# NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
# ORAL HISTORY 3 TRANSCRIPT

ROBERT L. CARLTON
INTERVIEWED BY KEVIN M. RUSNAK
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RUSNAK: Today is April 19, 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. The interviewer is Kevin Rusnak, assisted by Sandra Johnson and Carol Butler.

CARLTON: This is a little schematic of it [see Figure 1]. It had two fuel tanks and two ox [oxidizer] tanks, and I've only drawn the fuel tanks. The shaded part shows it's full of fuel or almost full of fuel. It had a quantity gauge down the center of it that operated onboard instrument. Then it had a pressure that sensed the pressure inside the tank that operated an onboard instrument.

Then the ground, we had a pressure gauge. I didn't draw it on this, but I should have, because it's important to us, as you're going to hear later. So I'll come out here with a little bubble, and that TM means it's telemetry. There's a shut-off valve in the top of that engine. But in space—if you're on the ground in gravity, if you put a pressure measurement in the bottom of a tank, or a pipe at the bottom of the tank, the higher you go up, the weight of the fluid causes a pressure. We call that hit pressure. That's caused by gravity on the Earth, but in space there's no gravity. Well, sitting on the Moon there's lunar gravity, so there's a little bit of pressure due to the head pressure.

But our pressure measurement came off of this pipe right here, which pressure should have been equalized all the way through the whole system, and it would be equal to whatever your gas is pressurizing the circuits of this liquid. We used the gas pressure to force the liquid out and into the engine, so it's a pretty good pressure. It wasn't just a slight pressure. It was equal to and equivalent to a pump. It was your pump.

The way we got this pressure on the tank was we had this tank of nitrogen, and it was actually a slurry. If you take water and you begin to freeze it, its changing phase from a liquid to ice, or if you boil it, it changes phase from a liquid to a gas. Well, there is a combination of pressure and temperature where [liquid nitrogen] can exist in… the same way, but you can visualize it better if we're talking about water.

If you put it in a closed tank, the higher the pressure inside that tank, the higher the boiling temperature would be. Or if you sucked a vacuum on it to lower the pressure, the lower the boiling pressure. The temperature where it freezes is slightly also sensitive to the pressure. So for liquid nitrogen, there is a combination of pressure and temperature where it can coexist as either a gas or a liquid or an ice, frozen. That's a triple point, I guess you want to call it. That's where this was maintained.

So in here was an exceeding cold—liquid nitrogen is cold. With the combination of pressure and temperature, where it also exists as ice, is even colder. So that exists as a liquid. We'll just think of it as a liquid for purposes of illustration here. The fuel coming out of this tank was forced by the pressure of which came in turn from the liquid nitrogen. I've shown it coming into the top of the tank here. There's actually a pressure regulator I didn't draw, because this pressure could just keep building up to big pressures. The regulator maintained it at a pressure at the top of the tank that was just right to force the fuel to flow, but wasn't too high to cause the tank to explode.

The problem is, you had a liquid, and how you get it from a liquid to a gas when you're flowing a lot of it, you had a heat exchanger right here. As you're burning the engine, the fuel comes through this through here and down into the engine. When you open the valve, you actually have fuel and an oxidizer, and I only showed the fuel. As the fuel flows, it flows through this heat exchanger, and the liquid nitrogen is warmed up by passing across the interface between the fuel and the liquid nitrogen. So the nitrogen comes in this side a liquid, and out this side a gas, and pressurizes this up here. That works fine as long as you've got a lot of fuel going through there. It will continue to take out the heat or take out the cold or warm up the nitrogen as fast as it comes in. You've got enough flow of fuel across it till it will vaporize it into a gas.

Now, what happened in that situation was just before the [Apollo 11] mission, this pressure tank, this fuel tank is okay. A metal tank, you think of a metal tank, is it just as solid and it will be solid until you got the pressure so high it blew up. Well, some metals have a characteristic called fracture mechanics. The best way to describe it so you can visualize it is lead. If you take a thin sheet of lead and you pull on it, with time it will be begin to stretch, and those little molecules will begin to slide with respect to themselves.

Well, in this metal tank, the metal does something similar to that. Metal is ductile, and if you got it down microscopically, the little slivers of microscopic particles of the metal begin to slide across each other, and you can have a little hairline crack begin, finally, under the combination of temperature and pressure. If you get the pressure high enough, it will happen explosively or with time it will happen anyway. Or if you got it at a given pressure and you get it hot, it begins this characteristic, to do the same thing. Fracture mechanics is the phenomenon I'm describing. Well, the tank is okay in normal circumstances, but if you let the inside of it get hot enough with the pressure that was there and let the pressure build up too much, you begin to have a fracture mechanics problem.

Just before the mission, Grumman [Aircraft Engineering Corp.] came in and they said—in fact, it was the morning of the mission. This was not something we had any opportunity to know about ahead of time or prepare for. It was a surprise out of the blue, a bolt out of the blue, that came in the morning. When I came in to the console that morning, there was a message there. "Grumman's got to meet with you. It's an emergency." So instead of going through the normal handover and transition, we allowed about an hour to do that, I spent that hour that morning listening to Grumman tell me what a big problem we had with the fracture mechanics in the fuel tanks.

What they said was that after we land, this tank has got to be monitored very carefully, because they had discovered that there is a fracture mechanics problem more serious than we had anticipated, and we're on the borderline of tripping into it to where we're in danger of blowing a tank up, which would have been a catastrophic failure.

Well, most times in the space business, the contractors, they are very conscientious. They come in and they warn you. They want to be on the safe side. So after a while, you sort of get a mental preprogramming. Most problems are not as bad as they're initially presented to you. Given time, you go back and do more tests. They're going to warn you, and properly so, but at the same time, the warning might be premature, and quite often is. So after you go back and do more testing, you find out your actual limits. But if you're warning a NASA guy, and you're a contractor, you're not going to take a chance right on that limit. If you don't know what it is, you're going to put yourself some pad in there.

So normally I take what a contractor comes in on a first cut with a grain of salt, and we watch it work. Then after a while, we get to the real true story. This morning, though, no chance to do that. No time. In an hour, we're going to power up the LM [lunar module] and start getting ready to land on the Moon.

As they talked about it, I thought to myself, "Well, it's right on the borderline of where we'll be in the tail end of the mission after we land and everything starts warming up and before we get it pressured, before we vented." We also had a vent. Let me draw that on here somewhere. I'll just come out with a line out here. To keep that from being a problem, we got a valve here. We vent this liquid nitrogen out and out of the top of tank, so the pressure in here goes real low. After we land on the Moon, we're all right.

So there's the situation, and there's the way it works. The liquid nitrogen goes through the heat exchanger, turns into a gas, pushes the fuel, pressurizes the fuel, and pushes the fuel into the engine. When you're burning it, as the fuel level keeps going down, more gas comes in. It gets turned from a liquid to a gas in the heat exchanger, and you keep replenishing it until you run out of fuel. Then after you land, you vent the gas and that lowers the pressure in the tank. That's the way it should work.

Now, what happened was—if I've already told you, I can't recall, if I've explained to you what the problem was.

RUSNAK: We do know. We wanted you to explain.

CARLTON: You listened to the tape. You know what happened. If I told you and you didn't know the answer, you'd scratch your head and think, "We can't get there from here." That's what I thought that morning.

What happened was, we landed on the Moon. We still had some fuel, a little bit of fuel left in the bottom of the tanks. This line was full of fuel on down to the engine. As we were watching the pressure, the fuel line is representing the pressure that it sends out of the tank. The tank's almost empty, just a few seconds, as I told you last time. There's about eighteen seconds' worth of burn time left in that tank. So it was just barely a little fuel here, and it was mostly gas. The temperature started going up.

We'd been sitting on the Moon now for—I've forgotten now just how far it was into the profile, but it was just pretty close to after we landed, ten to fifteen, twenty minutes. Pressure started going up. Well, at first, I was expecting it to go up, so I didn't really have any concern about it. They vented it. The crew vented the pressure and bled it all down. So right after we landed, the pressure went way down. But once they vented it, then they closed the valve again here. We had, then, a tank full of gas, and you would expect there to be a heat soak back from that red-hot engine down underneath it. So that heat soak back would gradually work itself up, and you'd expect the gas to build up a little bit and pressure, not much.

So we were watching it, and we had the data the contractor gave us that says that the pressures get this high and with this kind of a temperature the tank will blow up. So we had established some red lines that they had recommended. If it got this high, we would have to get off of it because we were in danger. Well, as we watched the pressure, this is what I was seeing on the ground on the instrumentation. I was watching the pressure go, peck, peck, peck, peck, peck. And Grumman, also, we sent that to Grumman at their plant. We'd give them a burst of data, and they could see it, too.

As they saw it increasing, they were alarmed. And it kept going up, and they got more alarmed. It kept going up and they got more alarmed. Then it reached the point where we were beginning to worry about it. After we watched it a while, we realized this is a problem and we've got to do something here. So we called the crew.

The first thing we did, we called the crew. See, they could read the pressure out also. I didn't show it, but they also had a pressure, several other pressures. When they first read it out, I thought they were reading the pressure off of the manifold on the gas. I thought they'd misunderstood us and were reading us the wrong pressure. So there's a little bit of back and forth. I kept asking them, "Go back and get me another reading. Go back and get me another reading," because what they were reading was not agreeing with what I was reading.

What they read sounded pretty good, and I suspected they were reading reg [regulator] pressure inside the manifold of the nitrogen line. I was scratching my head trying to figure out what was going on. The guy, Bob [Robert S.] Nance [Jr.], was the Propulsion [Prop] guy in the back, and he was scratching his head trying to figure out what was going on. We were watching the pressure going up. Well, it finally reached the point where everybody realized, "We've got a big problem here. This has got to get resolved."

I'm sure Grumman was climbing the walls. We have a guy in the SPAN [Spacecraft Analysis Room] that interacts with the contractor to keep from coming in the middle of a mission and distracting the control team. So one of our own, it's kind of like the CapCom, talks to the flight crew in orbit, our SPAN guy talks to the contractors. [James E.] Hannigan was back there, and Hannigan calls and says, "Bob, Grumman is going nuts."

That was before I really had concluded it was a real bad problem. I still, in the back of my mind, just thought, "Grumman always—all contractors always kind of expand things." So we were rocking along there, and when we finally realized this is one heck of a problem, then you can hear the excitement level come up and we begin to ask the crew, "What are you reading?" They didn't jive, and I asked them again, "What are you reading?"

I thought they were reading the wrong measurement, and you'll hear Nance in there tell me, "Bob, we had a little confusion over terminology take place." Finally they realized our concern. We told them to vent again. You'll hear us tell them, "Vent." My thought when I asked them to vent again, I thought, "Well, maybe this valve is just not opening right." I thought if we tell them to hold the power on it, you clicked it and it latched, and it would be open until you turn it closed. I thought, well, let's just hold electrical power on it and that will force it open. My thought at first was the valve wasn't working properly and the pressure was really building up in here.

