors. Kind of like one of those astronauts said one time, "I'm up here in orbit." He said, "You guys said there's 20 million pieces here and every one of them built by the lowest bidder. That don't give me much of a warm feeling." But they worked together. The fact that NASA could manage that horrendous a group of people with their own interests, and somewhere I think another thing took place. I think the people, all of the people that worked on the program, they had a sense of pride in what they were doing and a sense of "We want to make this work," just like that flight control team did. And I believe that transcended what we normally see in contractors with a profit motive overrides everything else. I don't believe that happened in Apollo.

I believe that was one instance in our nation when the whole complex of industry and government were working together toward a common national goal in the sense that we're going to accomplish this goal. Through the whole team there was a sense of pride in what we're doing, had nothing to do with the money they made. In fact, I doubt that the management of those contractors, I doubt they cared about the money at that time. We hope we make a profit, but I'll bet if you could look in their brains and see what was really motivating them, you'd have seen that same sense of pride that you see emanating from myself over what we've accomplished, and everyone.

When we get together, it never ceases to amaze me, when we get together in some of the old reunions, there'd be contractor people come in a lot of times. Or if you run across one on the street somewhere, it don't matter where they worked, there's that sense of "Boy, we did that, yes." Everyone of them, it don't matter what he did, probably even if he swept the floor in the plant up at McDonnell Douglas, there's a sense of "I did my part in that."

I look at the flight control team, and I was talking about the sense of camaraderie amongst them, I believe in the sense that sense of camaraderie really is bigger than that. It encompasses everybody that ever worked on it. I can't tell you why it's that way, but I know it is.

Or if I looked broader than that, you could probably be a better judge of this than me, but if I look at our whole nation, when I see like one of the anniversary years come up and I see people talking about it, and I've gone out to colleges and talked to the kids and gone different places, as I hear them talking about it, I perceive that there's a national sense of pride in that more than any other thing this nation ever did.

I bet if you went out and you talked to the people who are thinking about what are we doing as a nation and you ask them, "If you look back at our nation's history, what is it you think are the tall poles extending high in your memory over our accomplishments? What is it you take the most pride in what we did as a nation?" I'll bet you Apollo landing on the Moon would be probably the top. If not, it would be right up there amongst them. We've done a lot of good things in this nation, a lot of things, things we're proud of, great accomplishments. Probably, notice I said "probably," some greater than that. Probably some greater than that, but we take a lot of pride in it. So that sense of camaraderie is not just unique to my flight control buddies, it's a national sort of a thing.

[Well] as we went on, the thing I think that, as I started out about thirty minutes ago in this rambling conversation, that made it a success and I think was unique to it was the teleconferencing. The program managers would have a teleconference. I'm not sure about this, but I believe NASA probably pioneered that concept. I had never heard of it before. We would sit down in a big room, and there'd be a table there and there'd be a screen at the end of the room. The program manager would be at the end of the table, and everybody that was going to have a vote in this process of today's business would be around the table. Then there would be another table at Marshall [Space Flight Center, Huntsville, Alabama], there'd be another table at KSC, and another table at Headquarters. Everybody, we'd call that a teleconference.

Today's agenda, whatever decisions were being made, they'd list that up, and the other centers would have sent their charts in. So if we were debating a change to a booster of some kind, Marshall's booster charts would be up there, and the guy on it, you'd hear him talking. He'd start talking about this chart, and the guy in the back would throw his viewgraph up there. Then you'd have someone of our propulsion people that had been talking and intimate with what was going to be said by Marshall would point out on our screen so you could follow easily what was being discussed and debated. When you got through, the program manager would set there, and we'd all looked at this story unfold on the screen. We heard the guy down there that proposed it.

The program manager would ask everybody else, "What does this do to you, Cape? Does that obsolete some of your equipment? Do you agree? What's your thoughts about this? What's this do to you, Contractor?" Everybody that was impacted had his chance to put in his two bits and then the decision was made on the spot, easily.

Bob [Robert F.] Thompson, I believe he was the program manager, or the program managers with Bob Thompson would say, "Well, guys, look, we've got to move on. We're willing to baseline it today if you had it." You knew when he started out like that, he still had some people that wasn't happy with it. There wasn't a decision available to him that made everybody happy. He was taking the middle of the road. He had to keep the ship moving. He would say, "Guys, we're going to baseline this today, but we'll come back and revisit it if we run into problems we can't surmount." So everybody, "Okay, boss." So the team marched on.

I think that teleconferencing was a tool that was just invaluable to NASA in planning and putting the program together. We did it just extensively. Not just Thompson, but we had teleconferences all the time. Maybe that was a new era that just arrived in the nick of time that enabled the program to work so smooth as it did with so many people all over the United States.

