NASA Johnson Space Center Oral History Project
Oral History Transcript

Jack Knight
Interviewed by Sandra Johnson
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The questions in this transcript were asked during an oral history session with Jack Knight. Mr. Knight has amended the answers for clarification purposes. As a result, this transcript does not exactly match the audio recording.

JOHNSON: Today is October 25th, 2007. This interview with Jack Knight is being conducted for the Johnson Space Center Oral History Project in Houston, Texas. The interviewer is Sandra Johnson, assisted by Rebecca Wright.

I want to thank you for joining us today.

KNIGHT: Okay. Thank you.

JOHNSON: If you would, share with us how you first became interested in the space program and how that interest led you to pursue a career with NASA.

KNIGHT: Well, the background is that my father was in the Air Force. He was a career Air Force officer, and I was their first-born in 1943, so we moved around a lot. pace at that time wasn't a big deal. As I grew up I read a lot of science fiction over the years. In school I preferred math and science, because it was objective, so you either got the problem right or you got it wrong, whereas in some of the other subjects it was very subjective, which can be annoying from time to time.

Anyway, I read a lot of science fiction about space travel, [Robert A.] Heinlein and Poul [W.] Anderson and those kinds of things. Isaac Asimov. As it turned out, we were stationed in North Africa at the time of Sputnik [1, Russian satellite] in [October 4, 19]'57, and that, of course, was a big thing in the world. Not a big thing I guess with me, but I recall it. Then we came back to the United States, and I went to senior year in high school in Montgomery, Alabama, and wanted to go to Georgia Tech [Georgia Institute of Technology, Atlanta, Georgia].

My father and mother were both from Georgia, but most of my time was spent on Air Force bases. Georgia Tech was a home state kind of thing. It was an engineering school, and I really wanted to go there. It turned out I got in and picked electrical engineering for no other reason than, well, Dad recommended it. He was a lawyer, so it was interesting. He recommended electrical, because it was broad, had broad applications. So essentially it was going to school to get the tools to earn a living.

Then, of course, [President John F.] Kennedy had already announced we were going to the Moon, and there was a lot of pride. I watched the launches, the ones that were on television, while I was at Georgia Tech, and when graduation time came around in '65, I had interviewed like a lot of other people do. NASA came there, and I believe it was a gentleman from the Cape [Canaveral, Florida], probably, the Cape or [NASA] Marshall [Space Flight Center, Huntsville, Alabama], but anyway, because that is the closer. But they apparently took the forms and filled them out and sent them to the three big Centers, which were Marshall and KSC [NASA Kennedy Space Center, Florida] and, at that time, the Manned Spacecraft Center [MSC, Houston, Texas].

But like engineers, you interview with a lot of other people, Sperry [Corporation] and General Electric and CIA [Central Intelligence Agency] and—gosh, who else?—Atomic Energy Commission, which no longer exists. I interviewed with all those people, but then I got a call from a fellow named Jim [James L.] Tomberlin here at Manned Spacecraft Center. We chatted about what the job was about; it was in Flight Operations.

As it turned out, apparently my résumé had come across Jim [James E.] Hannigan's desk, and Jim Hannigan was a Georgia Tech graduate, who, had roomed with John [W.] Young [as an interesting sidelight]. Of course, people know their schools and what they produce. So I assume Jim said, "Give this guy a call."

I had a pretty good grade point average at the time, and so we chatted, and they made me an offer, and I said, "Wow, this dovetails in perfectly with the science fiction interest in space, with the lunar project." What other grand opportunity was around? Dad at that time was at Randolph Air Force Base in San Antonio [Texas], so that was another nice, convenient thing.

So I took that offer. It wasn't big at that time with the government, a GS-7 [General Service] I think it was. But the opportunity was there and I took it. So it was just kind of luck, being at the right place at the right time, and picking the right field to be in. I reported July the 1st, 1965, At that time Personnel, they called it, Personnel was at Ellington [Air Force Base, Houston, Texas]. I went out there and signed in, took the oath of office, and they gave me a little booklet of how to behave and that sort of thing.

I reported to the Manned Spacecraft Center in Building 30, Admin. [Administration] wing, on the second or third floor—I've forgotten; I think it was the third floor. People were busy, and they didn't even have a desk for me, so for the first two days, as I recall, I had a gray chair, next to somebody else's desk, and they handed me some books or documents to look at, become familiar with the kind of things that was going on.

The guy who probably became the best mentor I ever had was Don [Donald R.] Puddy. Jim Hannigan had hired him, and he became a Group Lead, or Section Head. It was a mix of civil servants and contractors. I was signed on with NASA, but there were a number of contractors, Grumman [Aircraft Engineering Corporation, later Grumman Aerospace Corporation] in particular, because they were the manufacturer of the Lunar Module [LM]. I was in the Apollo Systems Group, Lunar Module Section of it.

At the time the Gemini Program was going on, and it had a Gemini, which was a manned vehicle, and the Agena, which was an unmanned vehicle that was used for boosting or docking. The Agena was an Air Force vehicle. So they had a number of people. There were people from Grumman, who represented the Lunar Module, and there were people—who were called the tech reps or technical representatives that were employed by Philco Operations, I believe. They [Philco] were people that had contracts with the Air Force. They installed remote sites around the world, and they had technical representatives that did things like operate the Agena.

Well, the Lunar Module and the Agena were grouped together, and the Gemini spacecraft and the Command Service Module [CSM] were grouped together. So new guys, and there were another couple that came right after me, Jim [James A.] Joki, I think, came two weeks after I did, and Bob [Robert H.] Heselmeyer about a year later. You have interviewed Heselmeyer, I think, already.

Anyway, we were sort of, I would call it, apprenticed with somebody who knew what they were doing. So, you've got, "Here, read this documentation. Listen to this. Follow this. Go to these meetings. Listen, listen, listen. Try to acquire the jargon."

The first sort of consequential thing I was assigned, I think, was they paired me up with somebody for Gemini 8. Their names, I think were Jim [James F.] Moser and Myles [E.] Franklin, both of whom are deceased now. We went to Corpus Christi, Texas, which had a site down there. Gemini 8, I believe, was Neil [A.] Armstrong and [David R.] Scott, maybe.

What you did at the Texas site—because it wasn't very far; it was Corpus Christi—usually they didn't send a remote site team down there, because I think they just took some data from it or something like that, or the guys would send data, whereas the other sites around the world, they sent remote site teams with a CapCom [Capsule Communicator], which was equivalent of Flight Director, and a Gemini Systems Engineer and an Agena Systems Engineer and a surgeon rep [representative].

Anyway, what we did at Corpus Christi: The Gemini spacecraft didn't have a consumables monitoring system on their orbital maneuvering system, but they had a recorder on board, and they recorded the engine firings, so if you take the duration of the firings times the fuel consumption rate, and subtract it from what you knew you loaded, you could come up with where you were. So they would dump the recorder over Texas, and then we'd play it out on a strip-chart recorder, and you'd go unroll that strip chart, and you'd count all the pulses and the duration, and add them up.

So a couple of guys went down there, and I went with them. Well, as it turns out, the way the Gemini was launching, Texas does not have a pass the first day. So we went down there, and we did site check-out, and then we went back to a motel, and for some reason, didn't turn on the news or anything. Then the next day we came back out there, and they asked us, "What are you doing here?" They said, "They've already splashed down."

That was the flight that the Gemini had a stuck-on thruster. They [the crew] thought the original problem was on the Agena, and separated from it, and the spacecraft spun up, and when that happened, they had to apparently fire the reentry rings. When you did that, the mission rule is you come home. So, as it turns out, we never got a pass, but it was an interesting little exercise for me. So Jim Moser—I think it was Jim—drove us back to Houston.

Then the next time I went out, and I think you had that on one of your questions, was Canary Islands. There I went with a full remote site team, with Harold [M.] Draughon as the CapCom, and Jack [John E.] Walsh was the Gemini rep. He was, I think, a Philco guy. And Robby Robinson, Willard [D.] Robinson, was the Agena Systems Engineer, and I was sort of a trainee Agena Systems Engineer.

Well, at those sites you had a bank of meters for the Agena side and a bank of meters for the Gemini side, and these meters were just standard meters, they ran on a zero-to-five-volt scale. So whatever was driving them, you had to have an overlay that says this is a pressure or a voltage or a temperature or something like that. We would carry those overlays down and put them in and set up the bank of meters and verify that it had the right things driving it, the right signals driving it. We'd do some simulations.

We also did simulations back here at the Manned Spacecraft Center, because they had a remote site sim [simulation] room. So you could go in there and pretend you were at the remote sites and go through a couple of sims there. Then you'd go out to the remote sites, and once you were out there and got things set up and ran some site tests, you would go run some sims there as well.

We didn't have any of the high-speed data that you have today, so for those sims you had to take the tapes out pre-made, it was all choreographed. The sim taps were built back at Houston, and they would tell you, "Okay, call up tape number one," or two or three or whatever it was, that corresponded to the pass that you had. Well, that, of course, meant you had pretty canned sims.

So we flew to Madrid [Spain], and we flew to Las Palmas [Canary Islands, Spain], and then we drove out to the site, and we stayed in a motel and that sort of thing. Again, my recollection of that mission, on the launch day they launched the Agena first, and the Atlas blew up going uphill. That was GT-9 [Gemini-Titan]. Well, so much for that mission.

So we packed up and headed back. Apparently they [Houston] tried to catch us at Madrid, because they had a new plan, and the new plan involved a thing —it was a docking simulator, which ended up being called the "Angry Alligator." They thought they could pull that around and get it off in a couple of weeks, and so they said, "Hey, let's leave all those guys out there."

As it turns out, they didn't catch us. We flew back to New York and then to Houston and that was it for me. It was the last time I went out, but it was fun and it was interesting. I learned stuff. But after that they did go ahead and do that flight again with that other thing, and rendezvoused with it. Couldn't dock [because of a problem jettisoning the shroud], but they rendezvoused with it, and that was the backup to the Agena. They did that in a couple of weeks or so, but I was no longer involved.

When I got back, we were much more focused on the Lunar Module, so I didn't do any more Agena work. I was on the Lunar Module. LM-1 was the first Lunar Module flight.

Now, just so you know it wasn't all technical stuff like that, some guys, we would go and played—I guess we were playing at Ellington in those days—softball out at Ellington, fast pitch in those days, and flag football and basketball and volleyball, so I was involved in those kind of things as well. At one point some of us got together and we went canoeing up on the Guadalupe River [Texas Hill Country] and so on.

Anyway, coming back to the Lunar Module, the first Lunar Module flight, LM-1, AS-204 [Apollo-Saturn], I think it was, and that was operated by what was called a program reader assembly. It was a little automated thing. Let me back up a minute just to give you an anecdote.

When I first got there, again, they give you books and this and that, and one of the sort of assignments, I think, was—well, this might have been when we were getting back in the Lunar Module—it was “let’s talk about mission rules”. So I said, “Well, I don’t know what mission rules are,” but I got some examples, and I went home and I wrote some and I came back the next day, and I said, “Okay, let’s talk about them.”