But then the crew said, "We see the pressure so-and-so." They also said and so-and-so and so-and-so, and they were seeing it decline. Now, the instant they said that, I knew that we did not have a problem in the tank. Now, how did I know that? There's some logic associated here. This is flight controller logic I'm fixing to share with you.

Here is a tank. When you open the valve, the pressure is supposed to start declining. If the valve opens, and the gas leaks, the pressure is going to decline. It's just that simple. It's got to. So now I had my pressure was going up. Their pressure was declining, and they had opened the valve. This is a matter of how many failures does it take. If the valve opened or failed to open, that's one failure, isn't it? If it failed to open. If their pressure meter said it's declining when it's not, that's a second failure, isn't it? See my logic? For it not to be doing what it's supposed to is one failure, but for it not to be doing what it's supposed to and their meter reading what it is like everything's normal, that is a second failure.

But if my measurement is wrong, that's one failure. If my measurement says it's climbing or going the wrong way, and it disagrees with the other two things, I've got one failure. So the instant he told me, "I see it declining," then in my own mind I was satisfied. The pressure in the tank is all right.

Now, I didn't know at that point what was wrong with my measurement, and there's still concern. But I had a supreme confidence that the tank's okay. Now, there's a period of time there before Grumman—Grumman didn't realize that, and I didn't think. That was my own fault. I should have called them and told them, "Hey, guys, here's why we say it's okay." They still were climbing the walls. They were seeing this pressure going up.

So after we thought about it and looked at it and there was some verbiage took place, telling the astronauts to hold it and so forth, then after ten eternities, Nance figured it out in the back room. He had seen the same thing in the one of the ground tests years earlier when they were testing this system at White Sands or somewhere.

What happened was, this fuel heat exchanger, with this liquid nitrogen going through it, froze the fuel. So I'll illustrate this on this drawing by doing this. Plugged it. That's just like a valve turned off. Now then, once you froze that slug of fuel in the heat exchanger, you've trapped a little piece of fuel between the engine and the heat exchanger. Now the engine is hot. So the heat of the engine going into that fuel caused it to expand. It's a liquid, but normally you think liquids don't expand. But there is a very slight coefficient of expansion due to temperature. As that liquid expanded, it increased the pressure, just like it were a gas. That's what I was seeing here. I was just seeing the pressure increase due to the heat coming back into that little slug of fuel. It appeared like it's just a steady. Well, I'm so accustomed to looking at this and thinking that I'm reading this, till I didn't make the connection at first, and none of us did for a long time. We didn't realize, and Bob Nance did. As he saw the result of that and tested it, it didn't register what that might could imply. Well, when it come to him that what it was, well, then instantly we knew what the problem was. So then we were with a situation, is this dangerous?

A liquid, unlike a gas, if you've got a liquid under pressure, it's fundamentally constant volume. You can just leak one drop out of it and the pressure drops to zero. Well, I knew that was what was going to happen. I thought probably what would happen is either we would overpower the O-rings in this valve or we would collapse the little bellows in this telemetry measurement point. But either way, there wasn't going to be a big mass exodus of fuel out of this little short piece of line.

If you listen in there, we won't need to go through it this morning, but if you listen, you'll hear I was concerned about what's in the vicinity of this line and how long is that piece of line and how much volume of fluid is in there. But I knew as soon as we dripped one drop, pressure is going to go to zero. Sure enough, it did. It went up and hit the limit of telemetry measuring ability. The transducer's got limits. Your pressure is normally in here. If you carry the pressure far beyond what was ever anticipated, it will hit the upper limit of where the transducer measures, and it did this time. It went up, and when it pegged out, it just stayed there.

After a while, if you listen to the tapes, you'll hear me explain to the flight director, it's probably going to drop back down in a little bit. We'll leak a drop and then it will come down. Sure enough, in a little bit, and down—whop—it come, which exonerated our conclusion. That's what really happened.

Now let's go back if you want to play that tape and we'll see if you can hear that scenario unfold. It will be simpler knowing what was happening. It wasn't so simple that morning on the console.

RUSNAK: I've got a couple of segments marked out. The first one, I think, is the first recognition that there is a pressure problem, the first call from the back room that is going up. Of course, this is the Apollo 11, the LM Control tapes that we're listening to here, for the record. So we'll listen to—I think there's about thirty seconds or so here of relevant stuff from the first point where they identify there's a problem.

[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.]

[start taped intercom loop segment 1]

[unidentified voice]: Check, Flight.

NANCE: Control, Prop.

CARLTON: Go Prop.

NANCE: Let's go on and tell him to vent the fuel some more. It's getting pretty high now.

CAPCOM CHARLES M. DUKE: Tranquility, Houston. We'll research this problem and be back with you momentarily on the mission event time - correction - the mission timer.

NANCE: It doesn't have to be done immediately, but I'd do it pretty soon. It's getting up to 152 now.

CARLTON: Okay, but 247 is the time it approaches problems for T-2, isn't it?

[end taped intercom loop segment 1]

CARLTON: That was Bob Nance. He's at Control Prop. He was watching it going up and, being conservative, he wanted to vent it some more to get the pressure back down, is what was happening there. So this is where the problem started. He recognized the pressure getting a little bit on the high side and, uneasy over it, he sat in on all those meeting with Grumman, so he was sensitized properly. So I'll go ahead and you'll see it pick up.

RUSNAK: How much concern did you have at this point that there might be—

CARLTON: None. I didn't have any at that point. To be honest with you, and this is a deficiency on my part, I'm sure, but I really thought Grumman had it blown out of proportion. I really didn't take Grumman serious when they came in. I thought this was one of these cases of "We're covering ourselves here." This is some far-out, maybe, and it had not crossed the threshold of my pain barrier here yet. I felt pretty comfortable about it at that time. I thought when we vented it, and we vented it the first time, and it dropped the pressure. I thought, all we got to do is just vent it and it will be all right, which we should have if the heat exchanger hadn't been what it did anyway. It vented.

Okay, go ahead now.

RUSNAK: The next segment I've got marked is just a few minutes later. There's actually several things that go on. I think he makes remarks that the pressure is still going up and they make this call to the ground where to vent it again and to hold the switch open and such. A little bit longer piece here.

CARLTON: Yes. At that point we told them to vent it again. It should have dropped down. So the second time you hear, what you're fixing to hear here is us reacting to what appears to be a failure of it to vent. That was the line of thought I was on at that time. Well, for some reason, it didn't vent. Let's see what happened. Okay.

[start taped intercom loop segment 2]

FLIGHT DIRECTOR EUGENE F. KRANZ: T-3 countdown.

CARLTON: Flight, Control.

KRANZ: Go, Control.

CARLTON: Ask him, go ahead and hit fuel now.

NANCE: It's really lousy.

CARLTON: It's going up. It's getting too high.

[unidentified voice]: Looks like a good AGS [Abort Guidance System] alignment.

KRANZ: Rog. Capcom

DUKE: Tranquility, Houston. Please vent the fuel. It's increasing rapidly. Over.

[unidentified voice]: That was a good AGS alignment and [unclear].

[unidentified voice]: Roger.

NANCE: Fuel's still going up.

[unidentified voice]: Control, SPAN [Spacecraft Analysis Room].

CARLTON: Go SPAN.

NEIL A. ARMSTRONG: We show 30 psi in the fuel and 30 in the oxidizer.

SPAN ROOM: Uh, [Building] 45 [Mission Evaluation Room, or MER] would like a readout.

DUKE: Roger. We're reading somewhat different than that. Standby.

[end taped intercom loop segment 2]

CARLTON: You've got the SPAN telling me 45 was—Grumman people were over in 45 and at the Grumman plant, and that was SPAN alerting me that they're concerned. All right. That was Nance. We're working the problem a little stronger now. I didn't catch it. That wasn't where I told him to hold the switch.

RUSNAK: Yes, that comes up in just a minute, I think. I think you also heard the crew started reading some of the pressures.

CARLTON: Yes, I missed that. I was listening to Nance. Can you back it up, and let's see if we can hear the crew again.

[start taped intercom loop segment 3]

CARLTON: Go SPAN.

NEIL A. ARMSTRONG: We show 30 psi in the fuel and 30 in the oxidizer.

SPAN ROOM: Uh, [Building] 45 [Mission Evaluation Room, or MER] would like a readout.

(CARLTON: Hear it? Now that's [Edwin E.] Buzz Aldrin.)

DUKE: Roger. We're reading somewhat different than that. Standby.

[end taped intercom loop segment 3]

CARLTON: That was Buzz Aldrin saying, "Now here's what I'm reading." And his pressures were good. But the instant after that, Nance said, "They're still going up." So that left it in a quandary there for a few minutes. You know what happened, so it sounds simple to you. It wasn't simple to us. We had conflicting information.

Okay, go ahead now, and you'll see the scenario unfold a little further.

[start taped intercom loop segment 4]

NANCE: What did he read?

CARLTON: Thirty on the ox.

NANCE: That's fine. It's the fuel that we're worried about.

CARLTON: He's reading the regulator, is what he's reading.

ARMSTRONG: The fuel temperature is reading—.

NANCE: He doesn't have a regulator.

CARLTON: Standby.

ARMSTRONG: 64—

(CARLTON: He's reading it again.)

ARMSTRONG: —in the descent, and the oxidizer.

KRANZ: Control, Flight.

CARLTON: Go ahead, Flight.

KRANZ: He said he's reading 30 on the fuel and 30 on the ox on board.

ARMSTRONG: That's descent 2. And the oxidizer is off-scale low.

CARLTON: I think he's got the wrong measurement. Stand by.

ARMSTRONG: Descent one is showing—

CARLTON: He's showing ullage pressure, is what he's showing.

ARMSTRONG: —61 in the fuel and 65 in the oxidizer.

NANCE: [unclear] is 63.

DUKE: Roger. Stand by.

NANCE: What do we want him to do?

KRANZ: Bob?

CARLTON: I want him to try to vent the fuel, to try again to vent the fuel, hold the switch open with his—hold it open.

KRANZ: Rog.

DUKE: Tranquility, Houston. Please take the fuel vent switch and hold it open. Over.

[end taped intercom loop segment 4]

CARLTON: Now, I had the information at that instant to have been able to make a decision, but I hadn't thought it out yet. I was still concentrating on the idea that I wanted him to close that fuel. I was still focused on, is he venting, and I still wasn't convinced. I still thought he might be reading the regulator manifold pressure instead of the tank pressure. Nance, I think, corrected me on that. All right now. Were you fixing to ask me something?

RUSNAK: The next segment I had marked was where they make the call, the realization of what the problem is.

CARLTON: At that time, you could hear Buzz Aldrin. He realized we were concerned, and he began to read the pressures off. That was the clue that solved the problem. After the smoke settled for an instant and I had an instant to think about it, I realized then, and what I explained a minute ago about the pressure, the pressure he's reading is following the path it should be following. Therefore, I know that tank, his pressure measurement is right and mine's wrong. At that instant, I didn't know what was wrong with mine. So that's probably where the next segment is going to carry us.