Well, that brings us up to where we're beginning now. I think I've covered and sort of ticked off some of the points here of interest. I don't know where your interest, and other people who try to record this as how it all happened, will be strongest, but that's sort of the programmatic aspects of coming up to the mission.

So then if we move our attention on in closer to the mission being accomplished, the team gradually got all of their paperwork and their procedures and their plans together and began to get them trained. Maybe there's one thing that ought to be mentioned in the preparation for the mission, is training this new group of guys. By the time Apollo got here, our troops had—somewhere in Kranz's outfit, I don't know who it was, [Gordon M.] Ferguson was part of them. There's a whole bunch of them. There's one group of guys whose job was training. They were the ones that laid out the simulator and guided the simulator being put together. They also laid out a schedule of special training sessions, where we had people who specialized in training come in and teach us the systems. That was good, but it didn't carry a flight controller's knowledge down to the level it had to be. A flight controller's training had to be a lot stronger than, I guess, anything else

I've ever seen. My background is aircraft, and I saw military training. I've seen training of a lot of varieties, but I don't think anything ever approaches what we demanded of a flight controller. Generally speaking, you tell an operator, "If you want to drive a car, here's the way you shift the gears and here's the way you run the motor and here's how everything worked." Or if you want to teach a pilot to fly a plane. "This is how everything works, and if it don't work right, well, I don't expect you to worry about that. Land it, and we can get it fixed."

With a flight controller, that's not sufficient. When you put a crew in orbit and they're halfway to the Moon and something quits working, you don't just bring it home and fix it. You have got to live with what it is and you've got to figure out some way to make it limp along and come back home safely. The flight controller is the troubleshooter of the systems.

To troubleshoot the systems, he's got to know how it works down to the intimate detail. But not just how it works. He don't really come into play until it quits working. Now it don't work, and how do you make do with what you've got?

For example, to illustrate that, I'll give you two illustrations. Let's say that here is a solenoid valve that opens the valve and lets fluid flow through to an RCS thruster. Let's say that I had a failure in the electrical system and my battery voltage is going down. Now, this solenoid was designed to work at 24 volts, plus or minus a volt. The contractor designs it to that. The specs [specifications] says it's got to meet that before you launch. If it don't meet it, they'll change it out. Now I'm in orbit, and the electrical system has a malfunction and my power starts going down. I can see the power going down, and I can project ahead, this battery is dying, but it's going to live twelve hours before its voltage goes to zero.

Well, at five hours its voltage is eight volts prior to the end. And at ten hours, its voltage is sixteen volts, and so forth. Where is this solenoid going to quit working? That becomes the question. I would like it—I'm going to be ten hours before I am close enough to home to do a retrofire and come in. So is it going to be alive, and will I have enough voltage at ten hours? Somebody's life is hanging on how well I know that. Well, I don't have that information, folks. They don't test you to that. The contractor said, "You asked me to build it to work plus or minus one volt around 24 volts. Don't ask me. I don't know that."

And we went over it. We could not. It was very difficult. I won't say we could not. It was very difficult to make program management understand we need to know the outer limits of where everything works. And it's very difficult to get these young flight controllers and the contractor flight controllers and contract engineering people to appreciate why you wanted to know the outer limits of where everything worked. If you call the engineering people at the contractor and said, "Where's this thing work? Where's the outer limits?" he says, "Man, I don't know. We never tested that. It's going to fail somewhere."

So we pored over the test results of where they had failures and had abnormal tests, and that's what I expected the flight controller to know. Now, he couldn't get the information, was the problem. So we went around and around and around with the program office. That cost money to do off-nominal testing. So we got it. Sometimes they'd test stuff and sometimes they wouldn't and sometimes they'd have a failure.

They were running a thermal vac [vacuum] test over in the NASA center. They had a piece of hardware sitting there in a big vacuum tank. Somebody flubbed up and they turned off the cooling system to it. So this thing is sitting there working in a vacuum with no coolant. Well, we got to find out where it quit. We could never in the world get the program manager to have jeopardized an expensive piece of equipment like that. That was pure gold information to us. As I had the flight controllers, trying to teach them the systems, I made them go hunt. We scoured every test report that went on. In doing that, they'd come back and say, "This thing failed."

Now I'm circling the wagons here. The subject I'm on is how do you train a flight controller. The knowledge is not always there to train him, but you get it in bits and pieces. Now I've got the guy, beginning to get him conditioned to what he needs to know. Then it comes a failure on this test over at Timbuktu on thrusters, and I call that prop [propellant] guy in. I say, "Well, Bob, how come that failed? I want you to go get all the results on that and you come back and explain to me why that failed. Should it have failed there or at a higher level or a lower level?" So he's digging into that system component by component by component as opportunity presents itself. So that was one mechanism to train him in what he needed to know.