The guy looked at it, and he says, “Oh, I though this would keep you busy for a couple of weeks.” It was kind of busy work, I guess, for the new kid, but you learn [from it].

Anyway, the program reader assembly, the next thing was to work on procedures; what sort of procedures should we be following on this flight. I said, “Well, since the PRA, or the program reader assembly, defines what’s going to happen on the flight, if you start with that sequence of events, you can build procedures around it.” And I did, and that was a great learning experience. You talk to people, and you can write down what you anticipate, where are the site passes, because, unlike today, when you have TDRSS [Tracking and Data Relay Satellite System], and you’ve got data all the time, in those days you didn’t. You had it only when you had passes, and passes might be a three-minute pass, two or three minutes, or maybe it’s as much as ten minutes. Sometimes, if you go across the United States, you might have three in a row, so you might have twenty minutes. Well, that makes a big difference. You can only do things when you’re watching it [the spacecraft], if you’ve got commands or things of that kind. So that [LM-procedures] was a tremendous learning experience.

It wasn’t just me. There were a lot of other people involved, and we had a lot of meetings where you talked about rules and procedures and what are we going to do and what if this happened, what if that happens.

I ended up being I believe the first editor of the Lunar Module Systems Handbook, which was another tremendous experience, because you had to get other people lined up to build the drawings. Systems handbooks were the core learning tool of all the systems Flight Controllers; has been ever since then, because you have to research the systems. You have to get the drawings. You've got to make a schematic drawing combining things that the engineering community doesn't do. They'll do a certain type of drawings, very detailed, and we used that plus parts of other things, and simplify to some degree, because what we were trying to show is cause and effect, where the switches are, where the circuit breakers are, where the instrumentation is, and therefore what it means. Building all those drawings is a great learning experience. If you're editing the book, then you're also working on schedules and reviewing the drawings and looking for certain standards and so on. So we produced the first LM Systems Handbook. That was a great experience for me.

We did the first Lunar Module flight. It turns out that it didn't go [perfectly] —the descent engine was supposed to fire off and burn, and then it was going to do an abort stage, and then the ascent engine would fire off, which would get one of the objectives of flight. But as it turned out, the descent engine started to light, and because it didn't pressurize fast enough, the auto sequence shut it down. So that was a little bit of a disappointment, but they went on with the sequence in the abort stage, and the ascent stage went off, and it was a great flight. Eventually the LM was at a low enough altitude it ended up burning up, but that was long after we left it. So Lunar Module number one, great experience.

The next one was Apollo 9—that I was involved with. , The other Command Module and the Saturn Vs and the booster flights were still going on. I wasn't so involved in that other than to watch them. [Saturn V, AS] 501 [Apollo 4] was the first—see, I'm rambling here now.

But 501 was the first Saturn V, and, boy, I don't think I'll ever forget that, nor will any of the people that really saw it. Just to illustrate it, I watched it on television. [I never did get down to the Cape to see a real Saturn V launch, but that's okay.] But I watched; I think it was on CBS, because Walter Cronkite had his trailer there. You may have seen that. But I think it was a little closer to the launch site than they let them get now, maybe it was a mile or so, a mile and a half, two miles away. He had this big picture window on the trailer, and the camera was looking at him, and in the background you could see the pad and the Saturn.

Now, you've got to remember this is the first [time a whole Saturn V vehicle was launched] —I guess they had fired all the engines at Michoud [Assembly Facility, New Orleans, Louisiana] before, but never a whole vehicle. So we had all the eggs in that basket. So here's the countdown, ten [seconds]; Cronkite, he turns around to look at the pad. At six and a half seconds before liftoff, the [first stage] engines start, so they've got to build up thrust. Once they build up enough, you can release and go. Otherwise, it'll just tip over.

Well, at about six and a half seconds on that vehicle you've lit them off, and this great whoosh and smoke and all this, and you can see the fire and the flame and the steam and all that, but right then you don't sense it, because the acoustics hadn't had time to get there. Just about the time it starts to come off the pad, the sound hit the trailer, and you could see the whole trailer was shaking, and the window was shaking, and Cronkite says, "Oh, my god! Oh, my god!" He puts his hand up on the window. But, of course, at that time the thing [vehicle] was moving, and it was—I guess if you'd been at Michoud or anything, you'd have seen something like that, but if you hadn't, this is the first time the world had seen that thing.

JOHNSON: Right, and it was something that you had all been working so hard to achieve.

KNIGHT: Well, it was just incredible, the power of the thing and the noise and so on, even coming across the television set, and it was majestic. It lifted slowly then, and faster and faster.

WRIGHT: Someone described it to us as almost slow motion.

KNIGHT: Well, sort of, but sometimes you could get faked out [if you see replays], because the cameras there may be running slow motion. In fact, the one they show most of the time over in the Control Center, in the monument over there, it's always slow motion, because there's a whoosh, and then you can see these things, and you can see the flame—they've filtered it and so on—and then it moves slow. So I think they slowed that down a little bit, but it did [appear to move slowly partly because it was so big]. It didn't move as fast off the pad as the [Space] Shuttle does, because its thrust to weight was smaller.

But it was so impressive, and so that was my memory of 501. Then on 502 and 503, I think 502 had—again, I was a Lunar Module guy, so I just know this in passing, because I just listened to everything—502 had, I believe it had, an engine shutdown on the second stage. One engine shut off, and they had miswired the shutdown controls, so engine *x* shuts down; it shuts off engine *y*; and engine *y* turns around and shuts off engine *x*. So you had two engines go out, boom, boom, just like that. But it had enough speed, and the three remaining [engines] kept on chugging, [there were five engines on the S-2 stage], and they made it on into orbit and got done what they needed to do.

[AS] 503 was Apollo 8, and I'm trying to remember the sequence of events. Yes, we did 503, and that went to the Moon, which was a—there's a certain history behind that, of which I was not privy at the time, so it was a surprise. After that I believe Apollo 9 was a Lunar Module flight, and that was around the Earth, and that was on a Saturn V with a Command Service Module. I guess Apollo 7 was just a Command Service Module. I wasn't involved in that other than just watching.

I was here at the time of the [AS] 201 [Apollo 1] fire. Again, I wasn't in the Control Center, so I just heard about it, and you think, "Oh, my god, what's that going to mean to the program?" and so on. But that was—I mean, when you think about it, it's amazing that, considering what takes place today, we were down two years on both [STS] 51-L [Space Shuttle *Challenger* accident] and the [STS-]107 [Space Shuttle *Columbia* accident]. For Apollo 201, they were down about a year. I sort of remember there was a committee, but it was self-investigation. It was done pretty fast. There were congressional hearings. I think Frank Borman went to that, if I remember this right, and he said something to the effect of—he told the Congress, he said, "You guys need to stop this witch hunt," and they did. The redesign was done on the Command Service Module, and the Lunar Module was still in process and so on, and we got back on track.

That [event] was one of the things where a pure oxygen environment [exacerbated an ignition event]—they changed it [atmosphere] after that to a—well, it was changed so it was not pure oxygen on the pad. When you got up to orbit, eventually it became pure oxygen for other reasons having to do with the way EVAs [Extravehicular Activities] were conducted. But anyway, so they redesigned a bunch of stuff. Flammability was a huge, big thing after that.

Apollo 7 went off okay. That demonstrated three guys, a couple of weeks. Apollo 9 was where I was involved the first time [on a crewed flight.] I was in the SSR [Staff Support Room] for LM-1 and I was in the MOCR [Mission Operations Control Room] for Apollo 9 and for all subsequent Apollo flights.

JOHNSON: Well, if you'd like, before we go on—you've been giving an overview of the progression of your duties during that time. If we can just for a minute go back and talk about those first assignments and what you were doing at the beginning, if that's okay. As you mentioned, you said that Jim Hannigan was instrumental in hiring you. At any point during that process and when you first started, did you have any indication of what you would be doing in flight control, or what type of understanding did you have of flight control?

KNIGHT: Well, I mentioned the telephone call with Jim Tomberlin. I said, "What is this? What is this operations about?"

Now, I was still in school, my EE [Electrical Engineering] things were essentially math oriented, mathematics and circuit design; you had certain circuit designs in a simplified way, or in an academic way. Plus I'd had the physics and chemistry and some basic mechanical kinds of things. But I didn't know exactly [what operations was about].

If I extrapolated what I'd had at school—because I took the electronics end of it. [Electrical engineering had two paths in those days. There was an electronics oriented option—electronics and communications—or power. If you went the power way, you had more exposure to transformers and high-tension electricity, because you were headed for the electrical power industry. If you took the circuits, you were more oriented towards communications and little circuit designs, although we had some of each.] So I said, "Well, I don't know. What do people do in these environments?" Because I didn't really know at the time. I didn't do any co-op [cooperative education] work or anything like that. I just went straight through school, and I was not a ham radio operator or anything like that. So I asked Jim Tomberlin, "What is it?"

The example he gave always sticks with me. He says, "We don't care so much how a transistor works. What we care about is does it work or not." So that makes it an either/or, on/off kind of a thing, which, as it turns out, is something the way operations is. Now, it helps an awful lot to understand the whys this is working this way, to understand why it does this or that. So that was my exposure to it, and that was the idea I had. That was all I had. But just having the opportunity to be part of it, I said, "I can probably cope with this," and I was able to. So essentially it comes down to flight operations has to do with logical thinking and implementation of rules, recognizing failure modes and good operational modes, and being able to extrapolate those.

So when I first came to MSC, they essentially said, "Here's these books on the Agena or the LM," and it's a fam [familiarization] manual, which says this is what it looks like, this is what it's supposed to do. Then you get into more detailed systems. I ended up in the environmental control and life support, electrical power end of it.

So what are electrical power systems? Well, typically for the Lunar Module and the Agena, it was batteries, buses, circuit breakers, fuses, and if you had switches that were controlled by either an automated controller or by a command, so a command would open or close this switch. Then you can look at these things and say, "Okay, what if this fails? How is it going to look?" If you have telemetry points, they say the voltage is here [this value] and the current is there; you have a pressure or a temperature, or a pump pressure, or delta-P. [At that point I began to say [to myself], "Boy, I wish I'd paid more attention to the mechanical engineering survey courses, I had to take." I had not ignored them, but I hadn't appreciated that I was going to be in this field. But with basic physics, pretty soon you get a handle on it, and you talk to people. "What's this? What's the range supposed to be?"]

If you've got a -12-volt system, and your car is a 12-volt; there used to be some 6-volts; most are a 12-volt system. So you pretty well know you're going to be reading somewhere between 12 and 14 volts, or 12 and 15 volts, and that's what your meter is going to tell you. Sure enough, that's the way it works, right?