RUSNAK: This is just a couple minutes later on the tape.

[start taped intercom loop segment 5]

NANCE: Yes, it should be the same.

CARLTON: Okay.

NANCE: Oh, ok!

CARLTON: [unclear] an ullage pressure.

NANCE: Here you go. Here's the answer.

KRANZ: Could the vent have frozen over there?

NANCE: Here it is. That's it. That's exactly what it is. We've frozen the fuel-helium heat exchanger.

CARLTON: We've frozen the fuel to helium heat exchanger.

NANCE: That's exactly what it is.

CARLTON: Okay. Then we have the pressure downstream building up, huh?

NANCE: That's correct.

CARLTON: Okay. Now what are we going to do? That's gonna—

NANCE: That's not what I'm saying. That's on the line.

CARLTON: I know that. So the worst thing that'll happen is we'll rupture the line downstream somewhere, won't it?

NANCE: Yes, but the line will take a lot more than the tank will.

CARLTON: Okay. SPAN, Control. SPAN, Control.

SPAN: Go, Control.

ARMSTRONG: Indicating 15 psi in both tanks.

CARLTON: Okay. I think we have an answer to this. I think we've frozen the fuel-to-helium heat exchange and hence we're seeing the fuel trapped downstream of the heat exchanger is trapped and building up pressure. So we're okay up in the tanks. The worst thing that could happen here, and we best start looking at it, we will, is that we may rupture the line downstream at the heat exchanger.

KRANZ: Okay.

CARLTON: Be back with you momentarily.

KRANZ: Do you want him to release the switch, Bob?

CARLTON: Roger. He can release the switch.

[end taped intercom loop segment 5]

CARLTON: [Laughter] I forgot all about that. Yes, they'd been sitting there holding the switch all the time. I'd forgot all about that.

RUSNAK: I even read Neil Armstrong's commentary on the air to ground that he was indeed sitting there with his thumb on the switch for something like four or five minutes between when you actually told him to and when he released it.

CARLTON: Yes. Well, I wanted him to hold it, but I forgot he was holding it when we realized what it was. Nance spotted it. Now there's one other thing that comes through there. It might have went over your head. I've always talked about we tried to have skilled, two people looking at a problem, both of them knowledgeable. When Nance explained what it was, if you notice, it didn't take much explanation till I realized what he's talking about. All of our flight control teams try to work that way. You want the guy in the front room to be very, very, very knowledgeable about the systems. In fact, we used to ask that they be able to handle it if the SSR [Staff Support Room] were not there. Now, they could never learn it as well as the SSR guy, but that was what I tried to make them do.

You had levels of expertise that varied. There are some places it's your strong suits and your weak suits, but we tried to force our MOCR [Mission Operations Control Room] guys to really understand their system. It just happened that propulsion is one of my strong suits, so I picked up a little quicker. If he'd asked me a problem, if we'd had a big problem in the PGNS [Primary Guidance and Navigation System, pronounced "pings"] software, you'd have found me floundered. [Laughter] That's a confession I hate to make, but that was my weakest thing, was software. It was a new thing to systems people in those days and hard to get reaccustomed to how you handled it. In fact, I'm not sure we really handle it very well today. Software is too fluid, flexible, and changes so fast you can never really know for sure what those software guys have done to you.

All right. There you see it unfold, and after that we had a little more flurry of activity. They went back and looked at all the drawings. They had mechanical drawings in the vicinity, and they looked all in here to be sure there wasn't anything that could be damaged if that line ruptured. But my concern was over with. I knew we were home free then. Even if the line ruptured, I didn't have any fear of such a small volume of fuel in that line, that I didn't have any fear of contamination being a problem. It was enclosed down in the bowels of the bird.

There's one other thing I believe is important to appreciate in looking at that problem. I spoke to you before about the importance of teamwork and how so many people worked together. In there, even though I didn't really properly acknowledge them to start with, you had Grumman, you had the SSR, you had the MOCR flight controller, you had the Capcom, and you had the flight crew. All of them, and even Kranz, I heard him mention something about the heat exchanger, everybody was working the problem, but they were doing in unison together. Grumman was coming in, and Grumman, I don't know if you caught it, but I think that Grumman came in right there about that same instant. They figured out what it was about the same time we did.

So there's the Grumman team of contractors. Some of them were over in Building 45 with Don [Donald D.] Arabian. We called that the SPAN team over there. Then they had lines. Grumman, actually had Grumman Bethpage [Long Island, New York], had a team of people and they had data presented in front of them. So they, too, were following what was going on and were giving us feedbacks through our SPAN representative in the SSR. So that was an important part of the team, and they all worked together. And they worked pretty dog-gone smooth, too.

The teamwork, I think, was probably the very key to why Apollo was able to be pulled off so successfully. There were a lot of problems took place. If you go back and listen to all of the missions, I'll bet there won't be a single mission that you didn't have problems crop up. In every mission when you had a problem, you'll hear that same kind of teamwork going on. This guy spots it, but someone else, whoever's got a responsibility for some other aspect of it, they're all working harmoniously together as a team.

I've often reflected back on it and wondered why did those teams work so well. I believe one of the keys to why they worked so well is there was a clear line of authority and responsibility, was one of the keys to it. Everyone knew the flight director was in charge. The flow of responsibility went down, and the next guy on his shoulders, it's right there on his shoulders. On this particular problem, it was on the shoulders of the LM team.

But when it come to an action, had it gotten stronger or worse where we had to do an action that took us, say, an abort or something else, the flight director was in that line of chain of command. So when you have an action that requires him, it just automatically is there. If it requires a control guy, he's automatically there. Everybody knew who was the boss and who to listen to and who was responsible for what, and everybody played their part and worked in harmony with the team, the SPAN, the NASA team, and all together. That's what made it work.

Now, one last thought on that little episode. There is no way on this Earth we could have preprogrammed the software to anticipate and correct for that failure. That failure is typical of a lot of the failures you run into. It doesn't matter how smart you are, you just can't think of everything. When the unexpected comes to the forefront, most likely your software will not know how to cope with it. That was an illustration of man in the loop being able to solve unforeseen problems. Software can be programmed to solve foreseen problems. Very difficult to get software to react to unforeseen problems. I think that's an important lesson that you'll see, and that was just one illustration of it. You'll see it almost over and over and over.

I can think of another place where it comes to the forefront is if you go back and look at—I believe it was the next Apollo, or maybe 14, but, anyway, one of the subsequent flights we had a switch fail inside the LM. When that switch failed, it sent an abort signal into the computer. At the time, we had not started the burn to land on the Moon. While we were in a preflight checkout or in orbit around the Moon getting ready to do the descent, that abort light came on. It was a little microscopic hair in the switch that was waving around in there, and in zero-G it reached over and come in contact with the other side of the switch, and it's just like you made the switch. Had that happened during a landing, the thing would have just did an abort on us. It's just that simple.

But it happened before we started burning, and so what happened was, the guys saw it, and they figured out what it was. The switches, beforehand we had a lot of discussion about switches. One of the ground rules we were given by the program office was, "Boys, don't y'all worry about switches. We will make these switches so safe, they will never fail. You'll never have a switch fail. We'll test them. We'll special design them. We will X-ray them. You will never get a bad switch. So don't even do a malfunction analysis on a bad switch."

Well, when that switch failed, all we saw was the abort signal in the software. We didn't know if it was internal to the software or it was the switch when it first started. We told the crew, we said, "Cycle the switch." Well, when they cycled the switch, that bit, we had it on telemetry, and you could see the abort light lit.

You know how the switch works? Inside a mechanical switch, it's spring-loaded. When you pull the toggle, it's on one side, and when you pull the toggle, it overcomes the spring and it snaps to the other side and makes contact the other direction, a snap action. You have to move the toggle a good ways to overcome that and to shift the spring pressure. That's the way the switch works.

Well, when we saw the telemetry coming down, we told them to cycle the switch. We saw the position in the abort position. He cycled it and the telemetry said "Abort off, abort off," and then it settled on "off" again. There was one little microscopic instant of time when it should have went from one position to the other and stayed there, but it didn't. It went from one position with a little spike in there.

Now what, in reality, was happening is he moved it, this little whisker sort of got jiggled, and before that snap took place, that jiggle was sensed. Now, the reason we saw that was we had a high data rate. If we had not had a high sample rate, we would not have seen that. But that was a discrete, and we used to have great battles over what sample rates of telemetry do you need, and just went through a lot of agonizing. Which parameters need a high sample rate, which need low sample rates? That one we just lucked out. It was on a high sample rate and it was on an event light. Now, the TV tube, it just updated once a second, so you wouldn't have seen it.

But on an event light, on off, on microsecond and off, what would cause that spike? Software don't spike like that. Something happened in the switch. What could? Don't know. Got no idea. Later, after the mission, Grumman got to looking back over the X-rays and they discovered it. They might have even brought the switch back, I've forgotten. I don't remember if we took it out of the LM or not. But at any rate, they discerned and discovered later it was a little whisker, a little metallic whisker.

When we discovered it, when we saw that spike, we concluded it's something to do with the switch. So we told the crew, said, "Peck on the panel."

The flight director, Gerry [Gerald D.] Griffin was the flight director, he said "Peck on the panel?"

The flight crew said, "Peck on the panel?"

Everybody around there, "Why do you want to peck on the panel?"

Jim Hannigan was an old flight test engineer. If you've ever flown an aircraft flight test and you had failed switches, what do you do? You bang the dad-gum panel. If it's a relay or a switch, or you suspect a mechanical not make, hit the dad-gum panel. [Richard A.] Thorson was on the console and I was on the SPAN, and Thorson didn't have flight test experience. He was at control back there, but that was strange to him. SPAN said, "Peck on the panel."

Thorson said, "Peck on the panel?"

"Yes."

Thorson was hesitating, he didn't quite—Hannigan came on the line. I don't know where he was, but he came on the loop and said, "Yes, peck on the panel!" So he knew instantly what we were after. Sure enough, they pecked on the panel, and you make the thing come off. It would go back to abort. You peck on the panel, and it would go off again. In a little while, that whisker would shift back over.

But once we knew that, and knew it was the switch, then you could start working the problem and figure out how to work around it. The work around brought in again the contractor team. The software guys worked up a patch, and they read that patch into the onboard software to make it ignore this abort signal if it should happen. Then they worked up a little software routine, if you had to abort, how do you do it? So they worked up a little routine so you could punch some DSKY [display and keyboard, pronounced “disky”] buttons and do an abort if you needed it. So you didn't lose the ability to abort. It made it a little more complicated, but it saved the mission.

If we had had that mission automated and programmed in software, it would have never happened, never happened. So you see how man in the loop can solve problems given a little bit of time to do it.