Another mechanism to train him was we had our own flight controllers prepare what we call malfunction reports. What we did was we took every single telemetry parameter on the bird and took the prop guys. I said, "Prop guys, I want you to tell me what you would do with every single parameter on there if it went out of limits. Let's postulate how it might go out of limits. It might go high. It might go low. It might do this. Postulate everything it could do and then you tell me, what would that indicate to you. That one parameter now, what would that be a symptom to you of what kind of failure is impending or occurring?"

So he went in and he took every single—like he might take a tank pressure. Here's a fuel tank. That fuel tank is full of fuel. The way you get the fuel out of it is you put pressure in the top of it. Pressurization. You put enough pressure in there and that will squirt the fuel out the bottom. We didn't have a pump that pumped it. You used fuel pressure or blanket pressure. Where did that pressure come from? It came out of a tank of gas. In the LM it was the tank of liquid or mix, a slurry mixture of ice, liquid gas, nitrogen, and then gas, all. It would come out and it would run through a heat exchanger. The fuel running out of it into the engine would run through this heat exchanger and transfer heat and change the liquid gas to a gaseous gas. Then you'd come around the top to a pressure regulator and come in the top of the tank and apply that pressure.

But if you had a temperature sensor on the top of the tank, just to give you an illustration of looking at a parameter, and you saw this temperature now, and you're rocking along, and it's supposed to be in a certain band, you're rocking along, and all of a sudden you saw it go to—maybe it's supposed to be at eighty degrees, and all of a sudden you looked and it did a step function up here of 300 degrees. What would you do?

Well, the prop guy'd study on that a while, and he'd look at his information. If that tank gets hot, it loses its strength, and it's liable to blow up. The contractors told us, "If you've got a combination of the pressure of this much and a temperature of this much, fracture mechanics sets in and the tank is in danger of rupturing."

I say, "Well, should we abort the mission then and get off of it?" No, ain't nothing wrong. If I look at a tank and the temperature of that tank, it's got a thickness of the metal. Tanks, big pieces of metal, don't change temperature like that. You can put a lot of heat in it, and what's going to happen is that temperature is going to start doing this, won't it? So I know by the action of the parameter when I've got a temperature problem versus I've got an instrumentation failure. So we went through every one of the parameters like that, and he wrote a malfunction analysis.

Then after he got through with it, the next team of guys I wanted to train, I told them. This might be [Robert S.] Nance [Jr.] first cut around. Then come along the next guy, Bud [Bernard A.] Durand, and he's going to train. I say, "Bud, here's the malprocedures. I want you to go through them and rewrite them." Well, Bud starts through it, he does this same process, and if he wants to change that, Nance is going to come up in arms. You've just attacked his integrity of his work. So I had a check and balance here going on. But it forced Bud Durand to learn it just as good as Bob Nance. So it was a training tool.

Also, it developed a mindset that you might encounter a new problem that you hadn't even thought about, but you've done this procedure so many times that you developed, I don't know what's the right word, a technique, a philosophy. So when something new was encountered, you kind of knew how to go about it. You were always limited by how well you knew your system.

The flight controller had to know the system. You can see from what I've been trying to illustrate. He had to know things much more to a lower level than a normal operator has to know things to diagnose and troubleshoot a system. He had to know how to make the system work while it was crippled, not while it's just operating normally, while it was crippled. But, otherwise, we didn't hardly need him. That's where you needed him the worst.

Well, if we move on to—now, see, we're running out of time. Let me pause a moment here and ask you, first chart will help. The reason I'm going through this, and I've gone through this with you on the board, but whoever might be looking at this later, it might not mean much to them. This might help them understand what's going on.

Inside the MOCR there—is your video seeing this? Inside the MOCR this illustrates kind of the team of guys. This box is the flight director. As we go through the tape, the first time we hear a roll call, that's the flight director. He's the boss of the whole team. I've only drawn part of the team here. The first row of consoles under him are people responsible to him. The two guys in the LM called CONTROL [Control Systems Engineer] and TELCOM [Telemetry and Communications Engineer] and later the name is TELMU [Telemetry, Electrical, and EVA Systems Engineer] or it might be TELMU here. I don't remember. Somewhere we changed his name once. Then we had CSM guys and Capcom and FIDO and GUIDO [Guidance Officer]. I don't show their boxes. So as you hear a status check, the flight director's asking each position all the way through the room, "Are you ready? Are you go for power descent?" And each one of them's responding to him.