On these [space systems], typically, the military had gone and paid for 28-volt systems, so I think the Agena was a 28-volt, and the Lunar Module was a 28- to 30-volt system. Well, batteries—again, I'm learning characteristics of these things by talking to people, by looking at a chart that shows what's called a VI curve, or voltage versus current, so the higher the current, the lower the voltage. Well, you look at that and some people just take that and they say, "I'll memorize that."

Sometimes I'll look into it and say, "Well, what's the chemistry? What kind of battery is this? Is it lead-acid battery? Is it something else?" Or what kind of pump is this? There are lots of different kinds of pumps. There're rotating pumps. There're pumps that squeeze things. There're axial-flow pumps, and there're pumps that are—anyway, there's another kind of pump; it's a radial-flow pump. So those kind of things is what I began to learn.

The assignments that you're given [are learning experiences]. If you're given an assignment to do procedures, that [often] involves trying to figure out what is the telemetry supposed to read at this point. How do you know this is on or off? So then you go back into the systems and learn the systems as you're working on procedures and flight rules, especially flight rules, because flight rules say, if this happens, then do this, and then do that, and then do the other thing. The "if this happens," is typically something goes out of limits or something rises to this value, and then you take the next step.

[Aside] Much later on a movie came out called [*The Paper Chase*], it was about first-year Harvard [University] Law [School, Cambridge, Massachusetts]. It was about a kid who came off a farm and went to Harvard, somehow got in there and went to Harvard Law School. There was a scene in it in which there was a classroom exercise, and there was a Professor [Charles W.] Kingsfield, [Jr.] who was in the book [written by John J. Osborne, Jr.], who had a very interesting phrase in it that I thought was very applicable to what Flight Controllers do. In his course he said, "You teach yourselves the law. I teach you to think like a lawyer." A lot of Flight Controller training and exercises are like that, in that effectively these are case studies. They teach you to think like a Flight Controller, but you teach yourself the system in the process of learning to think like a Flight Controller, because a Flight Controller has to look at something; has a short period of time to assess it and make up his mind and make a decision.

All this [focus] was driven partly by critical phases and partly by the fact you have remote sites, and you have very short-duration passes. So if you were at a remote site, you'll get three passes a day, maybe; a six-minute pass, and an eight-minute pass or a ten-minute pass, and maybe a three-minute pass. That's your day, and if whatever happens, you have that period of time to assess it, make up your mind, and do something, or say everything's fine.

If you're back in the Mission Control Center, once we got high-speed data into it, then you have several—however many sites there are, you may have [longer] periods of time. You might go as long as an hour and a half without a site pass, but then you have periods where every rev [revolution] you might get 40-minutes' worth of passes. So that will range, but they're interspersed, because you might go Australia pass, then you get a Hawaii pass, and you get a stateside pass, and then you'll get Johannesburg [South Africa] pass, and then it kind of starts to spread out again.

That was the environment in which we worked [fore earth orbit flight], so again, the Flight Controller has to assess the data, make a decision, do it fast, and execute it if there's anything to execute. Then there's a lot of other things that you do as well. There's an assessment you do afterwards.

In the early days when you had remote sites and no high-speed data, they had teletype data, so the guys at the remote site at the beginning of the pass would push a little button, and that little computer out there would sample all the data, it would format it up, and it would teletype it back [to the MCC]. Then they'd print it out here at the Control Center in the form of a summary message.

So the guys [at the MCC] would cut that out, because you'd set up a format so you had parameter one, two, three, four, five, six, seven, eight, and then you had the values for each. Then at the end of the site [pass] they'd have another cut at the data, so you'd have typically two or maybe three cuts at the data from that site, and they'd be teletyped back. So the [MCC] guys would then have a strip here, and they'd tape it up, and they had another strip and tape it up; another strip and tape it up. And there was time across the top, so after a period of time you'd have several of those, and you could look at trends. You could take those and put them on a plot if you wanted to so you could compare them with something else as well.

Well, anyway, that summary message became kind of a history thing, and soon, they'd got the ability to send a signal from the Mission Control Center to the site that would cause that summary message to be executed, and that would be sent back. Then once they had it back here in electronic form, you could put it on a display driven by the computer, so you could reduce the paper traffic. Those [displays] became history tabs, and they had a thing called a summary message enable keyboard, or SMEK panel. They still kind of call it the same thing. Well, they did as long as had the mainframe [computer environment and Apollo type console], the SMEK panel contained the buttons that you push to cause your history tab to update.

[I think] that kind of answers the question that you were after. Again, you've learned to look at these things, and you mentally calculate rates and things like that. Now, if you're at the remote site, you're seeing this stuff on your meters. Well, they're moving like this [demonstrates], so you have no time sense of rate of change; you have to mentally invent them. You say, "Okay, that's coming down. It's coming down fast," or slow, or something like that, and you had little limit tabs you could show on there, or you hand-calculated it [during site passes]. But you did not have much time.

There were things called PSATs, or predicted site acquisition tables that were generated. They were sent to all the sites to say, okay, here is the azimuth and the elevation where you should be expecting the vehicle to come over. They would point their antennas at that, and then they can track it [the spacecraft]. You could both auto track and manually track, and the tracking had to follow a certain profile. All that stuff was generated by computers at [NASA] Goddard [Space Flight Center, Greenbelt, Maryland] and at MSC, and sent out to the remote sites, and so they could program their antennas for that day's passes and the next day's passes. I wasn't so much involved in that, but I know that went on.

There was a whole bunch of work that went into calibration tapes that went out to the remote sites; programmed their Univac—I think their Univac 1218—computers. All these things changed over time. NASA stayed abreast of the technology at Univac and IBM and Burroughs [Corporation]. Those were the only guys in town at the time.

We had classes given by the training group. We had classes on telemetry, classes on the systems. I didn't mention those; they went along with the books. The classes came a little later, as I remember, or sometimes they were given by in-house [people], within your group. You had a, "Okay, let's go down to Room XYZ, and we're going to have a class on the Agena recorder," or the Agena this or so on. So there was a lot of self-taught, apprentice kind of thing, and people teaching each other and teaching the CapComs and Flight Directors.

There was a Training Group [set] up, and they built the trainers and generated the scenarios that we would sim with. There was a whole sim team. Over time, that was improved. Everything that was going was built [on something that came before]. Mercury was built on the military kind of things, and then Gemini was built on Mercury, and Apollo was built on Gemini, and then the Shuttle was built on Apollo. So the experience [increased], just kept getting more and more, and the technology got better and better. "Better and better" meant faster and faster, is what it really boils down to.

We were in the mainframe era. The bottom first floor of the Mission Control Center, the MOW wing [Mission Operations Wing], the original wing, was where you had all the computers. They drove the screens up on the second and third floors. We were in that mode, I guess, from Gemini through—which would have been about 1966 or '67 through 1995, so it was almost 30 years we were running off mainframes. So we ran the Apollo Program, the Skylab Program, [and part of] the Shuttle Program, off the mainframe environment.

We didn't start to get minicomputer-class machines until the nineties, I believe—no, eighties; it was the eighties, late eighties—and begin to use them. But still the mainframe was the technology that we used; it was a monochrome screen. Now, some of the other tools got a little better. TI [Texas Instruments] finally came out with a hand computer, and so that [kind of technology] gradually supplanted slide rules, because I came with my—still have my slide rule. We used slide rules.

[Aside] The thing about slide rules is slide rules is an approximation, and it's only good to so many digits, depending how you set up your problem up. But that's what [most] Flight Controllers do—they do approximations. Today, since you've got these handheld calculators and it will run things out to ten decimal places, you think you've got that accuracy, and you don't. It's no more accurate than the slide rule, because your input data is not all that accurate. because you can divide numbers and this thing will just calculate it out [to many decimal places], but it's [a false sense of accuracy]. Your accuracy is only about one or two digits past the tenth. When you're running computers and you're running trajectory [computations] and things like that, they can calculate with high precision, but it's not necessarily any more accurate. But they still run the precision out. So people tend to forget that. They tend to look, "Oh, it's accurate, yes. There's eight decimal places. It must be." No, it's not any good out there, and it's meaningless. But a lot of people don't know that, and if you don't grow up that way and you don't get that embedded in your brain, you can mislead yourself and other people.

But anyway, so I was the slide rule generation; used slide rules all the way up until we finally had a calculator out here that I bought. The first one that I saw, really the great one, was HP [Hewlett-Packard], but it was expensive. The HP-35, but it was 190 bucks or 200 bucks, and in those days I'm not going to spend that much money on that. But TI was about 50 or something like that, but it wouldn't do most of the stuff the HP would. Now you can get all that stuff real cheap. Sometimes they give them away. But today's calculators are much better. You can program them, and they're anywhere from 50 to 80 bucks, graphing calculators. But I didn't have those then.

In the trajectory world you need to work with a lot of those sorts of big numbers. In my world it was again mostly the voltages and the currents, and they're just not large numbers. But you're doing projections. If you have leaks, how long is it going to take to run out, and can you make the end of mission.

We did take some field trips. I didn't travel as much as some people did. It was still the taxpayers' money, but I went to Grumman once or twice; Ham [Hamilton] Standard. You could get to see the hardware. I went to the Cape once or twice. Again, if you see and touch the hardware, you get a feel for the actual size of it, the spatial thing. I can tell you the room is an eight-by-ten room or ten-by-six or something like that, but until you're in it, you don't quite get the feel of it.

JOHNSON: What was it like the first time you saw the LM?

KNIGHT: It was impressive. They had one down here, LTA-8, that was in the SESL [Space Environment Simulation Laboratory] Chamber over in Building 32. In fact, that's the one that's over in the Space Center Houston [NASA Johnson Space Center official visitor's center, Houston, Texas]. But, then you get inside it, and this is not very big. In fact, with two crewmen in there, and they've got their space suits, and they've got PLSSs [Portable Life Support Systems] hanging around; there is not a lot of room, and they have to do everything in there. Go to the bathroom; you eat, and you dress; you change what you can. You try to minimize that, but that's what you do. So as I think one astronaut put it, "Fourteen days in the men's room." [This quote may have been from a Gemini flight.]

The Lunar Module was 235 cubic feet in a slightly odd shape, sort of a T-shape. See, that was one of the things I felt I had to know, because volumes matter when you're talking leaks and things of that kind, and how much you've got to repressurize and so on. So some of those things you committed to memory, and they're still there after all these years.

The Command Module was slightly larger than that, and of course, you had the combined volume when they were together, plus the tunnel. The Shuttle, the Shuttle [cabin] is about ten times as big as the Lunar Module. It's about 2,300 cubic feet with the middeck and upper deck, and that matters whether the airlock is in there or not. But again, when I went to the Shuttle, I essentially did the same sort of a thing.

JOHNSON: You mentioned Grumman and going to Grumman and observing what they were doing. I was wondering about that working relationship with Grumman, and you mentioned some of the other contractors, too. How did that relationship work, and as they were designing it, and then your group was trying to write all the systems and the procedures and that sort of thing?