On the other hand, that man in the loop, as we discussed the other day, sometimes man in the loop causes problems. So the balance of knowing how to use him is something I think is a lesson that was forthcoming. Out of the whole space program. You see that.

Another instance, I'll give you one more instance of man in the loop. Every mission had something. We had one mission where we developed a leak in the pressurization system to the RCS [reaction control system] tanks. Have I already described that to y'all? Okay. The RCS tank was a little similar to this. You had a pressurization tank, and if you imagine this is a fuel tank here, only it's not liquid nitrogen, it's gaseous, just a bottle of gas under high pressure, and it comes through. Imagine this is a valve. So the pressure comes through the valve and then through a pressure regulator that is not on this schematic, and then goes in the top of the fuel tanks and pressurizes them and forces RCS gas out, or the fuel out.

The line between the tank of gas and the on/off valve developed a leak somewhere. We didn't know where it was. Might have been in the transducer in the tank or somewhere there was a leak. The pressure in the tank began to dribble out, a very slow leak. As they projected that pressure ahead, they saw that at the rate it was going, all the gas would be gone and we would not be able to have pressured RCS tank and force the fuel out of it, so we would lose that RCS system because you couldn't force the fuel out.

We'd only have one RCS system left. We had redundancy, so you could come home safely, but it would put you in a posture of where a failure in that other good system and you couldn't get home. We never allowed ourselves to be in a posture where a single subsequent failure would endanger the crew. So we were faced with an abort-the-mission situation.

John [A.] Wegener was on the console that time. What they did was they went in. Now, there were check valves between this valve and up here, and… this [check] valve isolated the RCS tank from this helium tank that was leaking. So what they did was they burned, deliberately burned the RCS fuel out until they had about half the fuel left in the tank. Now, at that time, the top of the tank was full of gas. The bottom of the tank still had enough fuel in it to do a safe return and rendezvous and dock.

So then this [check] valve isolated all of this from the leaking oxygen tank. Now then we can blow that fuel out of there by just by under the expansion of this gas that's in the top of it. So we wasted half the RCS fuel, but that allowed us to have access to the remaining half, using what we call blanket pressure. Now, the ability to do that required us to know, which we did, beforehand we uncovered the data and got the information that said that as this pressure expands and blows the fuel out, it will drop. But it didn't drop below a point that the thruster would be dangerous to operate. It would reduce its thrust, but you can still operate it safely far, far outside the boundaries of normal operations.

The contractor goes crazy when you say, "I want to operate this thruster with inlet pressure instead of 250 psi where it's supposed to be, I want to operate it down at 15 or 20 psi." Well, it won't work that low. But somewhere it will work to a level that's still safe.

So there was another instance where there's no way on Earth you could have foreseen, software-wise, to have foreseen and accounted for such a thing. It required a "Here's the problem. How in the world are we going to work around it? Well, why don't we do this." Knowing how the system worked in an off-nominal mode and knowing the outer limits and outer boundaries of this operational abilities, we were able to come up with a scheme that allowed the mission to be continued.

Now, every mission, you had stuff like that happen. Early, at the very front end, I said, what is the job of a flight controller. I think these three illustrations perhaps do more to sort of bring out what the real role is. The flight controller, he was working in the boundary where failures had occurred, and he's outside the boundary of normal systems operation. He's working out here in the outer limits in a new ball game in the space business. You can't fix it, so what do you do? You try to salvage as much of the mission as you can and try to keep the crew safe with systems that are malfunctioning to the limits.

Flight controller is a guy that not only can troubleshoot. This is a systems flight controller, which principal supplies to the guys, and trains the FIDOs [Flight Dynamics Officers] and the GUIDOs [Guidance Officers] and the software people. He's the guy that can not only isolate malfunctions and diagnose problems, but he's also a guy that understands that system so well and to such a level that he can go back and come up with a way of operating it completely out of the normal spectrum of boundaries of operation. He knows how to work it and make it work when it's limping along with Band-aids all over it. He can take the mule with three broken legs and somehow splint him up and keep him plowing.

I think I've covered sort of the things that would give you an insight as to what happened inside the control center and how the team worked together, and maybe a little insight into what this flight controller guy's role was and how the flight control team worked together. I think I've touched on the things that I believe would give an insight into what took place in the space program. Were there any other areas that you want to?

RUSNAK: One thing I was thinking about as you've been discussing the value of man in the loop: how useful did you find simulation [sims] in improving the value of man in the loop?

CARLTON: Exceedingly important. I think it would be impossible to give those guys enough credit as to what they did there. Their simulators were so realistic until you just couldn't hardly—you'd get caught up in it and you'd forget you were in a simulation. Or thinking back in your memory, it was so realistic till I can't separate the sims from the real a lot of times. A lot of the things I remember really were sim problems instead of flight problems, they were that realistic.

In that environment, all of these things that the guys did in a mission, that ability only came after exercising in sim and in training. You got to where you could react to something new and unexpected, and after you did it over and over and over, it takes kind of a programming of the mind to be able to do that. But you got to where you could do it, and that getting to where you could do it rests on the foundation of the simulation system. I don't think you'd ever have achieved that ability outside of just a tremendous amount of missions.

The guys who had been in flight tests maybe had some semblance of it from experience of the many hours of flight test, but most of our flight controllers were not raised up in a flight-test environment. The pilots, pilots run into airplanes, especially military airplanes where you've got a new airplane every five years. You get a new airplane and it's going through growing pains and unexpected things are happening. Probably military pilots get that sort of training. But the bulk of our flight controllers were people who didn't have any flight-test experience, so the simulation gave that to them. I think it was invaluable.

I shared with you earlier, I think, about the RCS failure and how the sims people had given us RCS failures, and we come up with a way to identify RCS failures. That was a direct offshoot of the simulations. They also, sometimes, a lot of times, they made us realize things would work differently than we anticipated worked. They had very realistic simulators.

My hat's off to the sim. They never get credit for it. Probably if you look back at all the things we did, I'll bet we'd be amazed at how much [that] we accomplished that went back to directly to the simulation training. But they didn't get any—except amongst the flight controllers. We knew what they did for us, but I don't recall anytime anywhere in any of the public rewards that we've passed out, I don't remember them ever getting any recognition for what all they did. Kranz gave them some recognition as he wrote his book. It tickled me to see him do that. It was well deserved and long overdue.

RUSNAK: Just a few days ago we had Carl [B.] Shelley, who was one of the simulation guys, in here.

CARLTON: He was kind of "Mr. Simulation" for a long time.

RUSNAK: So we're certainly happy to get that story, because as you said, there's not much coverage of these sim guys.

CARLTON: That might be something that somehow you can bring to the forefront as you try to record what took place. We tend to only show the tip of the iceberg. Probably this happens anywhere you go in any big event that takes place. You see the astronauts in almost any documentation, program, documentary, or what happened, it will focus there. Or it might go down in the control center and stop there. But the story is a lot bigger than there. It starts out with the program office. In fact, it really starts out earlier than that.

Before the program ever got started, there was a group of guys that do advanced systems studies or advanced studies. They studied the thing and come up to, "Hey, this is a feasible thing to do." They might look at a dozen different things that are feasible to do, but they're the ones that start the ball rolling say, "Well, we should have a Shuttle system," "We should have an Apollo system," or an Apollo Program. "We propose landing on the Moon. Is it feasible or not?" And they do a lot of assessments and advanced studies, we used to call them, and they would finally reach the conclusion yes. So then they'd go sell that to the program office and to political leaders.

Then the ball got to rolling, and it gets handed over to the designs people in the program office. You set up a program office, and then they go through all of the nitty-gritty to translate that initial feasibility concept into a bunch of hardware. They work for years. As the program office itself picks up and sends out proposals to get this system going, they've got to learn pretty well themselves what they want this program to be.

Then when the engineers and the contractor comes on board and he starts working on it, he's carried a big piece of the effort. Probably the biggest piece. He works for years and years and years before the flight control team comes in and works a couple of months, and then his hard work is all gone. Where's the next program?

Then there is another ingredient to it that I haven't discussed at all because I'm ignorant of it, but I bet that [its] also a very important aspect of the program that most of us never even hear about or think about in the aftermath of all of the publicity: there's a lot of science that took place. I don't know how much. I remember us putting instruments on the Moon's surface. Every time they landed, they did something, and did stuff en route to the Moon and coming back. To me, you know, I wasn't interested in that. I just wanted to get the hardware there and back.

But there's just as big a bunch of flight control people and contractors—well, not just as big, but a tremendous effort took place. We left a lot of instrumentation there. Even today, the lunar scientists, I guess, are still going strong. I think they turned their instruments off on them a few years ago, but they continued that for years and years and years. What all we learned from it, I have no idea. Maybe there's a moral to be learned there. American public. When we see them climb Mt. Everest, that goes in the history books. See them land on the Moon, that goes in the history books. First man to the poles went in the history books. Been a team of people down there ever since, and who cares? We're not interested in that aspect of it. We Americans, and probably the whole public everywhere, we get excited to see a first and to see an exploration and to see man do something brand new. Only the scientists get excited to see the science taking place. Now, why that is, maybe you know, but I don't. It's just our nature, isn't it?

RUSNAK: I suppose so. Some of the scientists have been a part of this project as well, so we've gotten their story a little bit.

CARLTON: That's good. That's good. They deserve some credit, and I always badmouthed them. They were in my way. Every one of them, his was the most important experiment. If you give him less time than you give his other experimenter over there, well, you were a bad guy, and you couldn't win with those guys. Every one of them thought his was most important. That's the way it should be.

I think I toured you through. Now, where do you want to go from here then?

RUSNAK: Before we left Apollo, I wanted to see if you had any remarks about Apollo 13, any involvement with that.

CARLTON: The best way I know to describe Apollo 13 is it was a nightmare of nightmares. If you watched the *Apollo 13* movie, I believe it was a fairly accurate depiction of the overall environment of what took place in Apollo 13. They glamorized some of the people and some of the things, and maybe even some of the problems they reported, most of the problems were real problems, but overall they captured the intenseness of the concern and the danger and how uncertain it was right to the end.

My overall way I would describe Apollo 13 is from the instant that thing blew up, the fuel cell blew up in the CSM [Command and Service Module], it was nothing but one long series of new problems. Just about the time you thought you'd solved one, another one cropped up. When it first happened, we were in a non-return mode to come back to the Earth. So the first thing they had to do was to get this combination back on a return path toward Earth. They did that while they were still en route to the Moon. [Glynn S.] Lunney was on that shift, and that was the first thing he did.

The way they did it was they burned the LM engine. Now, there was something that we just absolutely—it's spooky to even thinking about it. Neither the LM nor the CSM was designed to be done in that way. The LM weighed 32,000 pounds. How many cars is that? That's the weight of eight cars. Imagine eight cars glued together, how much weight that is. Now, if you went over there and looked at that little docking port where the LEM and CSM docked together, that thing wasn't designed to be thrusting at 32,000. That engine gave lots of thrust, and the CSM, I don't know how much it weighed, but it was heavy. Here's two big dumbbells hooked together with a spring, and you're burning this engine. It's just a miracle it didn't tear that interface in two. But that's what they had to do. When you get to there's nothing else to do with us, that's what you're going to do.