You'll hear one, that's the GUIDO, that was Steve [Stephen G.] Bales. He was a real young guy, and he really was excited that day. He was spring-loaded. He screamed to go. [Laughter] We all kind of had humor. It kind of broke the tension at the moment when Steve was so excited. I could hear Kranz kind of chuckle a little bit as he went on around. But, anyway, that's what he's doing. He's taking a status check.

Everybody's looked at the systems and this is really, "Is there anything in your system? We're fixing to land on the Moon, guys. So you tell me if your system's go." That one, the reason I picked that was two things. One it gave you, you could hear Steve's voice. And it gave you a sense of the humanness in this team and how uptight everybody really was. The other thing was, it gives you also a feeling of how smoothly the team works together and how Kranz, the flight director—and this would apply to every one of them—the flight director is the boss. He's in control. This status check lets you see that team working as a unit and the boss leading the team. Like the orchestra, he may not can play every instrument, but the director, he can hear when that music is not right.

Once, I asked Kranz, I said, "Kranz, why do you make this big deal about a status check? Why don't you let us just punch the button?" I had on my console a green light and an amber light and a red light. Green says I'm go. Amber says I got a problem I've got to work on. Red says abort. I said, "Use the lights. That's what you want to know, isn't it?"

He scratched his head and he said, "Well, Bob," he says, "I like to hear the quiver in your voice." He said, "I can calibrate how bad things are when I listen to your voice."

I think it was [Christopher C.] Kraft [Jr.] once, and they was interviewing Kraft, and they said, "You don't know all these different positions." They said, "How do you boss all these people?" He said, "I'm like an orchestra conductor." He's the one that used this analogy. He said, "I may not could play the fiddle, but I can tell by listening if it's in tune."

Anyway, with that, let's listen to the status check. You keep in mind, as you listen to this now, there're three loops you're going to hear. One, you're going to hear the flight director as he talks to the people. In the status check, that's the only one you'll hear. Later on, you'll hear the air to ground. Anytime you hear, Charlie, the Capcom talking, Charlie [Charles M.] Duke, he's talking via air to ground, generally speaking. You can tell when he's talking to the ground, or he might be talking on the internal loop. But that's the second loop that's on this tape. Then the third loop is the systems loop between myself, CONTROL position, and the back room with the three guys, Props, PGNS [Primary Guidance and Navigation System, pronounced "pings"], and AGS [Abort Guidance System], and you'll hear those guys interrelating later on, but not in this status check.

Each of the other console positions in the MOCR also has a team of people in the SSR that's supporting, and that's illustrated here. So the voices you're going to hear, you may hear some of the guys in the back room communicating to me, but most powerfully and probably the only thing you're going to hear is the flight director taking a poll around the room in the MOCR. So with that introduction, why don't we turn it on and see what it sounds like. You're going to play it for just a short distance and then skip to the next.

RUSNAK: And to provide further clarification, these are tapes you made off of your console.

CARLTON: That's correct.

RUSNAK: And this was Apollo 11 getting ready for the lunar landing.

CARLTON: That's correct.

RUSNAK: We'll go ahead and play the first segment.

CARLTON: We'd just come out from around the Moon, looked at our vehicle systems. Kranz gives us a chance to—.

[Editor's note: The following segment was recorded on 20 July 1969 in the Manned Spacecraft Center Mission Operations Control Room. It includes intercom loops between the LM Control Console, its support rooms, and the Flight Director, as well as communications between the Apollo 11 spacecraft and Mission Control. Conversations over these loops frequently occurred simultaneously. Mr. Carlton's verbal comments made over the tape during this oral history session are included in parentheses.]

KRANZ: Ok, all flight controllers, Go/No-Go for powered descent. RETRO.

CHARLES F. DIETERICH: Go.

KRANZ: FIDO.

JAY H. GREENE: Go.

KRANZ: Guidance.

STEPHEN G. BALES: Go.

KRANZ: Control.

CARLTON: Go.

KRANZ: TELCOM.

DONALD R. PUDDY: Go.

KRANZ: GNC [Guidance, Navigation, and Control Officer].

BRIGGS N. "BUCK" WILLOUGHBY: Go.

KRANZ: EECOM [Electrical, Environmental, Communications Officer].

JOHN W. AARON: Go.

KRANZ: [Flight] Surgeon.

JOHN F. ZIEGLSCHMID: Go.

KRANZ: Capcom, we're go for powered descent.