KNIGHT: Well, the flight operations at that time, its influence on the design, in my opinion, was minimal, mostly because most of the guys just didn't have any design experience. But you could say that we think it would be good if you had an instrumentation point here. I remember we had a couple of valves that had three or four positions, and the way they had wired it up, it was a little bit ambiguous, or could give you some ambiguities. I said, "Well, why don't you put the instrumentation on this position instead of that one, and then we could infer certain other things."

So, they said they're okay with doing that as long as the engineering community signed off on it, and engineering said "Well, that's fine with us." So you can influence it that way.

The relations were good. Flight Operations cut a deal with the program saying we would like to have some representatives from the manufacturer of the Command Service Module and the Lunar Module located here, resident at MSC, and having ties back to the plant so they can have the liaison. Because sometimes plant people, Grumman or—they talk to their own people and not necessarily talk to NASA, because there's always this little bit of, not friction exactly, but you've got the evaluator and the evaluee, and sometimes the evaluee doesn't want to share everything with the evaluator necessarily, because, the dirty laundry kind of thing. But they'll talk to their own people and then expect their own people to filter it.

So anyway, we established that. That's where the Grumman guys were from. They were technical representatives of the corporation here. Now, they may or may not have come from Grumman in Long Island [New York]. Sometimes, in fact, they were probably hired locally, because, they didn't necessarily go back to Grumman. Once a program is over, a contract is over, Grumman's got to figure out what to do with these people. , Often they just cut them loose and say why don't you go over to the next program, which, as it turns out, works out quite well.

You have turnover anyway, no matter what, given long enough; because people job shop, even in those days. They do today even more so. So the Grumman contingent, people kind of come and go. Some people would come, and they looked at it a while and says, "Well, this is not for me." In fact, there was one guy who thought this was a dead-end job, and he left, and he missed out on being part of the team that went to the Moon. Now, does he ever have any regrets? I don't know, but maybe he does.

Anyway, so you've got the Grumman guys, and there were North American [Aviation, later North American Rockwell] guys for the CSM, and we were face to face. They were involved in the flight rules and procedures and that works really well, because then ; they can go back to the guys at their plants and, "Hey, I need a drawing *xyz*." And they'd get the drawings quicker. They would make trips back to the plant and get inside information.

So I think that worked extremely well. There were NASA guys and the contractor reps, and then we had the tech reps, the remote site guys, and they were part of the team as well. Just that group of guys, and built a rapport and played together and worked together and were a team together.

Over time when you see the end of a program coming, those guys, like I say, there's always turnover no matter what, but a lot of the guys stayed all the way through. Like Fred [A.] Frere, he was a Grumman guy. He started out at Grumman, and I think he moved with North American, and Rockwell bought out North American at one point, so he was Rockwell, and he stayed on for the Skylab Program. Then he became part of the Shuttle Program; stayed with Shuttle until he retired. So, stayed and just moved from contractor to contractor.

Jim [James F.] Nelson, the same thing. He moved to Martin [Marietta Corporation], but he stayed [in the area]. He got into management. Then I think he left and started a restaurant out in Colorado, but stayed, in contact because he'd come back at the reunions that we have, until he passed away.

So, yes, there were those kind of things that went on. It's probably not uncommon; like in the military will do a similar thing through the various projects or programs, aircraft programs they have.

It certainly happened here, and mainly, as long as the space program was going to stay with Johnson, or Manned Spacecraft Center and then the Johnson Space Center, Marshall, KSC. Since those Centers stay and they keep doing the same thing, well, you're going to have the people. If they like the work, they will stay and they will find whoever the next contractor is, because most of these contracts, their viability depends upon capturing the experience base, unless you're going to something absolutely brand-new that has no relation to what was in the past, then that experience base counts. That's what MSC and JSC have done over the years.

We worked very well with the contractors. You work through them; you work with them; and, of course, having that relationship paves the way if you went up there. In fact, typically, when we went up there, one of them would go, too, because they knew the people, and the ins and outs, and where to go, and can smooth things over.

We did a lot of things on the telecons [teleconferences] as well. I remember sitting there with the malfunction procedures. You have step one, and you have "yes, no." Step three, "yes, no." Step five, "yes, no." We talked that over the phone. I was on the phone, like three hours on the phone, going through these steps, talking with the Grumman guys. So we would do that.

JOHNSON: Along with the systems handbook and the procedures for what would happen if something went wrong, as you were mentioning, what about the design of the actual console where you would be controlling it? Did you work on those designs?

KNIGHT: Yes. The original layout, that is, the sizing, the distance, how far you sat, was a human factors study done by Philco, or Philco Ford I guess it was at the time. They were in charge of the Control Center. They did desktop heights. Of course, your chairs would move up and down, and we're all different sizes, right? I was five-seven, and the other guys are six-four, so nothing is going to be perfect. But the distance here was calculated out with human factors, and the slant, the angle that you were looking at, and how many tubes you could have. Those things were boxed out by Ford.

Then after that, you could have so many rows [of event lights], depending on the size of your console and how big a one you could justify. You had so many rows of event lights, and communications panels, and they had to be within reach.

Now, for me, in the Lunar Module TELCOMs [Telemetry and Communications Officer], TELMUs [Telemetry, Electrical, EVA Mobility Unit Officer] group, there were guys that ranged from my height, which I was probably about the shortest one, up to six-three. So a guy that's six-three has got long arms. The com [communications] panels that are mounted on the same level with the screens, CRT [cathode ray tube] screens, that's fine with him. If I had a choice, I preferred to have it mounted on the turret because it was closer, so when I had a chance to design it—or we could have one of each, that sort of thing, I would request it.

Once you were assigned a console, then your group had to agree on location and size and how many lights and so on, and you had to write requirements for all of that, which we did. We were totally in charge of that. Then the displays' parameters, you had to get everybody to agree on what went where, and you argued a lot about that. And you argued about light color—green, yellow, white, red. But you established some standards, like red was bad.

[Aside] This is interesting. Typically stoplight, red, not good. Green, go. Well, if you happen to be in the power business—and this is an aside—out at Reliant, their control center, red is hot, meaning that you've got voltage there; green means it's open and so that if you're on the ground, you can do work. So, it just depends on what your point of view is. But it makes a difference if you go from one to the other, because, if you go from a place where the culture is red is "stop, do something" to a culture where red is "things are okay," it takes you a while to get oriented, and if you don't get oriented real well, emergency situations can be really bad, because you will revert back to what you used to do.

I'll give you an example of that. I'm hopping up to Shuttle now. We had a period of Shuttle where we had approach and landing tests, and that was where they went out to Edwards [Air Force Base, California] and dropped the Orbiter off the back of a [modified Boeing] 747 [Shuttle Carrier Aircraft], and it went down and landed. We had four or five—five of those. On one of them, Fred [W.] Haise was the commander, and [C.] Gordon Fullerton was the pilot. Well, they separated, and he came down. They were coming down to landing, and for some reason, the vehicle, if you watched, it went like this. [Gestures] That wasn't the right thing for it to do. Well, what happened was in the design of the [Orbiter] vehicle they had arranged the rotational hand controller so if you're sitting here like this and your stick's in the middle, your arm is [at an angle]. So they set the stick up so the pitch was like this along the axis of the arm, which was different from the axis of the vehicle. Then roll was that way, and yaw was by the foot pedals, which is conventional aircraft. But as it turns out, T-38s [Talons] are not like that.

On T-38s and most military aircraft, the axis of this hand controller is along the axis of the vehicle, so this is pitch. [Gestures] Well, whatever happened down there when he was coming down, Fred—who, they fly T-38s a lot—he reverted back to his T-38 thing, so he did this. [Gestures] Well, now he's doing a pitch and a roll. So that translated into the vehicle going like this, because it's a roll and a pitch. [Gestures.] Fullerton says, "Fred, let go of the stick," and when he did, of course, the vehicle just leveled right out and came down. But again, that gets back to [your] culture and what you're used to and reverting to type, or reverting to your embedded training.

So it does matter, and these arguments that we had over light colors and so on, they need to apply, and they need to apply across the whole Control Center. So you eventually move them up and say—although there is variation, a little variation as to what's red and what's green and amber. But usually green means everything's fine. You know, "all green flight," that means everything is fine within limits.

Today, with the new Control Center, we don't have any event lights. It's all color TV monitors, so you can arrange your light colors and you can define them however you want to, but you still follow the same convention. Typically, green is good. But they've now got different colors, because the color maps are different. Some people are colorblind. You did have a few people that are colorblind, so for them sometimes it doesn't matter much. [They might say:] "Not much sense in me arguing about this; I'm colorblind anyway, so I've got to learn patterns." So we had those kinds of discussions.

JOHNSON: How much did the controls and the actual consoles change between Gemini and Apollo? Obviously, you were adding a LM.

KNIGHT: Well, if you look at the Control Center, just a cursory look, you couldn't tell any difference. Just more people in there; a few more people in there, and a few more consoles than you needed on the Gemini. But it was set up for Apollo. Now, the first thing we flew on it was Gemini. You remember, Apollo was approved before Gemini was conceived, so Gemini was a program that came after Apollo started, and it was to acknowledge we need to learn some things about rendezvous and docking, maybe, and long-duration flights, so let's create this new program.

So it was created, and the whole thing was done in four years, Gemini, from scratch. Because the Air Force has got this Titan vehicle, and they [NASA] took typically the design of the Mercury capsule and scaled it up. They said, "McDonnell Douglas go build us one of these for two guys," and they did. Got it all together; got the Titans built—I mean, the Titans, we just had them modified to "man-rate" them. The Agena already existed, and it had the Atlas already. So, stuck it all together and built a plan and executed it. It was amazing, considering what it takes today to do anything.

So essentially the Control Center was built for Apollo, and then we used it for Gemini as the first user. In terms of how it looks, you can't tell much difference. If you are in the game, you can tell a difference between Apollo and Skylab and Shuttle, but it's subtle, and you have to know what you're looking for. The com panels are different in the Shuttle than they were in Apollo and Skylab. They went to [DVIS, Digital Voice Intercommunications System] panels. But that was late.

We started Shuttle out essentially on the Skylab base, and they had removable event light panels so you could have new overlays. They [event lights] were hard-wired in Apollo. But they looked about the same. The CRTs were exactly the same. They were monochrome. They didn't change at all, so what changed was the computational capability behind them, and so the number of displays you could have; and they had plots, character-based plots and things like that, which they didn't have [on Apollo].

So basically what changed was the computational capability, and it became much more robust [after] Apollo, and particularly for Shuttle, and it improved on Skylab, too. But the environment was about the same, the same remote sites and so on.

Once you got into Apollo and got to lunar distances, or at least a fair way from the Earth, you now had much more coverage, because you had the three Deep Space Network sites. The Moon's up here a long ways away, and as the Earth's rotating, one of those sites covers a large portion, and then the next site comes up before this site goes down because of the distance. So you had essentially continuous coverage on the lunar flights, especially for the LM when it's on the surface, there's continuous coverage. The CSM, when it went around the Moon, you had nothing, but when it came back, you did. So there became a difference in the way you handled things or could handle things at lunar distances than when you were in Earth orbit because of the site limitation.