I remember, to illustrate that point, we were talking in mission rules review one day, and I think this was with Armstrong and Aldrin and that team. We were talking about the LM, if you had a big enough slant on it when it landed, as you took off on ascent to go back, you're on a slant. The instant you severed and got a little off the ground, the ascent engine hadn't built up enough thrust and velocity to get going, so it would just fall off. Its thrust vector wasn't straight up. You lose it, and it would hit the lunar surface. I forget now, but it wasn't much of angle, though.

We had great debates. What if the LM, when it landed, ended up in an angle that's too much? So we were discussing in the mission rules what to do. We said, what if we landed on the lunar surface and it's on rock and you can't dig it and it's too big an angle? I think it's Armstrong is the one that made this comment, he said, "I just get out there and what I do is I'd start scratching that rock with my pencil and whatever instruments I could find, plastic, or my fingernails."

Somebody said, "Neil, that's crazy. You don't have anything there that will cut rock."

He looked around and said, his eyes twinkled, "Well, I wouldn't have anything better to do." [Laughter] Might as well try it.

Well, that's kind of the way Apollo 13 was. We burned the engine, didn't have anything better to do, couldn't think of any other way to do it. Then on the way home, burn it again, but I'll get to there.

So now we're on a big looping return, and the next thing that happened was we powered the CSM down and then moved into the LM. Then we think, well, maybe we're going to make it, and we begin to look at battery power. No possible way to make it. You're going to run out of battery power. You got to get to here, and you're going to run out right here. No way on Earth to make it.

So the team got together to figure out what all you could turn off. So they turned off everything you could turn off, except the LM platform. Now, the contractor had told us the LM platform's got gyros in it, and they're in a little jelly kind of compound fluid, and you got to maintain that at a temperature. If you let that get real cold, it will damage the gyros. You can't guarantee it's going to work. It probably won't work, so you got to keep the heaters on. If you keep the heaters on, here's where you got to get. Here's how much power. Here's how long we'll live. If we turn everything off, we can live to here. Those heaters have got to stay on. Well, we can't get to there. Well, we got nothing better to do. We turn them off. No choice. You're not going to make it otherwise, so we turned them off. We turned them back on down there, and they worked, by the way.

But, anyway, for a while there wasn't any way to get there. So after we turned everything off you could turn off and you looked at the path of how much power you got left, you come out down here at the end of the mission, the line goes to zero. Little bitty margin, little smidgen margin there. Now, the guys running those power curves, they gave them to Kranz, Kranz looked at them, and said, "Oh, look here. We got so many watts surplus power." [Laughter] He felt so comfortable. I don't know if anybody ever told you. The area of uncertainty, there's your little surplus power, the area of uncertainty is like this. We could have not made it.

If we'd lost a battery, we'd for dead sure not have made it. We had seven or eight [unclear] batteries, as I remember. Every one of them had to be full. Now, every battery has got so much power, plus or minus so much. We had to have the power and we had a little margin down there. But we kept looking down and I kept looking down watching the guys put those curves together and seeing that little margin, and hearing Kranz say, "Oh, we got this margin." [Laughter]

I never did go [unclear] "Hey, Gene, look, you don't have any margin. You may not make it." But you look for umpteen days and this line looked almost flat and come out to zero just about the time you got there.

So anyway, those power curves at the front end of the program after that first burn, those power curves trying to get that back end stretched out to where you can make it, it took a lot of iteration.

John [W.] Aaron headed up the Tiger Team, and they went around and around and around. You ought to talk to him sometime. I hope you have talked to him.

RUSNAK: We did.

CARLTON: He'd probably tell you what all he went through. They tried an iteration. It wouldn't work. Tried something else, it wouldn't work. You take this off and it wouldn't work. Everybody, "I can't turn this off." The contractor, "You can't turn this off." But they finally got the power.

So now it looked like—no, wait a minute. I missed one thing. They got everything turned off you could get off, and you still can't make it. So that made us come back and got to do another burn. Who wants to do another burn? We got nothing better to do. You don't have a choice. So they did another burn and accelerated the speed toward the Earth. Now, then, you're going to get there quicker. Now you brought your return point back inside to where the power is at zero. That's where that power point was they figured out.

There's a problem, you can't possibly make it, you figured out a way to do it, and then another problem, power problem. You can't possibly make it, you figured out a way to do it. Then another problem, can't make it.

I'm probably not going over these in the sequence they happened, but you can see the picture. We have an insurmountable "can't make it" problem. Everybody, it would be a feeling of despair, but attack it and try to figure out some way to make it work. You'd finally come up with a way to make it work. "Whew, man, I believe we're going to make it." Another problem. That was the whole mission. All the way down to the very end, it was that same way.

The one thing that came up was they had canisters that remove the $CO_2$ [carbon dioxide] as the crew would breathe. The LM had, I forget whether LM had round ones and the CSM square ones or what. The CSM had a lot of canisters to go for the whole mission. The LM was only a short mission on the surface of the lunar surface, so it didn't have enough canisters to carry this many, many days it took to get back. So, okay, we'll use the CSM. Well, they don't fit. The guys came up with some kind of jury-rig where you got them in there with tape and cardboard, and I've forgotten now just what all they did to make them work. But at the front end, when it was suddenly realized the level of pollutants is going up, that's when suddenly somebody woke up to the fact, hey, you can't change any more. We're out of canisters.

So that was just typical. I don't remember all of the other things that happened. It was a nightmare. My overall impression was, I've never seen a nightmare like that one.

Now, earlier I said software would never—that's another. If you go back and look at that, you'll see that team working together in the control center, outside the control center, the simulators were humming the whole time, going through the procedures. They had a new set of procedures to get that little beauty home. The contractors had crews working around the night. You asked them a question and they had people working twenty-four hours a day to get the answer for you. I mean, the whole world pulled together.

The other thing, all over the world people were praying for us. We had telegrams coming in, "We're praying for you." Prayer vigils going on everywhere. If I look back, I just can't help but think that all of the things we went through in that whole program and all the problems we ran into, God's hand had to have been on us. I just can't see how on Earth you could ever see we could have gone through so many problems we encountered and come out smelling so good. It's just far beyond the law of probabilities, even with men in the loop and even with how we trained and working together as a team. It's just still more than that involved in that.

I can't think of anything else about 13. I do think that that movie captured it mighty well. If you take out the little personal stuff they put in it, it captured the whole thing mighty well.

What else now? Where else does your interest lie?

RUSNAK: Did you have any other comments on any Apollo flights or maybe what you were moving into as the Apollo missions were going on?

CARLTON: From my side, from my perspective, as I had mentioned earlier, we had been told we would have a lot of Apollo missions, and so we had hired people. I had several MOCR flight controllers that I was training to handle this a forehand announced horrendous flight rate, Hal Loden and John Wegener, and we were bringing on board Dick Thorson and Larry [W.] Strimple, besides myself. So I had myself and four other MOCR flight controllers, and all of a sudden we're only going to have about seven more missions.

As it turned out, Apollo 11, after Apollo 11, as I tried to get Hal [Harold A.] Loden to be the prime MOCR guy for a flight, and John Wegener to be the prime MOCR guy for a flight, and then behind him Dick Thorson the prime MOCR guy for a flight. So the net result was, I never got to sit on a console again. [Laughter] Eleven was my last flight.

So what happened from that point on, my guys were there, and I usually was in the back room or looking over their shoulder as they were going. I became a desk-bound manager from that point on, a pencil-pusher, as Hannigan used to frustratedly say. He was an old flight-test guy, and his frustration was he wanted to be in there with his hands on the hardware, too. I guess you hear it a lot. You probably heard it a lot. Everybody bemoans the fact, you know. What you did, you can't do anymore. Maybe there's a little lesson there that's got application. You'll reach that point sometime yourself, Kevin.

If you listen to guys think back over what they did, and they start, just as you've seen me do here, you can tell how animated I get when I think back to the time on the console. I just talk about that with great enthusiasm and vigor and recollection. You start talking to me about some of the jobs I did on the desk-bound program management, and I can't remember. We remember what the high points are, but they've got nothing to do with what we would look at and say, "Now, here's a career path and here's areas of responsibility." The more you mature, the more things you do, the more responsible and more important you are. You move into a point where now you've got a pretty desk and pretty office, and you remember it's not just when you're sitting on the console.

I laughed at Mel [Melvin F.] Brooks. He died a few months ago. Did y'all interview Mel?

Kevin: We did.

CARLTON: Good. Mel Brooks, I got so tickled at him one time. He came in, and he was getting ready to change jobs. He came in and said, "Bob, look at my resumé." He was interviewing for a top manager kind of a job. Now, top manager, what should a manager be? He should be able to show he's supervised lots of employees, managerial responsibilities and positions, managerial training. I looked at Mel's resumé. Do you know what he talked about? Just like me here. He talked about those missions on the console. [Laughter] He didn't even mention what he should have been talking about. I laughed at him, and said, "Mel, you want to go back to being a flight controller? Is that what you're trying to do?"

He scratched his head and he looked at that. He said, "Well, I guess you're right." He took his pile of papers and left. He didn't consult me anymore. [Laughter] But that's what we do. That's what we do.

When you become a desk jockey, and I imagine astronauts and the pilots, you hear that expression a lot down there. Their recollections always go back to when they were doing the fun things. Maybe there's a moral here, folks.

Kevin: I think no matter what you end up doing, after having helped land men on the Moon, it's a tough act to follow.

CARLTON: It was exciting. It was fun. Probably the sense of what you were doing makes you think back to it with great pride. I know it does. Don't have near the pride of the other things. Worked later on the Shuttle, was involved in a lot of the Space Station studies. I thought sure we'd have a Space Station and launch it off the Saturn. We were studying that. Then Headquarters at that time had some advanced study going on about a Shuttle. I didn't know what a Shuttle was. I'd never heard of a Shuttle. I had got involved in the Space Station studies. I felt sure that's where we were going, that's what we'd do. We had Saturns there to put it up with. We had CSMs and we could send men up and down to it. It's just automatic in my mind that's what we'll do.

Headquarters came in and said, "Hold up. No more studies on the Station here. We're going to look at Shuttle first." So they did the study on the Shuttle, and they came back and said, "Okay, let's restudy the Space Station with a version that can be delivered by a Shuttle." I thought, "What in the world?" I couldn't comprehend that. But we did and ended up building the Shuttle, and now we're seeing the Space Station come to fruition.