[end taped intercom loop segment]

CARLTON: All right. Now you heard him take the poll around the room, and when it got through, then he made the decision to tell them. He said, "Capcom, we're go for powered descent." If we followed along, we'd heard Capcom tell the crew, "We're go for power descent." So that was a go/no-go point in the mission. As the Capcom relayed that up to the crew, then they were ready to proceed to the next stage.

As we went down the mission profile, you'll hear those go-no goes at several places. In the actual middle of the burn, going down to the lunar surface, we went through phases. We took a go/no-go status check to go to the next phase. For example, as you were going down in the early part of the flight, if you had a problem that you saw would jeopardize your ability to land and you knew you weren't going to land, you're going to abort, well, you'd rather abort while you've got the whole descent stage there and use the descent engine to abort back. So as long as you have the descent engine with enough delta-V [change in velocity] in it to get you all the way back home, you're going to abort right now. You're not going to wait a little ways. Later on, you'll reach a point where the descent engine don't have enough delta-V to get you back to orbit, and you're going to have to stage. It might get you half way and then you stage and go the rest of the way with the ascent engines. So that is a discrete point. Before you cross that point, you want to be dad-gum sure everything's go. So that would be a status check. A little later you get on down and so on and so forth, you've got checkpoints.

Now if you can go forward to where we pick up the burn, I forget what checkpoint I call that.

RUSNAK: Where they're doing the checking that they had at least 10-percent thrust and they're starting the engine.

CARLTON: When you start the engine, there's a short period of time when you burn at very low thrust and it settles under. That creates artificial gravity in the tanks. The fluid settles down against the bottom of the tank. That's an ullage. We call that an ullage maneuver. Then after you had that settling effect, then you power the engine up and you begin to burn in earnest. So you may hear the ullage call take place. Okay, go ahead.

RUSNAK: All right.

[start taped intercom loop segment 2]

DUKE: I got ignition.

(CARLTON: That's Charlie Duke. He's nervous.)

DUKE: Let us have it if you don't see it.

(CARLTON: He's on my loop.)

DUKE: Do you see anything there, Bob?

[unclear]

CARLTON: DPS [Descent Propulsion System, pronounced “dips”] arm.

KRANZ: Rog, DPS arm.

(CARLTON: I heard ullage call.)

CARLTON: Ullage.

EDWIN E. “BUZZ” ALDRIN: [Z]ero. Ignition 10 percent.

NANCE: 10-percent TCP [Thrust Chamber Pressure].

(CARLTON: That's Bob Nance.)

CARLTON: 10-percent TCP.

KRANZ: Rog, 10 percent.

[unidentified voice]: Looks good.

[end taped intercom loop segment 2]

CARLTON: Hold a minute there, and let's talk about that. What you heard there was a variety. That was Charlie Duke. He's watching the systems, nervous as a cat. He's on system loop. There's three loops you're listening to. The systems loop, if anybody comes and talks to me on the systems loops, they're supposed to be on the systems loop, and that's what Charlie was doing. He's coming up there, saying, "Bob, let me know. What's going on? Is it happening? Is it happening?"

Then you heard Bob Nance's voice in the background saying this and that. I forget what he said. You also heard Bill Sturm saying we had something happened. So they were reporting to me, and I was reporting what I needed to report. Certain things were important to know. Ullage taking place was important to know. Bob Nance reported, "I see ullage." I passed that on to the flight director. That was the report that he wanted to hear. So that's what you heard there.

You heard the flight director and you heard—did we hear the flight director? I think we did. You heard the Capcom, Charlie Duke, talking on the Systems 2 loop. Then you heard the SSR guys reporting what's happening on the Systems 2 loop.

Okay. Go ahead.

RUSNAK: The next one you had marked was the go/no-go point for landing.

CARLTON: Okay. I don't remember where that was in the trajectory. Play it and maybe I'll be able to recall where it was at.

RUSNAK: Okay.

[start taped intercom loop segment 3]

KRANZ: TIGO is go.

CARLTON: We have position 2 on LR [Landing Radar].

KRANZ: Rog. Position 2. All flight controllers, 20 seconds to go/no-go for landing.

DUKE: Eagle, you're looking great. Coming up 9 minutes.

(CARLTON: We've been burning nine minutes.)

NANCE: Margin is looking good. We're coming up on our nominal here.

KRANZ: Okay, all flight controllers. Going to go for landing. RETRO.

DIETERICH: Go.

KRANZ: FIDO.

GREENE: Go.

KRANZ: Guidance.

BALES: Go.

KRANZ: Control.

ARMSTRONG: Manual attitude control is good.

CARLTON: Go.

KRANZ: TELCOM.

PUDDY: Go.

KRANZ: GNC.

WILLOUGHBY: Go.