Once the first couple of Shuttle flights took up the TDRSSs, and once you had two of them, then you had almost continuous coverage in Earth orbit. So that's how that evolved.

The evolution of display capability started out on Gemini with meters [at remote sites], and then you had the Control Center. In fact, the first thing they did [at the Control Center] was they put a couple of little meters on those consoles, and then they put pictures of meters on the CRT. That was not a very good use of space, but you could see things move up and down relative to what the range was.

Now, once we went to digital data display, you just see the number, so it's 32-volts for example. Well, that gives you no idea of what the range is or what the expected range, the normal range, or the whole range of the meter. Now you've got to memorize that, if you're a good Flight Controller. So it [display capability] changed; that changed things a little.

So we went from the meters to these CRT monochrome-type displays, mainframe driven, and then the next step up was to the color displays driven by a minicomputer or a PC [personal computer]. So now everybody's got their own [display and computational capability]. They do a lot of sharing, but it's all self-contained, so we have no more mainframe anymore. Sometimes a group has a server, like these trajectory guys have a trajectory server, which does a bunch of comps [computations] and sends it out to all their users. The telemetry guys tend to do their own, within their own computers.

The mainframes hung on until 2002. We first started to get off them in 1995. The work started about ’92 or ’93, and then we had our first flight with the distributed system plus the mainframe in ’95, and then finally got off the last mainframe with trajectory, in 2002, and moved the trajectory mainframe apps [applications] to servers.

So that’s the evolution. I see it as three phases, and we’re in the third phase now and probably will be there for quite some time, because the other thing that hasn’t changed is people are still what they are. Two eyes, two ears, you talk, you’ve got to communicate, so you see things—we read English left to right, top to bottom, typically. So you find that’s the way displays are laid out.

Today, you’ve got a lot of computational tools that will do a lot of the grunt work for you. I used to hand-plot everything. Today you’ve got computers that will plot it for you, and you can expand the range, and you can compress it, and you can do a lot of things with it. You can calculate slopes and you can do a lot of logical—and we do all of that—a lot of logical computations; if this and this and that, or this and that, and if this is greater than such and such, illuminate the light. There’s a lot of that being built in now, and it helps.

The vehicles got more complicated. The Shuttle is a much more complicated vehicle than Apollo was, complicated in the sense it’s got much more variety of things you can do with it, and the systems are triple, and you can use partial this and part of that, and you can power down. Just a lot of “flexibility;” therefore a lot of options that you can execute with them, and that makes the job more complex. The Apollo was built to do a [specific] job, and it did that job very well. Then they expanded it, the system, to do Skylab, and then that was all shut down.

JOHNSON: Well, let's talk about the relationship in the Control Center of the front room with the Staff Support Rooms and the SPAN [Spacecraft Analysis] and the different rooms that supported that.

KNIGHT: The way it started out, the Flight Controllers that I was a part of were essentially just the MOCR guys. They were the NASA guys. It was a NASA project, program, and the support rooms were contractors, generally. It started out being Engineering, MSC Engineering, and then we got into turf battles; who's in charge of what. [Christopher C.] Kraft [Jr.] wanted people that reported to him and were responsible to him and didn't have divided—potentially, as he saw it—divided loyalties. He wrote about this in his book, and Gene [Eugene F. Kranz] wrote about it in his book. Some Mercury incident where he didn't—well, he wanted to have people he could trust.

So he built FOD [Flight Operations Directorate], and then over time, and especially when we had the remote sites guys, when they quit having to go to remote sites and they could all be in the Control Center, they wound up in the SSR. Of course, what the front room or the MOCR guys did is high-level integration. They were focused on higher level integrated kinds of things, so they were responsible for three or four systems.

In the SSRs, you had one guy per system, and they had more detailed knowledge. They had the strip chart recorders back there, and they had a little more room to lay things out and look at them. There were no strip chart recorders in the front room, so there were data sets and data presentations that the front room guys didn't have. They had TV channel [attach and] sometimes where there was a TV [camera] in the back room, [closed-circuit TV], and it could be focused on the strip chart recorder, but that's all you can see, and it's rolling by.

The SSR guys, could keep the documentation up. They could research things while the MOCR guys were working something else. "Hey, go take a look at that while I talk to so-and so-about this," that kind of a thing. Or they could prepare an upload or a flight note or something like that

That became more refined over time. I think the LM guys probably pushed harder, because the Agena was an unmanned vehicle, and it was pretty much run by the NASA guys and the remote site guys. Engineering here in MSC didn't have any role in it.

Now, for the Gemini program, MSC engineering personnel, were in the back room to support the Gemini front room. Over time there were turf battles, this is Engineering's role; that is Flight Control's role. The Grumman guys and the resident folks, we wanted them to have the SSR role. So with that critical mass [of people] here, we pushed to have something that was under Flight Operations' control, lock, stock, and barrel.

In Engineering they liked to be there for the flight, but they didn't have time to be there for the sims. They had other things to do. They were out witnessing tests. They were doing the kind of things they do on certification. They were writing qual [qualification test] plans. But on flight day, they wanted to be there.

Well, we ended up setting up a place they could be; I think it was the Mission Evaluation Room or something like that. I'm a little fuzzy on how that evolved real early on, but that's my recollection. FOD consolidated its position, and it became self-contained in the sense that they provided all the positions that were manned up in the Mission Control Center, and Engineering came over there if requested. People were badged for rooms.

Then the SSRs became the feedstock for the front room, because eventually guys moved on to other jobs or moved up in the chain. Somebody had to replace them. So you started out here, and then you moved up to the MOCR if you could qualify for it. But you had to learn your system and the other systems as well, and be able to communicate with the Flight Director.

A function called SPAN, or Spacecraft Analysis, was set up, and was staffed by management. It was Jim Hannigan and a number of those guys, the Branch Chiefs that weren't in console operations. They were SPAN, and they would interface between the flight control team and the engineering community, because their notion was they didn't want Engineering calling you on the phone in the middle of a critical phase. So that [SPAN] became a buffer, and these were guys that were supposed to be more experienced, and they could filter things out and ask the right questions or formulate the right questions. If somebody in Engineering wanted to know something, could you do this or that, then they would filter that.

So that's how the organization grew, and that's essentially the way it is today. There are good personal relationships between the Flight Controllers and Engineering. Now, there was friction for a while. People, especially when you get to downsizing and people are worried about their jobs. You've got potential RIFs [Reduction in Force]. Well, you tend to protect yourself and protect your database. If you're the only one that knows it, you got picked.

So we had periods of time when you had more friction and less friction. There were periods of time they [the Program] tried to combine it, and then generally they were trying to do a lot of consolidating until 51-L happened. After that the MER [Mission Evaluation Room] became a more rigid thing. But that's in Shuttle.

Apollo, essentially, we got over with in a relatively short period of time, developed a way of operating and operated that way. There was a Program Office rep who usually sat on the back row of the MOCR, up sitting with Kraft or whoever was representing MOD [Mission Operations Directorate]. Sometimes, like Jim [James A.] McDivitt, he had been an astronaut, and so when he was a Program Director, they had a pretty close relation, and those guys would talk over the back of the consoles.

On Apollo 16, after the Lunar Module undocked, and [John W.] Young and [Charles M.] Duke [Jr.] were on it, and [Thomas K.] Mattingly was the Command Module guy, something showed up funny on his service propulsion system, and if it represented a certain failure mode, we couldn't do the flight. So the Lunar Module had to stay in orbit circling the Moon. We didn't have a lot of time. They [FCT] figured out we could power down and get maybe six hours; that was about three revs [revolutions]. In the meantime, the Program Office got with North American and as fast as they could, and asked, "Can we test or do anything with this engine to show that it's okay?" They finally were able to pull that [test] off, and so six hours later they went ahead and landed, and the mission turned out to be very successful.

But, yes, the Program Office and Engineering needs to be there, because you'll have situations like that, and they have the ability to accept the risk, and they may have other data that FOD did not have. We didn't have time to get it all, and they wouldn't give [all of] it to us. They had a lot of off-nominal testing they wouldn't tell you about, because there were conditions associated with it that, if you didn't know, you could make the wrong decision on what to do with the data. That was annoying, because that [also] meant that you'd made rules and procedures and all this, and then these guys come up and tell you, "Oh, no, it's okay to do that." Well, that's annoying. That doesn't lead to good relations.

So over time we tried to find ways to remedy that, to share as much as we could. We said we would not use it [off normal data] but at least be aware of it, so it wouldn't be a surprise. The worst thing you can do in a critical situation is bring up a surprise, because it causes people to lose focus. Their mindsets are off, and now they're asking, "What does this mean?" and so on and so forth, because they're now having to reinterpret things. It just is not a good thing to do. In fact, it's a very dangerous thing to do from time to time.

So they [MER engineering] need to be there. They always had the same [real-time] data we had. It was available data. But the flight controllers operated in a different mode. They were very procedure oriented, very task oriented, keeping track of exactly what's going on with the flight plan; anticipating if this goes wrong, what do we do next. Engineering didn't have to worry about that, and they weren't set up to worry about that, because they were mostly vehicle oriented, and a lot of the timeline stuff is payload oriented, especially on Shuttle but sometimes on the Apollo as well, and the Skylab especially.

So we've had this relationship and made the best of it. In fact, there were times a couple of guys came from Engineering over to MOD, and they did okay, and a lot of MOD guys have gone to either Safety or Engineering and are there, today. For instance, I think Brad Irlbeck is the Subsystem Manager for hydraulics for Shuttle. He started out in MOD. I don't know; he may have moved by now. So there's a number of cases like that. People can operate in both environments.

Another thing is that when FOD started out, the people were hired in as aerospace technologists. When you went into Engineering, you were an aerospace engineer. Both guys went to the same schools, got the same education, same degree, but if you signed up for Engineering, you were an aerospace engineer. If you signed up for FOD or MOD, you were an aerospace technologist. Well, a technologist is [perceived to be] a different type of skill, supposedly, and a technologist was looked at as an operator, that is, you operate or work within certain boundaries, and you don't go outside those boundaries. The engineer supposedly is capable of going outside the boundary. Well, that's a little fuzzy.

If you're a professional engineer, you can sign off on drawings, like for bridges and electrical circuits and so on. Just an ordinary engineer can't. You've got to pass that professional engineer's test to be able to do that. But the way the program looked at things and the way they held people responsible and accountable and the experience that a Subsystem Manager goes through as an engineer of a given system, it makes him or her in the program's eyes more technically capable of making certain risk trade-offs. But even so it's the program that takes the risks, but this guy's the guy they listen to.

Now, I've sometimes found certain Flight Controllers that have been there long enough, longer than guys who are Subsystem Managers, and they frankly know certain systems better than they [the subsystem manager] do, because they've researched the heck out of it, especially things like MDMs [multiplexer/demultiplexer]. They've just been there longer.