The other day I saw Dr. [Christopher C.] Kraft [Jr.] commenting about his frustration with what our nation's done in the Space Station Program. Well, I share his frustration. I recall when we first started trying to sell the Station to the Congress, we were talking about an $8 billion program. Many years later, I think we spent 8 or 10 billion and didn't even have a piece of hardware yet. Winston Churchill's famous phrase, "Never in the history of mankind have so many owed so much to so little," or something to that effect, there ought to be an analogous saying, "Never in the history of this nation have we spent so much to achieve so little." [Laughter] That Station Program ballooned all out of proportion. Looking back, if you want to see how not to do something, I believe that program would be a good way to do it, become a WPA [Works Progress Administration] for Russia. A lot of what we did was, I think, political to provide stimulus to Russia. Not that I say that is bad or not, it's important to this nation that Russia survive. Probably the stability of the world is very strongly tied to it. So the money is probably worth it, but, boy, it sure did make a disaster of the Space Station Program. It changed its nature. Now it's like a swimmer with a brick tied to its foot, with all of the encumbrances that we've put on the program.

I have a saying for Space Station. I almost ought not say this. I kind of hate for my NASA cohorts sooner or later going to see what I said here probably, and especially the guys at Headquarters that have worked their hearts out for years trying to satisfy the politicians and satisfy the scientists and satisfy the growing program requirements with a shrinking amount of monies. But, nevertheless, I think my saying is very apropos when I look at the Space Station. There is a medical term. Have you ever heard of this disease called elephantiasis? That's where a member of your body just grows to where it's totally unable to accomplish any function whatsoever. I think our space program suffers from programmatic elephantiasis. [Laughter] I see components, you know, that just don't make sense to me. I'm sure NASA Headquarters guys will take great offense to my conclusion there, but that's the way it looks to me.

The only thing we haven't talked at all about is [Skylab]. [Skylab], there was a mini space station. It got in orbit, launched on a Saturn V, did a lot of things, stayed up there a long time, had some big problems. Those problems got worked just like the Apollo problems got worked. As I remember, it lost a paddle of its power off. When it launched, it shed one of its power panels, and had great damages. The first mission was all involved in how to get some use out of this thing and get it back to operating. They spent a great deal of effort doing that.

Then we abandoned it, and downstream it became a great disaster waiting to fall out of the sky. It was a great effort. I remember we had a lot of publicity about what's going to happen when that thing reenters. It wasn't. The Russians recently reentered one, and they still had power and could do a burn and reenter it. On the Apollo, we couldn't do that. It was coming in, and all we could do was change the attitude a little bit, but mostly we just looked at it. I'm not even sure we could change the attitude. I've forgotten now. I think we could, though. We had a little bit of umph left. We couldn't do a burn to make it reenter, but we could change the attitude and that would cause the drag to change.

As you projected ahead and said, "Okay, here's where it's going to land," you could modulate that a little bit by changing attitude months ahead of time and make it be more streamlined so that would make it go a little long or this way and make it go a little short. But your knowledge of predicting that far ahead was sort of overshadowed by the uncertainties of what's the atmospheric pressure doing and the atmospheric influence from the sun hitting it. There are a lot of influences there that made a big uncertainty loom on your projections. But it came in and didn't hurt anybody. As I remember, most of it sprayed into the ocean.

But it was a good program. I thought we did a lot of stuff, sent a lot of people up there, and it was a very successful program. You rarely ever hear very much about it. I commented earlier about science don't get much recognition. Maybe there's the application of it. That wasn't breaking a new frontier, so nobody's interested anymore. How many people have you interviewed on it? Have you focused on that in your—

RUSNAK: We have talked to people about Skylab, both the flight crews and people who—I don't think we talked to anybody who worked solely on Skylab, but people through their career who worked in some managerial or technical aspect on Skylab. So we do certainly cover that.

CARLTON: I'll bet everybody talks about Apollo and Shuttle and almost forgot about what we did on Skylab. Are you going to do the same thing as you compile this historical—

RUSNAK: Most people, their strongest recollections of Skylab are in the first few days after the launch, when they're trying to figure out how to fix this thing. For many of the people, that was their Apollo 13.

CARLTON: Yes. And it was a big one.

There's one point in that Skylab that I hope you caught. The design guys were the ones that saved the Skylab mission. It wasn't the flight controllers. Max [Maxime A.] Faget and the Marshall [Space Flight Center, Huntsville, Alabama] design people, they come up with all kinds of crazy schemes, trying to come up with a panel, parasail, or whatever you call that covering they put on. That was a problem that you had time to plan and do it, and the people down at the design level were really the ones that came up with that solution.

Maybe that points out something I should have made note of as we were going through these things. Your ability to respond to a problem and who you can bring to bear on it is directly related to how much time you have to get the solution. If you're doing a lunar landing, your solutions will, of necessity, be dictated by a lack of time, be constrained by the people in control center. There won't be time to consult. If you try to consult outside of control center, you'll waste—I'm talking about in measure of seconds and minutes, and seconds, certainly. In minutes, even, you can't. If you've got a problem that's deteriorating and you've got to solve it in minutes, and you ask a contractor to help you, you'd spend those minutes explaining to him that what was going on instead of solving your problems.

If your problem's got to be solved in minutes, it will be inside the control center. If your problem has hours to respond to it, then you can get back into your contractor team if they're already set up and manned and ready to go. If you have the luxury of days to respond to a problem, then you can go back and get into design solutions. If it's bigger than days, then your sphere expands out into the political cost factors and you go ask for more money and build new equipments and so forth. So the time to react to something directly constrains the point where you're going to get your outer bounds of supports coming in, flowing into the thing.

We've touched on everything I thought of that you would find of interest.

RUSNAK: Okay. And we've covered most of the questions I think I had prepared. I don't know if you had any more charts that you'd wanted to discuss. I know last time you brought several of them.

CARLTON: No. I made a set of notes. In fact here's some points that are worth talking about.

RUSNAK: While you think about that, let's go ahead and take a break and change out our tape.

CARLTON: Okay.

RUSNAK: Did you find any other points that you wanted to make?

CARLTON: No, I think I touched on most everything. As we've talked about everything, I think I've touched on every point I thought was worth bringing to your attention.

RUSNAK: I did want to ask you about your leaving NASA and when you did that and why you decided to retire and maybe anything you did after that.

CARLTON: I retired from NASA in 1980 and went to work for a company called the Aerospace Corporation. I worked with them until 1990, ten years. The reason I did that was NASA had come to a point to where—well, there's two or three things that sort of all went together. Part of it was that the excitement of the NASA job was just not there anymore. The NASA was beginning to be a bureaucracy and you're fighting for the money and you're being criticized why you're not doing everything, and just the excitement of the job. Maybe part of it was, too, it don't matter what you do, if you do it long enough, it begins to grow old and mundane and stale.

I can remember reaching a point in some of our programs. We'd get a new program coming along, and by this time I'd long many years been in management of NASA, in NASA management circles. A new program come along, and I guess this was about the time the Space Station was moving into high gear. They came over one day and said, "Okay, we're powering up here to get ready a team to support the Space Station studies all over again," after the Shuttle was beginning to be successful.

I was sitting down there in the organization, worked in the DaSyD, Data Systems Directorate. I said, "Okay, let's lay out a plan how we support this." So I sat down with the guys, and Bill [Howard W.] Tindall was our chief. "Okay, we'll have this team of guys do this and we'll have to do this," and we began to lay out all the steps to support this new program. I was sitting there thinking, "I'm doing exactly—this is exactly—it's just old and stale. Yes. We do this again and this again and this again and this again and this again and fill those squares in, it's going to work." The first time I did it, we were scratching our heads going "How are we going to do this?" But now it's just become mundane and dull. I thought to myself, "I'm tired of this." That was part of it.

Part of it was financial. In NASA you were in the civil service system, and there was an expectation of here's the way your pay will go if you follow the normal course of events. I got to looking at the alternative of what my financial situation would be if I retired. I began to draw little charts and plots and said, "Okay, what if I retired and I took my NASA retirement and I'll go ahead and retire and I'll go to work for another company and they'll pay me a heck of a lot more than NASA's paying me." So there I've got a jump in pay.

Not only that, I will have the NASA retirement check. So I assume I'll put it in a kitty, a pot, and just let it grow. So now I've got this retirement growing in a new company. I got this kitty growing. And you combine those two, and it was no contest.

Bill Tindall, he was my director chief, was the one that set me on this line of thought. He did the same thing ahead of me, and I heard him going through the iteration. I hadn't really thought too much about it prior to then. But he got to doing the same thing. In fact, he's the one who stimulated me to do it. He come in one day and said, "Bob, you'd be a fool not to retire. I'd be a fool not to retire." He said, "If I were to elect not to retire, I've got no regard for money."

I thought at the time, "Well, who cares?" But then after I got to being unhappy with the mundane-ness, then I got to thinking back and started doing the same thing. And he was right. So financially speaking, it was no contest. The combination of those two things led me to retire.

I went to the Air Force and that was sort of a natural thing, just like having been in the aircraft business made it a natural thing to come to the spacecraft business. When I finished with NASA, it was just an accident I went to the company of Aerospace. They approached me. They came to me and asked about it. They said, "We heard you're fixing to retire, and wondered if you'd be interested."

I had been planning to get with some aerospace contractor, and it just happened that they were the first ones that approached me. I didn't look any further. They got a great reputation, and they were a great company. In retrospect, I couldn't have made a better move. I just loved working for the Aerospace Corporation. It was a great corporation.

It was not-profit motivated. It's a unique company. They are, I guess, I would describe it, they're like a nonprofit group of consultants of expertise that the Air Force has as—what do you call a lawyer when you keep him on retainer, kind of like on retainer. Anytime a problem crops up, they got a level of expertise to apply to it. But more than that, they are more than on a retainer in all of the new programs, they are also the engineering oversight that assists in maintaining a nonbiased oversight of the engineering aspect of what's taking place, and the program management aspect of what's taking place.

So working with them was a great joy and it brought me back. I started out in the Air Force. I think I shared with you how that took place. I went from the farm to the Air Force and now it's kind of ironic that I ended up with the Air Force. I thought of myself as back in the Air Force. Of course the Aerospace people worked so close with the Air Force, too, and they kind of thought of themselves as "We're Air Force." You're looking at the Air Force's interests You're hired to work for the Air Force and protect their interest in the system and what they're doing. So you get a mindset of "I'm Air Force in civilian clothes." So to me it was a little bit like coming full cycle, you know, back in the Air Force. I enjoyed every minute of it.

They did do some weird things to my brain. I had gone through all these years with NASA and become so sensitive, or cognizant, or aware of, or appreciative of, how important it was for man to be in the loop. When I first went back to the Air Force, they didn't have a manned space flight program. They started out to have one, but the more they looked at it, [the more the concluded that] anything you decided to do they could do it already in orbit. So their question is "Why do I need to put a man up there? I can do that already. I want to take pictures. Why do I need a man? I can point the camera, I can select my targets, I can flow the data. I can get just as good a picture on the ground as I could with a man. Why do I need a man up there?"