KRANZ: EECOM.

AARON: Go.

DUKE: Roger. Copy.

KRANZ: Surgeon.

ZIEGLSCHMID: Go.

KRANZ: Capcom, we're go for landing.

DUKE: Eagle, Houston. You're go for landing. Over.

ALDRIN: Roger. Understand.

NANCE: Nine minutes. Margin is about four and a half.

[end taped intercom loop segment 3]

CARLTON: All right, stop there.

RUSNAK: Ok.

CARLTON: We were nine minutes into the burn. We'd reached one of these go/no-go points. Kranz was going around the room before he went through that gate. You heard Bob Nance. In the go/no-go, you heard Kranz, the flight director, going through one position at a time all the way around the room. Each guy had to give a status that he's ready to go to the next phase.

You heard Bob Nance. He was the staff support room guy that was over propulsion, responsible for the propulsion systems. He was saying, "Our margin is okay." What he was talking about there, the descent propulsion system had big fuel tanks, and ox [oxidizer] tanks. If we projected the whole burn, I forget the exact number of minutes, we had around twelve minutes' worth of burn, ability to burn that long, supposedly we'd land on the Moon.

Before we ever made the mission, we did simulation after simulation and analysis after analysis, and they sized those tanks to have a margin left. When you landed, you had to have a good bit of gas left in the tanks. You didn't want to run out of gas, in other words, before you landed. Before we run this mission, all of those analyses and simulations said that we'll have a goodly margin of gas left in the bottom of the tank.

We had, in the very bottom of the tank—and I've got a chart there that shows you this. In the bottom of the tank, we had a sensor. We had two ways of telling the fuel in the tank. One was we had a level, just like a gas gauge in the car. The other is we had a low-level sensor. The Volkswagens used to have a little emergency tank in the bottom. You had I don't know how much left. In the LM we had this little low-level sensor, so this represents two fuel tanks. This low-level sensor is right down at the bottom, and if you uncovered it, you had X seconds left. I forget exactly how many. Around 120, I believe, of seconds of fuel left if you continued to burn at a 1-lunar G, in other words, a hovering kind of a thrust level. You had that much time left when you uncovered this low-level sensor.

The reason you needed that was twofold. The granularity on this main probe here measured the quantity in there, and that indicated to a gauge onboard this. The fuel gauge is onboard. This probe, we also came down to the ground with telemetry to read that probe. But it went in increments, like 1 percent increments. So you'd go along, and when you'd burn enough fuel to step down one, you'd step down one. In other words, the coarseness of this, the precision of his reading was not sufficient to get you down in the seconds. So when you tripped this little low-level, you knew how much you had left, and then you counted it down.

Well, when Bob Nance was reporting margin, he had been looking at these trips, and then he had been extrapolating the points to give a smooth curve. Here's the usage rate, and each engine is a little more or less efficient than another one. They're not all identical. So he was measuring the delta-V we got out of this quantity of fuel to see how efficient the engine was, and then he was projecting that down to what margin we'd have left when we landed, how much margin would we have, how much fuel would we have left when we landed. Bob's reporting that margin way back up at nine minutes. He's already projected it down to see if we're going to have enough fuel.

Well, now as I was listening to the FIDO, he had previously been saying, "We're long. This trajectory is going to be long." I never really did understand why it was we were long, but for some reason, and we were going to be burning longer than we thought. So we were nervous about that, and I'm bugging Bob and we both are nervous about it. He's reporting, "The margin's okay, the margin's okay." Well, now, as we got down close to the surface, we were not supposed to ever trip that low-level. We're supposed to have a big margin in there.

But unbeknownst to us at that time, when you got down to the surface, there was a big crater. Armstrong took over manually and flew it over this crater and landed on the side of the crater, the edge of the rim over there. But prior to that, we're not going to land where we're supposed to, so what looked like good margins turned out to be we tripped low level. We'd been assured that would never happen. We didn't expect that to happen. Not only did we trip low level, it counted on down to sixty seconds left. Not only did we count sixty seconds, it counted on down to thirty seconds left. After thirty seconds, when we shut down, I had a stopwatch that started when that low-level tripped.

So I clicked my stopwatch and started it. As the hand went around, I'd put a little piece of Scotch tape. Very scientific thing here. A little piece of Scotch tape and a mark on it that said when you hit this one, there's sixty seconds left. When it comes on down to this one, there's thirty seconds left. Then when it comes down to the point we need to abort, we don't want to be empty at that time. There's some uncertainty in this measurement process we're doing, so we need to put a margin in there to be sure that we don't run into that uncertainty. So we put a little extra in there to count for that.