[Aside: What an MDM is, it's a chassis with a bunch of circuit boards in it, so, what does the engineer that's responsible for that do? It's a chassis with a bunch of circuit boards. He may not know much more about those in terms of the circuit boards. Now, his experience base has been they did tests over here; they did vibration tests, and this circuit board came loose, and so on and so forth. But internally what's on the circuit board, he doesn't necessarily know any better than what the Flight Controller does, because most of it, it's a program, and the program does certain things in a certain sequence, and that's all it does. It's very regimented. Either it does or it doesn't do it.]

So the Subsystem Manager may know mechanically certain things about it, but he doesn't [necessarily] know internally about how it works with the computer. I observed that a lot, that a lot of the mechanical-type System and Subsystem Managers, like thermal control, like environmental control, APU [auxiliary power unit] hydraulics, they were pretty good on the APU hydraulics, and that's on the Shuttle now. The computer interface with it, they didn't know too much about, and the Flight Controller did, because his job was to integrate it all and have the crew interface associated with it.

Well, we built all that knowledge up over a period of time. Apollo was simple. Its computers were pretty straightforward. They were new at the time. Exactly the same box was on the Lunar Module and on the Command Module, and built by MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts], [Charles Stark] Draper Labs [Laboratory, Inc.], and programmed by those guys. But it was built to do essentially the flight control job. It had nothing to do with any of the other stuff [systems]. They were all mechanical in Apollo.

When you got to Shuttle, they interfaced a lot of these systems through the computer for systems management and things like that, so they did have certain other interfaces, although we still had [switches for] most of it, because most of it is manual. But there were computer interfaces, like the payload bay doors. That was computer-controlled. Now, the crew could go in and they could do it one at a time, but they had an auto sequence, too, they just let it run.

So that was computational power evolved, and other things went along with that. Some things you did because you could and not necessarily that you had to, but you could. Of course, Shuttle design had a goal of that sort of a thing, whereas Apollo had neither the capability—nobody contemplated it at the time, because you just didn't have the technology that was trustworthy enough. So that made it simple. That's why it was very simple.

JOHNSON: When the LM was being designed and it hadn't flown yet and your group was writing these procedures and that sort of thing, how much involvement did the crews that were going to be flying the LM have in those procedures and those handbooks?

KNIGHT: The systems handbook, they had almost no involvement in. We gave them a copy in case they wanted to look at how the system worked from power source to end. But in the procedures they had a lot. Now, in those days the way MSC was organized, Flight Operations was not directly responsible for crew procedures. The actual writing and fabrication and all that was in Flight Crew, as were the timeline builders. So those guys really worked in Flight Crew, but they got with us when you got around to systems operations, because certain things needed to be done in a certain sequential order.

So we worked with them, and the crew had a lot to do with the cockpit layout, because they were the ones who had to execute it, and of course, just physics had a lot to do with it, because you were weight-critical, and you wanted to make it as small as you could get away with, and of course, you'd have to have things within reach.

On the Lunar Module the crew needed to be able to see, because they had to see to land, though it was pretty much automatic down to a certain point, but when you got to the hover point, the crew had to land it, because they had to keep decreasing thrust and so on. We did not have an auto land, fully auto land system. And you had to see to dock, so you had to have a window up here when you were looking up, because your docking tunnel was up here [gesture] on the LM, and the exit tunnel to get out on the surface was down here [gesture].

So it had to handle all of those things, and then the crew, you had the commander and a pilot, and each one of them had certain functions, and so you had to have the controls that their functions did for them where they needed them, where it was appropriate. Like circuit breakers might be over here. You didn't use those very much. Then the controls that you did use, if you had a hand controller or something like that that you used in conjunction with looking, that was in the location for that. There was a telescope so that you could orient the vehicle if you needed to by finding a star and then you could orient a gimbaled platform, an inertial measurement unit.

So, yes, the crew was very much involved, especially in the layout. I'm not sure we were all that involved in the layout of the cockpit. That was pretty much the crew and the designers, and it was driven by the physics; where is the eye point? Where is the guy going to be standing? He's got to be able to see this up, left, right, the degree to which he had to. They didn't want very many windows, because windows were heavy, expensive, and a perceived risk, but the windows might have been the strongest thing there.

You're really at five psi [pounds per square inch], so I think the skin was probably about a thirty-second of an inch, maybe, between that and a sixteenth, so it was pretty thin skin. It looked okay when you looked at it, because it was opaque, but it wasn't very thick. There were cases on the ground where people actually jabbed a hole in the side, and it got patched up.

So, yes, I think the current MOD came about over many years. There was a big reorganization, and I believe it was after Skylab, before Shuttle, in which procedures came over to FOD. There was a period of time when FOD and Flight Crew were in the same organization, and then they split back out again. When that happened, the procedures stayed with MOD. But we [always] worked with the crew and with these procedure writers and so on, to build all the procedures. You basically figured out what the sequence had to be, and then you built the procedures to fit.

JOHNSON: You mentioned procedure writers. Were those separate people that were just doing the actual technical writing?

KNIGHT: By "writing," I mean they were book managers, and by "book manager," it says, okay, how does the crew want this to appear, and we had to use shorthand. There were military checklists that were models for this stuff. They had to be on cardboard, so the fabrication of it was their [book manager] responsibility. Then if there were any symbols and so on, they oversaw that.

We would handwrite with them a proposed checklist, and then they would go format it. If there were any special little—like they'd put a check mark there or something like that, you'd check this; or there were any other symbology, they would take care of all of that. They would go have them verified—"Okay, now, here's the checklist. Let's go down through it step by step," and they'd run it.

They [book managers] adopted a philosophy of run it in the highest fidelity simulator you could find, so the simulator was used, because it was a very high fidelity simulator over in Building 5, and it ran the flight software. For Apollo, they had a mainframe over there, and they had an [software] interpreter in it, and they'd run their real flight software there when they were running simulations.

They [simulator people] would wire up a switch so a computer could drive it, or it could drive certain things to happen. They would try to build simulations that looked like the way the system performed, and then to the extent you could, you would take your procedures and go in there and verify that it worked that way.

Then, [when executing the procedure in the simulator] you'd find out many things. Oh, if I do this, I'm going to bump into that. You could find a place to put—there were little cue cards that you could take out of the checklist and stick over in a place. Still do that today in Shuttle, a lot of Velcro. You learn where to put them; what the timing was if you rearranged procedures.

You had some contingency procedures, the malfunction procedures. They'd try those out, again in the simulator. First of all, you'd do desktop, and then you could try them out in the simulator.

JOHNSON: We've been going a little over an hour and a half, so why don't we take a break.

KNIGHT: Okay.

[pause]

JOHNSON: When we stopped we were talking about those procedures and the different systems procedures and things that you were writing. For Apollo 5, the unmanned mission, that was the first time the LM was launched, and you were in the SSR and for the first time, maybe, having a chance to see how some of those procedures and those rules were going to work. Describe that experience of being, first of all, in the Staff Support Room, and also how it was dealing with a piece of hardware, the LM, that was designed to be flown crewed, but then it was an unmanned mission.

KNIGHT: Well, it wasn't a very long flight, but it was obviously the first flight of the Lunar Module, and so it was real exciting in that sense. I think we had had a slight leak on the ascent oxygen tank, which probably didn't make all that much difference, but it was something that we knew about ahead of time, because it was showing up at the Cape.

So we went and worked out the leak rate, and what if it keeps on going, and is that going to be a big problem and so on. Of course, as a Flight Controller, you keep saying, "What if, what if, what if?" What if in the shake, rattle, and roll of launch it gets worse. They essentially, the Subsystem Managers, said, "No, not a problem. It will be fine," and it was.

But again, we got to see our vehicle. We were the LM Branch, and we got to see our vehicle fly for the first time. You got to see how it performed. You got to see how the cooling system varied and worked. The program reader assembly, and that's what I mentioned earlier, was essentially set up to run the sequence of events that would fire engines, separate the two vehicles, and fire the ascent engine and do some attitude maneuvers, and it did that, except for the descent engine start up, and then it shut down because it didn't pressurize fast enough.

Our GNC [Guidance, Navigation, and Control] guys, our PROP [Propulsion] guys, had predicted, "That's probably going to happen," but Engineering said, "No, it will be fine." Early on we did have some opportunity to adjust the procedures in the PRA. You could adjust the timing, because you had wait times. People apparently argued about that for some time, I heard later. It just turned out they didn't wait as long as they should have for it to come up to thrust. If you're not up to so many percent of thrust by a couple of seconds or however long it was, then it shut down, because something must be wrong with the engine.

Sure enough, it didn't [come up to thrust fast enough], and it shut down, but they went ahead and separated. Everything else, as I recall, worked fine, and that's what we were watching. So it was a relatively short mission, but it was the first one, and we got data to see what it was going to look like. Now, there were probably a lot of other things that happened, or some other things that happened. I just don't have a particularly strong memory of it. But I do remember those things, and I remember the discussions that we had relative to the PRA and trajectory and so on before the launch, and how they went, because I was pretty new in all of this.

JOHNSON: So many of you were young at that point, and the average age was twenty-six, I believe. Also, in the country there were things going on. 1968 when Apollo 6 flew, it was the same day that Martin Luther King was assassinated. So many things, as far as Civil Rights, the Vietnam War and everything, were going on. You were all in that age group of people that were going to the war and fighting. What was your awareness of what was going on?

KNIGHT: I was aware, very much aware, of Vietnam and that there was a draft. I think our numbers came up, but you could get deferments. Somebody, I think, did write a letter to the draft board, saying we were a part of this Apollo Program and that was very important to the national interest and so on and so forth, and could they let me off, and they did.

Now, my draft board was in a small town. My dad had been a lawyer there, and his father had been a lawyer there and had been judge. Whether that had any effect, I don't know. But Granddaddy had long since passed away, and my grandmother was still alive. I don't know whether that had any effect or not, but I got a deferment. But so, yes, I was very much aware of that.

Dad was still in the Air Force. In fact, he went to Vietnam. He was in Personnel at Randolph [AFB], and then he went to Vietnam in '68, I think, because he retired in '69. In fact, he retired August after we landed on the Moon.

Anyway, so, yes, I was aware, and I was paying attention and had opinions like everybody else about what was going on and what should have gone on with Vietnam, and the assassinations. But I was focused on the Apollo Program, and we had those flights. We had Apollo 6 and 7 and 8.

JOHNSON: The flights at that time also originally were scheduled—the LM was going to fly before the mission that was going to go do the lunar orbit, and there were delays on the LM development. How much do you think those delays influenced the decision to fly Apollo 8, or that mission which became Apollo 8, first?

KNIGHT: Well, I was not in that decision chain, but in subsequent readings, there was this intelligence about the Russians getting real close, and there was some threat that they were about to launch something, and the U.S. was interested in not letting them get yet another jump. We were still burned by Sputnik, even though we had done tremendous steps since then. But the Russians apparently had one [a rocket] somewhere on a pad or something like that that some satellite had seen or a U-2 [high-altitude reconnaissance aircraft] or something; I don't know.