It took me a while. I had a strong mindset of you just can't do space operations without a man up there. I quoted all the arguments that I've been quoting here to you about what man can do. But when you put man up there, it costs money. It complicates the system. So it breaks, you put another one up. That's the answer.

The other thing is, when a man's up there, you begin to complicate the design to protect him. As you complicate the design, you make it less reliable. Some of the guys used to quote the illustration, "How do you get something to work cheap and good?" Well, there's a fundamental principle you apply to it. You make it as simple as you humanly can. Now, the illustration of that is the refrigerator. Not a telemetry point on it. They just work and they work and they work and they work and they work. Why do they work? They're simple and they're sealed. It's a sealed system.

That's kind of the principle the Air Force applies to theirs. Not totally. That's an exaggeration, but it's a total contrast of principles of operations versus where I'd been focused for ten years. It took a hard shaking in my brain to get me to be able to appreciate it and to realize it and to realize there's a balance.

That brought me to maybe another point I should have brought up in all of this wandering conversation. In the exposure to that line of thinking, I've come to a new appreciation for a basic principle of operations, an appreciation of the way in which the importance of which you're doing or the criticality of what you're doing deals with the amount of flight control, the way you go about the flight control process.

If your program is all super-critically important as Apollo was, you will spare no effort and no cost to be sure it's successful. It's a major calamity both in terms of total program cost investment wasted and in terms of human life and in terms of national prestige for us to blow a mission on Apollo. So all of the tremendous effort we went to with this huge team of people was justified. It cost a lot of money, but it was justified. We went about it in a certain way.

On the other hand, there is a one-for-one amount of money you spend to that complexity and amount of everything to what you're trying to do. If you have a simpler program that's less important, let's just say, for example, something that's just really simple where you say don't waste too much money on it, but still in orbit. What if we're going to launch a satellite that gives us a communication ability, and we got twenty satellites up there already. We're going to put one more up there. We can lose any one of them, and we got five spares up there. We're going to put another spare up. If you have a problem, it's not a disaster to lose one of those things. You're not going to go to the effort we went to on Apollo.

Now I'm floundering to try to illustrate a principle to you. The principle is, there is from an economic standpoint, there is a right balance of how much money and time and people and effort you put on a program, and that balance equates to the importance of the program. If I were to tell you we want to keep this refrigerator in here working, it don't cost much, not important, not a whole lot lost if you lose it. You wouldn't allow me to go instrument that thing. It's ridiculous. That's a real further extreme.

But I don't believe anywhere, as I was going through my education in college and certainly as I was in NASA and even when I moved into the Air Force, we ever saw anybody try to quantify this idea of operations of what is the proper level for this program of cost and expertise and support that's proper for this program.

Here's an Apollo Program and here is that level of support. I give it because it's so important. Here's another program. What is the proper level for it? I have never seen anything, either within the Aerospace company or within NASA or in any of my college education, that gave me any guidelines as to what's the proper level of support to put for this particular program. It gets inside the program how much instrumentation do I put in it. It gets outside it how much external support do I put in it. I think the principle I'm describing here would have application to a nuclear power plant, to a chemical plant, to a NASA program in orbit, to an Air Force program in orbit. No one, to my knowledge, this has never been done, no one has ever quantified the parameters that would give you a new operations team coming on board the wherewithal to say here's the proper amount of support for this kind of a program versus this kind of a program versus this kind of a program. There's no guidelines.

In NASA, the way it's worked is the NASA team was [experienced, they could discern, "with] this kind of a program, [we need] this kind of support." This kind of a program came along and the NASA ops guy's still thinking this way. But the guy that's paying the bill, the program manager, says, "I don't have the money for that. You got to live with this."

Somewhere along the line, I would hope that somewhere some ops people hear the results of this conversation and they extrapolate and say, "Old Carlton's right, this is something worth doing." It would be useful to a program manager to have some understanding of how much ops money he [needs] to put to support his program. And the ops people to realize they've got to put together [an operations support] program that's within the bounds of [funds] versus…[needs. When] you get down to [the level of] a refrigerator…it's nothing.

Interplayed against that is [another factor,] the more you complex the design trying to give it… operational flexibility, the more expensive you make it. You reach a point to where you might be better off to build two of them that were more simple and don't fail as often and then just throw it away if it quits.

On the other hand, if we send a man to Mars, you want those people to come back. So you're going to be up there at Mars. You'll be down here with a refrigerator. You'll be here with an automobile, and you'll be here with an airplane. Somebody needs to quantify that. Maybe somebody will be stimulated as a consequence of this to go back and begin to…[help] turn operations into a science rather than a black art.

You know, I said earlier, it got old, [that] we done it so many times…. [One time] I heard the Cape guys one time. The Air Force was thinking about putting a launch site at Vandenberg [Air

Force Base, California]. The operations people from Cape Kennedy [Florida] came up and told them, "Here's the way we do operations at Cape Kennedy." They kind of went through what I'm going through here. They said, "Here's the way we do it," or the way I did it when I said we just fill in the squares, they would show them, "Here's the squares you fill in. Here's the way we do it." They were doing it at this level, without really appreciating why they were doing it at that level.

Now, what set me on this line of thinking was the Air Force challenging my thinking about it. I had everything up here. Air Force had it down in here somewhere, and they were proper in doing that. But I don't think they really had applied it from a scientific point. They applied it more from the restriction of the program management money that's available to do the job.

I'm glad that thought came back to me. When we first started out, I thought this is a principle I want to be sure we talk about. I hadn't talked about it very clearly, maybe, but it's something that could be done, I think. Somewhere you could quantify how much does additional system's complexity reduce the overall reliability of the system. Somewhere there's a tradeoff in getting it more complex to be flexible for manned operation versus less complex and more reliable system that's not apt to fail in the first place.

RUSNAK: Seems like an outgrowth of the motto that I understand was popular back in the Apollo days: Better is the enemy of good.

CARLTON: Yes. I forget who quoted that, but yes. That's right. The last 3 percent would cost you triple what it took to get the first 97 percent. We'd get into that ring. Where's a good balance point to have been.

RUSNAK: I wanted to see if Carol or Sandra had any questions for you as we were going along.

Butler: I wanted to ask about your thoughts on the first couple missions of the flight of the lunar module, Apollo 9 and 10. I think we, last time, kind of talked about them briefly, but not a lot. Here you were working on the LM systems.

CARLTON: Which one of them was the first unmanned flight? We had an unmanned LM.

RUSNAK: Five.

CARLTON: Five, unmanned LM?

RUSNAK: Yes.

CARLTON: Did you-all talk to Jack [B.] Craven?

Kevin: No, we haven't.

CARLTON: He was the LM Control on that unmanned LM. It was totally controlled by onboard program systems. It made it run through its series of maneuvers and had a little failure on it. It didn't work and they had to do an emergency burn that caused it to reenter.

If you go back and read Gene's [Kranz] account of that in the book, he talked about that a good bit. That will give you some insight into Jack. He had a wreck just before the flight. Oh, man, he was stove up. I was terrified that he wouldn't be able to function because [at that time] I didn't know [anything] about the LM at all. We had just brought Jack on board, and there was a lot going on. I just hadn't had opportunity to learn the LM like I felt like I should know it. I wasn't totally ignorant on the LM, but to know it like you should know it to be a flight controller takes a whole lot of time and I wasn't there. I knew I wasn't there.

If Jack had not been able to be there, I probably would have gone ahead and done it. But I could not have done it [right]. I couldn't have given it the support that it needed. So, anyway, Jack got hurt bad, stove up bad, and he was on the console. I had one eye on him the whole time wondering if he'd make it through the whole mission.

The LM had problems right from the start. They had a big emergency burn procedure and they did it. It went through its burn and in the process reentered, but they got the data. One of its primary purposes, of course, was to run the engine test of those burns and do a separation. It did all those things. People will never appreciate Jack. The burns that they did and that program that they executed… [by an onboard automatic system programmed] on a tape. The tape run, and it automatically did all those burns.

Jack was really the one that sat down, and he worked with Grumman and together they put together that sequence of commands to make everything work right. He had a lot more in that mission than just being a guy on the console. He was there earlier in a design role that actually…[established the sequence of events programmed on the tape].

If you move on to the next mission, now, after that LM mission, we had a—did we do a mission around the Earth? What was Apollo 7? I'm trying to remember. Did we do a LM mission around the Earth and then another one around the Moon?

RUSNAK: Yes, Apollo 9 was the Earth orbital mission with the LM, and 10 was the first time they took it around the Moon.

CARLTON: I don't remember much about the Earth orbital mission, what we did, other than we just powered it up and made everything work. But I don't recall anything about it that sticks in my mind.

The one around the Moon, the thing about that one that sticks in my mind is when we undocked the LM and they got out and they came back and tried to redock to the CSM, had a lot of problems doing it. If you got any of the tapes of that and you listen to the astronauts, it sounded pretty sticky. …Basically I think what it boiled down to was the LM thrusters on the RCS system were sized big enough to handle a 32,000-pound bird. That's a big mass of weight on it, so they've got to be stout to be able to move that weight around. After you stage, then the bulk of that weight is gone, and you're down to about a 10,000-pound bird. Then after you remove some of the fuel propellant, you're down to—I forget the weights, but it might been even a 3500-pound bird.

So, now, that thruster fire, even though it's at minimum impulse, it's going to cause some motion. [When] they…[tried] to dock, that thing, as I remember, it was just shaking around there like gangbusters. They had a problem getting it docked. Scared… me. But they got it docked, and they kind of learned how to deal with it. It didn't have any further problems in subsequent missions.

Now that reminds me of another problem that was back in one of the missions. It might have been the first one to the Moon. When they pull the CSM, here's the whole stack headed to the Moon, you ended up with the lunar module on the end of the booster and the booster did a burn. You're en route to the Moon, coasting, and then the CSM undocks and turns around and docks to the LM and pulls it out of the shroud. As they tried to dock to the LM, they tried and tried and tried and tried and tried, up ten eternities, trying to make it work. Finally, they got it to work. They put the nose in there, and they thrust and just held it. It worked its way in and locked up.

That was a long time frame. Another time there, it may have been in the same mission, we were sending commands, and it wouldn't go in. [We] sent the commands, and… sent them and nothing happened, [we] sent some more and nothing happened, sent some more and nothing. Finally, one or two of them got in, or something. I've forgotten which mission that was and what we were trying to command. But that was a scary thing. I think that was the first manned flight that [it] happened.

When we got to the Moon [with] the first manned [LM] flight and we did a simulated lunar mission, [they] did a rendezvous. They undocked from… the LM, separated, and then come back and did a rendezvous and then docked. That was when we had this rocking problem with the lightweight ascent stage. Prior to that, they exercised all of the systems of the LM. As I remember, the LM worked good.