Then we said, okay, when the astronaut hears this thing abort, we want to give him every chance to land, so we want it to be as near empty as it can possibly get, but on the other hand, we don't want him to run out of gas ten feet off the surface. That's a bad thing to do, you know. So you had to hit both. You wanted to make the mission, but you didn't want to jeopardize your crew, and you wanted to play it just as tight as you could safely.

So you put these margins in for uncertainty of your ability to measure the quantity, for the uncertainty in what the thrust of the engine might be doing. When we see that he's out and he's got to make an abort decision, we want him to hear the "abort" word to punch the button right now. Well, there's a time delay of almost two seconds from us sending [the message] up to the spacecraft. The engine's burning during that two seconds. So we had to put in a margin for that.

Then when Nance reports it to me, and my brain takes a little while to processing it, give me a half a second worth of burn for that. When I report it to flight, I'm going to give him a half a second to process it. I'm going to give Charlie Duke a half a second to process it. We had all these out. We had a little tat of margin that when we said "thirty seconds," it was really thirty more seconds of burn plus this little bit of margin. When we said "abort," that astronaut had to be programmed. He didn't think anymore. When he heard "abort," he better hit the button or he is not going to make it. There's just enough gas left in there. When he hears "abort," we had some margin in there to, if he had a downward velocity, there's enough gas in there to turn him around and start him upwards, because there's a little time delay. When he hits abort and stages off that descent engine, the ascent engine starts burning and firing in the hole and comes off of it. But there's some milliseconds of delay while he's building up velocity. You don't want to be falling in that. You've got a downward velocity, so you've got to stop that downward velocity. You assume you might have one. Then you can get it started back up.

So, anyway, when Nance said, "We got good margins," he is anticipating that we're going to have goodly amount of fuel left there. He's not realizing that we are burning long and that later on we're going to fly over a crater, later on as we got down there and we begin—and it did, we tripped low level.

When I punched the thing there, I didn't think there was a chance in the world of us landing. I was looking at the altimeter and we had a heck of a way to go. I didn't know we were over a crater and I was reading to the bottom of the crater. But when you come over the top of the crater, that distance to go went "ch," like that, we're there. But I didn't know that.

Well, anyway, that's what was happening. Nance was reporting on the margins. You heard some of the other guys making reports to me and so forth. All right. Now go ahead and pick up and let's continue.

[start taped intercom loop segment 4]

KRANZ: Sixty Seconds.

DUKE: Sixty Seconds.

(CARLTON: Low level's tripped.)

ALDRIN: Light's on. 6[0 feet], down 2 1/2. [2] forward. [2] forward.

(CARLTON: And we're puckered.)

NANCE: Using a lot of RCS.

CARLTON: Roger.

ALDRIN: 40 feet, down 2 1/2. Picking up some dust. 30 feet, 2 1/2 down. [unclear] shadow.

CARLTON: Stand by for thirty.

ALDRIN: 4 forward. 4 forward. Drifting to the right a little.

NANCE: Thirty seconds.

CARLTON: Thirty.

KRANZ: Thirty seconds.

ALDRIN: 20 feet, down a half.

DUKE: 30 seconds.

ALDRIN: Drifting forward just a little bit; that's good.

(CARLTON: And we're puckered right there. You notice how quiet it is in that room?)

ALDRIN: Contact Light.

(CARLTON: Contact. This'll be Charlie Duke.)

ALDRIN: Okay. Engine Stop. ACA [Attitude Control Assembly] out of Detent.

ARMSTRONG: Out of Detent. Auto.

[unidentified voice]: Shut down.

ALDRIN: Mode Control, both Auto. Descent Engine Command Override, Off. Engine Arm, Off.

NANCE: We're there!

(CARLTON: That's Nance.)

ALDRIN: 413 is in.

CARLTON: We've had shutdown. [Cheers in background]

DUKE: We copy you down, Eagle.

NANCE: APS and RCS [unclear]

KRANZ: Ok, everybody [unclear].

CARLTON: Roger. Ok, fellas. Steady now. Stay with it. Keep your eye on it.

ARMSTRONG: Houston, Tranquility Base here. The Eagle has landed.

(CARLTON: My guys. I try and slow them down.)

CARLTON: Don’t relax yet.

NANCE: Looks beautiful.

DUKE: Roger, Tranquility. We copy you on the ground. You got a bunch of guys about to turn blue. We're breathing again. Thanks a lot.

ALDRIN: Thank you.

CARLTON: Okay, keep your eye on it.

DUKE: You're looking good here.

NANCE: Everything is steady. Steady as a rock.

ARMSTRONG: Okay. We're going to be busy for a minute.