But in any case, apparently there was some word that came out. Now, I was not in that loop, so when they said we're going to take 503 to the Moon—the other thing, there used to be a policy about you had to have ten successful launches before you put a man on the vehicle. Well, we've had two Saturn V launches, and the second one, it had the engine shutdowns. So, I thought, "This is pretty sporty, but man, that's going to be really interesting."

There was no Lunar Module on it, so for me it was a spectator sport, and we were still working on the Lunar Module. There were delays, but that was that much more opportunity to train and learn and look at the design and that sort of thing.

You're right; there's a lot of other things going on in the country, and I just sort of watched that and said, "I hope it doesn't screw things up."

JOHNSON: We've heard that famous letter that they received thanking them for saving 1968 because of Apollo 8. So I know you weren't working that mission, but can you share your memories of that experience of seeing that happen?

KNIGHT: Yes. I still get emotional about it. Just the countdown, the launch of it, every time a Saturn V went off, it was mind-boggling, and that was on television. If you were there—one of the guys that I worked with was there, [R.] Terry Neal. He was there for [Apollo] 17, I think, which was the night launch. He said it was like a religious experience, because he was at the VAB [Vehicle Assembly Building], which is a little closer than the regular place. But nevertheless, the acoustic just goes through you, he says.

Anyway, yes, the launch, and then by golly, the translunar injection, and then they went into lunar orbit. Well, you didn't—you know, is this going to work? Because it was an automatic burn, crew-initiated, on the back side of the Moon. There was a story around; I don't know whether it's true or not, that [Frank] Borman didn't want to look at the Moon when they were going around, because if we had miscalculated, you'd just splat, like the [Ranger 4 unmanned lunar probe].

But anyway, they went around, and then you have LOS [Loss of Signal], and then you're waiting and you're waiting and you're waiting, because if they come back early, no burn. If they come back later, good burn. If you don't come back, what happened? But it came back, and it was just great. First, a big sigh of relief, and then "Yes!" Then the pictures and the reading from Genesis. Just very, very emotional.

JOHNSON: And quite an accomplishment.

KNIGHT: Oh yes. Well, once you were there, taking the pictures, yes, but it was very unexpected to me, the readings from Genesis, and on Christmas Eve. Then, of course, you say, "Okay, well, that's good. They're still there." Then they go around the Moon, and they've got a burn coming out, so you're sitting here waiting and waiting and waiting. Come back early, then everything's [good] —and they did. They came back the predicted time for doing the burn, and then you've got the translunar coast thing to do. [Of course, it never crossed my mind at all, but after Apollo 13, you say, "What if?" Of course, if what had happened on 13 happened to them, they'd have been lost, because there was no Lunar Module.] Then, you've got to hit the [entry] corridor right, and because of the plasma, you had the blackout periods, and then you'd always say, "Are they going to come out all right, and are the parachutes going to work?"

So there's always a lot of little wickets you've got to go through before they were safely back on the carrier, but it all worked out real well. Yes, it was just incredible. For me it's still emotional.

JOHNSON: I think for a lot of people it's still very emotional.

KNIGHT: It was risky, but, people say it's worth the risk when it's successful. Now, had it not been successful, there would have been a lot of talk about it, and who knows whether we would have kept going or not. We certainly did after the fire, but that fire happened on the pad and not in orbit.

After Apollo 13 we kept on going, because we'd paid for them, and they were built, and it was in the plan. We didn't miss a beat after 13, hardly. They had the [Edgar M.] Cortright [Review Board] Commission. We [FOD] did some things about documenting, and we did some things with critical event monitoring, so they did some changes to the Control Center software. But we did 14 and 15 and 16 and 17.

JOHNSON: After Apollo 8, for Apollo 9 you moved from the Staff Support Room to the LM TELCOM. Did you expect to move to the front room that quickly?

KNIGHT: I was nervous, because of the guys that were out there, I wasn't sure I'd ever have the nerve to do that, but Don Puddy, again, he was my Group Lead. I guess that he thought a lot of me and the way I behaved and reacted. But he said, "Well, if you don't do it, I'll just send so-and-so out there." I guess I took that as a challenge or something like that, and said, "No, I'll do it." But I was nervous, yes, because, it's like the astronauts that say their thing is, "Please, God, don't let me screw up. Anything, but don't let me screw up." Well, that was the way it was, for me, "Don't let me screw up." So I always intended to be cautious but responsive.

Again, we had a timeline to follow. There's people on it now, and there were guys in the LM and guys in the CSM. Let's see. That was a Saturn V.

We had the launch. Then they [CSM crew] did the turnaround and docking and got the Lunar Module off. There was some of what was called development flight instrumentation on the Lunar Module, DFI, and we had a timeline to crank it up. That timeline we had was tagged to the sites that we were going over. As I remember, we got a little bit behind the clock. But we came over that site, and I was following my site procedure, and I said, "Turn on the DFI," and they [crew] did.

[My] Memory fades, but in any case, when they did, they got a glycol light, and I said we shouldn't have. Of course, the crew reported it, and we saw a master alarm and so on. The Flight [Director] asked, "What's that?" I said, "Well, it looks like EMI [electromagnetic interference], Flight. We just turned on the DFI," and so on. "Don't worry about it," and sure enough, it either was or it sorted itself out later. It may have been a slug of fluid; I'm not real sure. But I don't think so. I think it was EMI when they turned that on.

And then I think Fred [R.] Wentland was my EPS guy. He said something to the effect from the back room, "Why are you turning that on now?" I said, "Well, the timeline says to turn on now." He said, "Well, we got behind the timeline a little bit." "Okay, well, anyway," and so on. So you can get little out of sequence there, and I guess I did, because I was looking for this to happen over this site. So there are little things like that.

I think on that flight George [M.] Low was standing behind me, and he had moved to be the [Apollo] Program Director. He used to be Deputy Center Director, and he was [assigned to be] the Program Director after the fire. He asked some question about which buses were on which batteries or something like that, and I was nonplussed and had to correct myself. I said, "Oh, god, I hope that's not the end of me there." But it wasn't. I survived that.

The flight went fine. They separated. They went flying around out there in earth orbit. In fact, there was something else going on, because I got off shift, and there was some other meeting out here at Ellington that I was supposed to also be a representative at. So I got off shift and went out there to that meeting and did whatever I needed to do or could do, and then I went back home to get some sleep, because I had another shift coming up.

So those are the memories of Apollo 9. After redocking, the crew transferred out, and then they separated, and I think we fired the LM off and burned its descent engine and got it into a very highly elliptical orbit, and it stayed out there for probably a long time, nineteen years or something like that, before it finally had enough drag to drag it down and it splatted down someplace; burned up someplace.

JOHNSON: Well, you'd had a flight now with the LM and with a crew on the LM. After these missions were you modifying those systems handbooks and those rules as you went?

KNIGHT: We did. We modified them as we learned things and as modifications happened. The vehicles were more or less modified throughout the program, especially the Lunar Module, because the extended LM added more tankage and more batteries. Although the basic design was the same; you just added more of it. We added the rover. Added the MESA [modular equipment stowage assembly] for the lunar surface operations.

On Apollo 11, prior to Apollo 11, the vehicle had already been delivered to the Cape, and Neil Armstrong had been doing some work, I guess, in the chamber over there, and he decided he was hot, too hot in that suit, because it was air-cooled when you were in the LM. He said, "It's just getting too hot," and so they made a mod [modification]. Before we launched, they made a mod, and they added a suit loop, a coolant loop, onto the Lunar Module. They modified the vehicle; added a heat exchanger and two water loops that the guys could plug in while they were in their suits getting ready to go down onto this lunar surface.

They made that mod after the vehicle was already delivered to the Cape before we launched. So, some of it wasn't all that unusual.

They also [modified] the hatch, [because] somebody decided that the commander was going to go out first. The hatch originally was designed with the hinges on the commander's side, which meant he would have had to trade places with the pilot so he could go out first. That was deemed to be awkward, so they reversed the hatch and reversed the hinges; put the hinges on the other side and the latch on this side, so that the commander could just [reach down] and open it, and then he could go out. Then the pilot would get on this side, and he would come out.

So, yes, they made changes. Of course, those eventually showed up in the simulators and in the handbook. Whatever other changes were made, we picked them up as soon as we knew it. But I guess there wasn't a huge amount. We generally republished the handbook, because people tended to run off with them.

But there were changes and improvements that were made, and standards that were changed. People would add stuff if they said, "Well, this is more important than we thought. We'll add this." Or if you got a picture of something, you could put it in, or a drawing, to give more information about it. The procedures, of course, were republished and changed as necessary, especially, the guidance and navigation. We'd go into different sites every time, so your cues were going to be different. So the simulators had to be updated and whatever other cues they had were changed.

JOHNSON: For Apollo 10 the LM, this time, went within nine miles of the Moon. Was there anything on that mission that comes to mind as far as anything you'd like to share or your experiences?

KNIGHT: Well, I think again I'm a little—that was [Thomas P.] Stafford and—

JOHNSON: [Eugene A.] Cernan.

KNIGHT: Cernan. There was a story. Who's going to tell Stafford he can't land if he decides he wanted to give that a shot? Well, the story was they didn't put enough fuel in the descent stage, so he couldn't have if he even wanted to. But I don't know if that story is true or not, and there may have been some other reason, too.

But they did the job they were designed to do; separated, demonstrated the separation; going up to the PDI [Powered Descent Initiation] point and then circled around and re-rendezvoused. They staged off the descent stage, and it [ascent stage] oscillated some, and then he went to manual mode, AGS [Abort Guidance System] mode or something like that. That wasn't my area, so I'm not sure whether that happened or not. We did say it happened in one of the articles that I read about it.

But other than that the Lunar Module, as far as I remember, worked just fine, at least my part of it. So that was good.

JOHNSON: Where were you for the Apollo 11 landing?

KNIGHT: I had a shift. I had the EVA shift, which happened right after landing. Don Puddy was the front room guy, the MOCR guy, with Kranz. They did the landing. At the time I was sitting in the back room with my ECS [Environmental Control System] guys, and we shared a SSR with the biomed [biomedical] guys. So, I was not in the MOCR [during the actual landing].

I'm really sorry I missed it, because they did the pre-PDI briefing, or Kranz's talk to his guys. That was on AFD [Assistant Flight Director] conference, and it was never recorded, unfortunately, so all anybody has is whatever their memories say, and I never heard it. But it was one where he supposedly said—he may have had some of it in his book, as best he can reconstruct it. But he said [something to the effect], "We've come here together, and I've got great confidence in you guys. Whatever happens, I'm with you all the way."

Of course, it worked. The LM landed. The whole ECS crew was in the back room with me. I was there; I think Jim Nelson and Fred Frere and me and I've forgotten who else. But as soon as they landed, they [LM crew] had a two-minute drill, because if they hit the abort stage and came back off it [the Moon] in two minutes, you could re-rendezvous. Otherwise you had to wait for the CSM to get back into position, so you were [stuck for] two hours.