The one thing about that mission that was really great was after they left the LM, they left it alive and [fully operational]. It was up there, and I talked to you earlier about how hard it was to get data on the systems. We ran that LM to the power of exhaustion. We turned the power off. We [had previously] worried about how long would the platform work. We turned the power off just to see. We just did everything that you could do to it to stretch it to its limits and gain a lot of information about it. It gave us a feel for how it would work all the way down to the limits of systems operations. It was an invaluable mission.

Every time we had a mission like that, we played with the LM after it was over with. The more we were able to do that, the more confident we were in our knowledge about the LM. That first mission was important from that standpoint. To me it was just that important from that standpoint as it was to verify we could do a docking and verify we could do the rendezvous and we understood the lunar, all of the gravity factors in the lunar thing.

Someone probably talked to you about in the early part of the lunar program there was a non-understood phenomenon that the vehicles wouldn't follow the orbit like they were supposed to. They'd do wobbles in it. If you're doing a rendezvous in this and the thing is doing wobbles, and you don't understand why it's doing wobbles, that gets to be a pretty—as a matter of fact, we probably, if we're not coming to an understanding of that we probably would not have been able to go through with it.

But I'm out of my area of expertise there. I just remember the concern over it and being curious about it. As I remember, they concluded there was some sort of a mass that caused an increase or a change or miss in the lunar gravity that was causing it. But I didn't know enough about it, and still don't, to tell you what it was. Some of the guys, the FIDOs, probably would understand that. But I remember, and my feeling was, just listening on the side to all that was going on, was it had the potential of causing us not to be able to do the lunar missions. I guess it sounded worse to me than it was because when something's not understood, you hear a whole lot about it. You get an impression of it that might be wrong later, and my impression could be wrong there.

That's about all I remember about those missions. Nothing else comes to my mind as being really standing out.

Butler: That's all the questions I had.

CARLTON: Okay.

RUSNAK: Just one follow-up to Carol's, I guess. Before the flight of Apollo 10 there was some discussion about whether or not that mission could actually be the first to land on the Moon. Do you remember any of this?

CARLTON: No. That would have taken place at Headquarters and at levels above me. I've read about it. When they came in and said we'll do that mission, Christmas mission, my recollection of that was sort of mixed emotions. One was sort of a thrill. "By George, we're going to the Moon? How about this?" That was a CSM. That wasn't a LM mission. But even so, that was a thrill of an undertaking and that was a lot accelerated over the schedule we'd been discussing. So on one hand, I felt a great thrill that we were going to do it. On the other hand, a great apprehension, are we premature in taking this giant leap this quick. But probably it was important that we did. That probably gave us the bonus to go ahead and keep with the schedule we had set out. It gave us more of a gung-ho, well, let's make some more giant leaps here.

If we hadn't done it, it could well be that we would have been in a more conservative mindset and wouldn't have made the schedule. It probably was important from that standpoint. It's funny what sticks in your mind as important. That mission was probably as significant as the lunar landing mission in terms of what we really accomplished, the magnitude of the jump, the leap in progress that you had made, versus what had gone on before. That was a giant leap in the progress and progression of the risk taking, progression of accomplishment.

Anything else?

RUSNAK: I think I had one anecdotal question. I'd come across a bit in my research where you're referring to, during simulations, Neil Armstrong pulling some pranks on you guys.

CARLTON: I don't know if he pulled this on everybody. You notice what happens to yourself.

I can remember being in simulations and the sim guys would throw problems at you. They would drive you to your knees. They would carry you far, far beyond what you ever experienced in a flight. What they would do is you wouldn't get a single [failure]—in flights you usually get one problem and you concentrate on it. But…the sim guys…knew you could fix one problem. That was not going to bother you. What they would do is they would give you a problem and listen to you on the loops…. They would wait until you got so absorbed in it… then they'd slip you the real problem. So what you had to learn to do was to keep your attention [on the whole bird], don't get completely ensconced in [the first problem]. You better keep your eye on the bird as well as work the problem at hand. But our human brains are such that we tend to want to focus on one thing at a time. So [after a while when] you saw [the real] problem show up [after the decoy]… you sort of got conditioned to it…. The first one was not the real one. You learned when you got this one, you better watch close because the bomb's going to hit you in a minute.

But the problem with Armstrong was if it got a little tame, [he would help things with his own inventions. The sim guys] …usually worked one group of guys at a time. So if it's my day to really have big problems, they'll throw me a lot of problems. But if it's going to be my day for big problems, they [usually] only worked on big problem at a time…. But Armstrong [seemed to delight in adding his own inventions to the sims], if it got a little tame… and Carlton's not got anything to interest him, [Armstrong would] reach over and pull a switch or flip a circuit breaker.

Well, I'm sitting there, and I know what we're supposed to do in every instant along the flight profile, and I see lost power on this circuit. Now, wait a minute, we lost a circuit breaker, so we'd start trying to figure it out. We could hear the other problem going along, so we hated to interrupt it, but we got to be sure we understand it. Well, he'd give you these freebies. If things were going a little slack to suit him, why, he'd spice things up.

But in… working with sims, [one] sort of gets conditioned to the way they work. [Armstrong's] problems were bigger than what he thought, because… I think I'm fixing to get the big bomb. I get a lot of gray hairs from all these little things he's throwing me as a freebie. Here Sim's [referring to the Simulation Supervisor] throwing me enough as it is and [Armstrong's inventions come] on top of it. It compounds and confuses the picture. He seemed to delight in doing that. He didn't do it all the time, but he did it enough that it gave me gray hairs.

We'd get through with [a] sim [run. For example maybe a lunar] …landing. Well, we'd do the landing and land or abort or crash or whatever the ending was. Then Sims would power everything down and we'd sit down and debrief it. We'd bare our souls as to what we did and then Sims would say here's what I did to you. You'd first tell what you saw and what you thought was wrong and why you did what you did. Then Sims would say, "I didn't do that."

I'd say, "Well, I saw it."

"I didn't do that. We didn't do that." Sim didn't know anything about it.

Well, old Armstrong says, "Well, it was a little slow there, I thought I'd just throw that in." He did that. He was the only one [of the astronauts] that really did that to me.

Thorson was [also] bad [about that. He] was my partner on the console. Thorson would go around to the sim people and he'd give them ammunition. A lot of times, they had some pretty smart guys themselves and they understood the systems real well. They'd come up with some wing-dingers of sims. But if that's not enough, old Thorson he'd go over there and he was diabolic sometimes. He would give the Sims a problem that would push our guys right up to the edge but stop just short of where they should have done something. He'd go study and see where the outer limits of normal system operation is and he'd run it up and then stop it right there. He caused us problems, too…. In personality, he was a little bit like Armstrong….

The one time, when I think of Thorson and Armstrong's antics, Thorson comes to mind. One time I was on the console in a set of simulations and we had gone all day long. We were just so dog tired. It got to the end of the day, and Larry Strimple, I was grooming him to be a flight controller. At the end of the day, we had gone through so many lunar landings, you know, it was just automatic. I thought, well, we got one more sim.

I told Kranz, I said, "Kranz, let's let Larry run this sim, this landing." Well, the room got real quiet. I thought, "What's going on?"

In a minute, Kranz's voice came on. "No, Carlton," he said, "I want you to run this one."

I thought, "Well, what in the world? That's chicken." Why would you? Larry could do this. I realized that [Clifford C.] Charlesworth had come wandering in a few minutes before that and Lunney had come wandering in. There was food back there and there was a whole bunch of people sitting there looking at me. I thought, "What in the world?"

We got ready to do this, and I looked over there. There was old Sim, Carl Shelley'd come in. The sim room was all lined up with guys. They had a console that looked through a window. There's usually just one or two of them there. By the way, they gave themselves away sometimes when they got something on you and they're waiting to see if you're going to, you can see their heads up there looking at you to see how you're doing. When you saw those heads come up above the console looking at you, you begin to cringe and look real hard.

Well, I began to cringe real hard. There was something going on. What I didn't know was that Thorson had been over, and he had put together a whole simulation that was going to kill me on this landing. What they were going to do is they were going to have the LM do an inadvertent torch off the burn just before I got acquisition, so the first [instant] I saw that sucker it's burning. It's going to do a bad thing. How quick are we going to be able to respond and get this thing corrected? If it hits you cold, it will be quite a surprise.

Thorson had gone through this. I don't know how long they'd been working on it. Well, they slipped up. The sim guy slipped up and saved my life. Somebody, and I don't know if it was somebody down in the sim, bowels of the sims that knew me and didn't want them to shaft me, or what, but for some reason before we got acquisition, we're sitting there waiting to see the bird come into view, and we got a burst of data. Pop, you know. Just one little macro second of data. Somehow they accidentally turned the data stream on. Nance was in the back, and he said, "Carlton, they're burning. We got data. It's burning."

Thorson was sitting beside me, and he started cussing. He said, "You're the luckiest blankety-blank ever. I've never seen anybody so lucky." Then I knew Thorson was the one that set me up. He knew what was coming. So we had a few seconds' time warning, and when it came into view, we were ready. We squashed that and then all the way down that sim, old Thorson had done his work well. It was boom, boom, boom, boom, boom, boom, all the way to the landing. When we hit that landing, I'm telling you, I felt like I had just been wrung out. But Nance, once those guys did their job, we landed. Got through landing, and Thorson was just fit to be tied. He really thought he really had a setup, and he did have a setup.

Charlesworth came wandering by, walked over and looked at me, and said, "Well, Carlton," he said, "I don't guess I'll worry about you anymore." But that was the same thing with Thorson as you saw with Neil Armstrong. Both of them had this quirk in their personality that they just wanted to see a guy sweat, I guess.

RUSNAK: A little bit of a test.

CARLTON: It was fun times.

RUSNAK: Did you have any other stories or concluding remarks that you wanted to make before we wrap things up today?

CARLTON: I think we've touched, Kevin, on the most all the things that comes to my mind. I hope that when you get this thing put together that somehow it comes across as more than just here's the events of what's happened. Here're the people that are there and here's what they did. That it somehow comes across of the appreciation of some of the basic principles underneath what was happening there and how that precipitated itself forward and influenced the shape of what NASA did on downstream there.

Probably, you'll see it better than me. I saw it and appreciated a little bit of it when it was happening. But I'll bet when you get it all together and you hear everybody's perspective, you'll have a better picture than any of us did. You'll have the benefit of everybody's perception of what was important, not important. I think you'll find a better perspective of what's important, not important when you look at it from or you hear the picture unfold from the viewpoint of the flight directors and the program management. Some of them are gone.

I sure hope you talk to Kraft, because his perspective is probably, him and Kranz and some of the program management people, their perspective will probably give you a better overview of what the whole thing was all about and how all the people played together than looking at a flight controller that's just [seeing] one little subset of it. I just looked at it from the LM, [that] was all I saw in those days. I was oblivious to the bigger picture of what was going on.

RUSNAK: Certainly your ability to reflect on these principles really brings them out of the narrative of the stories and events that you've described. We certainly appreciate that.

CARLTON: Good. Okay.

RUSNAK: All right. Thank you.

[End of interview]