ALDRIN: Master Arm, On. Take care of the descent vent. I'll get the pressure check.

KRANZ: Ok, all Flight controllers, about 45 seconds to T-1 Stay/No-Stay.

[end taped intercom loop segment 4]

CARLTON: As we came down there, you heard the sixty seconds. We had tripped low level, which no one ever expected to happen. When we tripped low level, things really got quiet in that control center. We were nervous, sweating. Came to sixty seconds, came to thirty seconds, and my eyes were just glued on the stopwatch. I didn't see it. The system could have fell apart at that instant, and I wouldn't have known it. I was just watching the stopwatch.

Nance had it on a strip chart. I was the backup to Nance. I talked earlier about backup to each other. He had a strip chart recorder, and it had the low level on it. So as it moved down, it moved at a certain speed so he could see much better than me, but both of us were pretty close. We were waiting for that low level. We knew we were very close to it, and the instant I saw it, it was on an event light with a high data rate hitting it. So I saw it within milliseconds of it hitting the ground and starting the stopwatch, and he didn't have to start anything. The strip chart measured it without him having any action, so he was primary for this. You heard him report low level and then sixty seconds and then thirty seconds.

When it got down and stopped, I had eighteen seconds showing on my stopwatch. I'll remember this little aside thing. I'll never forget, I looked at that and I thought, "You know, this watch, I'm going to encase this in plastic and never touch it." So I took it back to the office and put it in the desk drawer and thought, "I'll save this for posterity." Then I got to worrying about it. I thought, some of the janitors, somebody, will steal this from me. So I wrapped it up in a handkerchief and carried it home and put it in a box and saved it. Sometime later I got it out, looking at it, and I thought, "I remember that needle was sitting on eighteen seconds. Now it's on twenty-two."

I thought, "Man, I'm losing my mind." Well, a few days later, I got it out and looked at it again, and it had changed position again. I thought, "Ah-oh, something's wrong here." So I jumped my daughters, and one of my daughters was twirler, and she had been coming in and taking that watch and using it to time her. [Laughter] So it lost its position.

Later on, I brought it in and sent it to the Smithsonian, and that's where it is today. I don't know what they did with it. Probably lost it. [Laughter] I run it back to where it was supposed to be, and left it with the needle on the right thing. They probably think it's stopped just like the mission left it, but it ain't. I repositioned the stopwatch.

That's what you heard. He reported the sixty seconds, thirty seconds. That was from Nance. That was the Prop guy. You could hear the interaction. You could hear me reporting to Kranz, and Charlie, the Capcom, heard it. He instantly relayed it. So if you could go back and time those, I also told you, we allowed a half a second for reaction time, it sounded to me like it was pretty close. I've never gone back to double-check, see how close our reaction times all stacked up together. They reported it to the crew.

The way the crew worked, they knew their monitor onboard gauge, what they were looking at, was approximate. You heard him say "quantity light." He saw the quantity light. He was saying, "I observe the quantity light. Low level has been tripped." But if you just do it in your head, you will have no sense of how many seconds were gone. He was depending on the ground, and he knew the ground. He knew all the things we had put into it. They both knew, when you hear in your ear "sixty seconds," that's how long you, on board, have got until you're going to abort. When you hear thirty seconds, that's how long until you're going to abort. And when you hear "abort," you don't think about it. You do it. That's how close we were to abort. We'd been burning twelve minutes or something on that order. Ten eternities. And it come down to about eighteen seconds of aborting. We were lucky we made it. Just that simple.

I think that catches the things I wanted to point out to you. You can go back and play it again and you would maybe hear better Nance reporting and Bill Sturm reporting and the report to me and the flow to the other team. You can see that team all working together. If you listen to it the first time and you don't realize the background behind, it will just go right over your head.

Well, that's kind of brought me to the end of time, guys. I'm sorry. I wish I could just stay on with you, and I'd planned to just be available as long as you wanted today, and this other thing came up that's out of my control.

RUSNAK: I did want to point out that on that segment of the tape, of course, you can hear yourself telling everybody to calm down, essentially, and keep your eye on the gauges, but in the background you could hear people cheering.

CARLTON: See, everybody went bananas. That was not the time. That was the time to keep your eye on your business. You notice they settled down, too. Did you hear them? They were very—that pulled them back.

RUSNAK: So it's a hard moment not to applaud.

CARLTON: I know it. It was. It was a hard moment. You know, I got goose bumps listening to that.

RUSNAK: I did, too.

CARLTON: Just gives me goose bumps every time. I know we're going to make it all right. [Laughter]

RUSNAK: But we can finish that up next time.

CARLTON: Okay.

[End of interview]