So you had that two-minute drill, and we were supposed to check everything. It landed. Of course, there was heat soak back. So the temperature on the descent oxygen went up. They [ECS SSR] reported that to Puddy, and someone said, "It looks okay." And the Grumman guys were in the MER, and they were wondering, "What's this? What does this mean?"

So, it was keep your fingers crossed, and we did, and we stayed. Then I went out and took over for Puddy, and we did the EVA. I was assigned the EVAs for every Apollo flight. Lunar EVAs; I didn't do the EVAs that were on the CSM, but [only during] the lunar stay.

We were [Our MOCR call sign was] still TELCOM then. TELMU came about on Apollo 12, because they created the INCO [Integrated Communications Officer] position and picked up all the comm as an integrated function. There was a CSM INCO, but INCO was created after

Apollo 11, and they gave the comm to them, because so much integration across vehicles and with the ground was required.

There were comm problems with Apollo 11, because Armstrong for some reason wanted to look down when he started his burn. I have no idea why that was, but he did. That meant that he had to now roll back over, so that when you pitched over, he could see down where he was going. If he'd have stayed where he was, he'd have been looking backwards. Well, when you roll back over, the antenna has to track and re-acquire if it doesn't. So Puddy and his back room guy were busy trying to calculate antenna angles if it lost auto track and so on. It probably did, so the data was ratty. But it ended up working out, and they landed, and we all cheered, but with baited breath.

JOHNSON: They had the alarms coming down, too.

KNIGHT: Yes, they had program alarms, and that was because of the landing radar had—I guess the MIT guys had not quite calculated or taken into account the amount of time [required for its routine]. See, the way that the software worked, it had certain jobs to do, and it was given a certain amount of time to do those jobs before it moved on. When it didn't get the job done before it was asked to move on, it gave a program alarm. So they had apparently, prior to that mission, at MIT and Draper, they had worked out all the alarms you might get and which ones were okay, you could accept, because again, I wasn't a software expert, so I don't know how the priorities worked on that.

I don't think they ever flew with the same software more than once. They were always improving it. It was all done at MIT. It was all hand coded, hand compiled, and built using rope core memory. Amazing.

JOHNSON: Amazing. It is amazing.

KNIGHT: And they were always improving. This I will pass on, and I think it's documented, if I can remember it right. It was written by a guy who was one of the programmers up at MIT at the time, and I think it's on a Goddard website, but it's an anecdote. I think the Apollo 11 Lunar Module software was version 99, if I remember this article right. That software had a lot of things in it, among which it had rendezvous radar, landing radar. It also had the commands, throttling commands, to the descent engine. The descent engine was built by TRW [Incorporated], and they had a specification of the response time of that engine, which in control theory is fairly important. Response time is when you send a command, how long before the engine reacts and gives you what you're asking for, because when you're having feedback loops in a computer, it gives it a time delay to wait before you look at the output to see that it's doing what you expect.

So I think the spec [specification], if I remember the article right, was about three-quarters of a second. So the guy at MIT who was responsible for that throttling program, he kept working on it and working on it, and he got it down to where it would react to maybe half of that. He improved it to where it would react to something like half a second or four-tenths or something like that; as long as it will react faster, you're okay. If it can sample faster, you're okay. But if it's too long, it's going to be bad.

Anyway, after the landing, they looked at the data sent back, and the thrust profile had these little humps in it all along the profile. He said, "That doesn't look right. It should be very level." Well, as it turns out, the Draper people called TRW and said, "You know, we've got something funny here. What is your response rate?" [TRW's response] "Oh, we got that down to three-tenths of a second." They [Draper] said, "Well, why didn't you tell us?" Because if they [Draper programmers] had left it the way it was, you would have had such large transients on the thing you'd probably have had to abort the landing. So little things like that; it's just pure luck. Why did the guy keep working on the program? He just did. He had no reason to. Why didn't TRW tell him? That was stupid. They had no knowledge that they should, I guess. Because they weren't responsible for that control link, so, we were lucky there, because the [Draper] guy kept working on it.

I'm attributing all this to this article. I have no personal knowledge of this. But it's an interesting anecdote, and it just goes to show you all the little tiny things, the little details, that have to work right for your whole thing to work right.

So anyway, I was there. I came on at shift afterwards, not knowing any of this. [As a matter of fact, I didn't learn this anecdote until about two years ago when I ran across that article.] But hey, the object, get out there and pick up a rock. They deployed that little camera, and climbed down the ladder, and walked around, set the flag up, took pictures, [collected soil and rocks,] got back up, and they rested a while. Whether they slept, I don't know, but they rested. That was my shift, and then I think Bill [William L.] Peters came on and they did ascent; got back up; transferred over [to the CSM].

We separated the Lunar Module. And either that flight or another flight they were doing some other maneuver, and we wanted to get some data on the behavior of the secondary coolant loop, because in the Lunar Module the primary coolant loop and the secondary coolant loop were slightly different. The secondary coolant loop did not cool the PGNS [Primary Guidance and Navigation System], and we were interested in knowing how long you could go without any cooling. Grumman had a prediction, which turned out to be quite good.

If it wasn't that flight, it was another one where we didn't crash the Lunar Module into the surface, which was done later to get seismic data. But on whichever flight it was, we fired that thing off into the void, and it went into a solar orbit. But in any case, before they got out we had the crew shut off the primary loop and go to the secondary loop; it's a one-way thing. Then that would give us data on how long the PGNS would go, because we left it; we could keep reading the primary guidance computer. As long as it kept saying things were okay, then we knew it was working.

Well, within maybe ten minutes of the time Grumman said it would probably fail, it did. So we learned. We used those opportunities to learn things, off-nominal kinds of things. I forget whether that was on [Apollo] 11 or that was on another flight; it might have been on 12. But anyway, later on they wanted to use the Lunar Module as an impact thing. They used all the S-4Bs later on [for the same thing]. They used those to hit the Moon, so the guys with the seismic devices could measure it. Anyway, and then splashdown.

Now, Gene Kranz says—this is my editorial thing, and he has a very strong point—Gene claimed Apollo 13 was NASA's finest hour. I'm not sure I agree. I think Apollo 11 was NASA's finest hour, because we did everything we said we'd do, and we did it within the time frame [we said we could].

JOHNSON: And it was a success.

KNIGHT: And it was a success, the whole nine yards. Apollo 13 also, to some degree, qualifies, but it was the things you do under duress and the things you do when you have no other choices, and we were lucky that it happened when it did. Had it happened at some other time, we might not have [been successful]. We might not have been able to do it at all if it happened too much earlier or too much later. But certainly if it happened after we had separated the LM from the CSM, we wouldn't have been able to do it, because we'd have been in lunar orbit. And they were afraid to run the SPS [Service Propulsion System], so then you couldn't have gotten out.

JOHNSON: But the two missions were on both spectrum, the complete success and then what you do with a failure to turn it into a success.

KNIGHT: And in some sense, as NASA's finest hour, Apollo 11 was all of NASA. Apollo 13 was mostly MSC and the flight control team and the engineering team. Now, yes, there were a lot of people [involved], but it wasn't part of the aircraft part of NASA.

JOHNSON: Where were you when the accident happened on 13?

KNIGHT: Apollo 13, we were—hey, we'd had Apollo 11. [Apollo] 12 was great. We landed; Pete [Charles] Conrad [Jr.] landed. Then we had the lightning strike, but Conrad landed on the Moon, and there was the Surveyor [unmanned robotic spacecraft] out there. We cut the piece off and brought it back. I mean, it was just great. And Conrad always was funny. He was a great guy.

But so they [FOD management] were saying, "Why are we [continuing to support translunar coast periods when the LM is off]—?" Because the LM guys had stayed on [console] during translunar coast and so on. Why are they there? The LM is off. That [translunar coast period] was really boring, frankly, for the crew, so we decided to go into the LM, and they would do a little bit of stowage or something like that. It was something for the crew to do.

But on the 13 they decided, "Why are we keeping these LM guys here? Except for that time, they can just go home." Well, we had had that entry into the Lunar Module. [Aside] Oh, also, that was not a good free-return trajectory, either, Apollo 13, for the first time. On other flights, if you had not burned [behind the Moon], you'd at least come back heading for the Earth, approximately. Well, on Apollo 13 you'd have come back; but the Earth is over here, and you're heading thataway. Probably would have been captured, but it would have been way off, so it wasn't quite a free-return trajectory.

Well, anyway, after the LM checkout I went downtown to a softball game. We had a softball team, and we played downtown. Played the game, got back in the car, and turned on the radio, and then I hear this "It appears to be something wrong with the CSM." I thought, "Well, the news guy's just making something out of not much." But I got home and I called over to the SSR, and I think I talked to Larry [Lawrence S.] Bourgeois. I said, "Is this serious, or are they just making it up?"

He said, "Well, it's pretty serious."

So I got dressed and came over. There's a whole pile of people there. I asked a couple of questions, and they said, the CSM I think by this time was [powered] off, or nearly off; maybe it wasn't. But I asked, "How long does it take to get back?" Because the LM was set up for two guys, not three, and it didn't have enough lithium hydroxide, especially, to support them for as long as it turned out to be. So I knew that there was enough oxygen; there was going to be enough water. So it became the battery power and lithium hydroxide [as the limiting consumables].

If we couldn't get to the CSM lithium hydroxide, when they found out how long it was going to take, we weren't going to make it. So those were the questions, but again, there were the guys on the console. I think Heselmeyer was on. I think I remember Kranz had gathered up a team. I saw Don Puddy, and I said, "Don, do you think we're going to make it here?" [And how would he know?] But he acted like he did, and he said, "Yeah, we'll make it," which was a real confidence [builder] in your troops.

The FCT had established a rotation. Bill Peters, I believe was taking off to go work with John [W.] Aaron and other people on powering down the LM and other things. Meanwhile, the LM was all we had, so when the crew had started to go into it, again, I'm a little fuzzy. I knew this happened; whether I was exactly there at that time, because like I said, I had come home and then gone over there. So some amount of time had elapsed, and I think there was about a couple of hours from the time that the event had happened and the time they were in the LM. I'm not exactly sure how long it took me to get there. Anyway, I think I went back home, tried to get a little bit of sleep, and then came back to pick up my shift.

The big deal from our [LM TELMU] point of view was that if it's going to take *x* hours to get back, we've got to get this thing powered down, because we can't make it the way it is. The Flight Directors and the guidance and navigation people, they wanted to leave it [the GNC system] on, because they didn't want to lose the platform, and they were afraid to do anything with the service propulsion system, because they didn't know anything about that. So the Lunar Module was all you had.

I believe what they [Flight Directors] did was they decided they wanted to leave it powered up until they got around the Moon and back into sight again and could burn the descent engine. So that's what they did. So this allowed a certain amount of time to go by, and the flight dynamics guys were working feverishly to figure out could they speed this thing up a little bit, and I believe they did. That's why they burned the descent engine, to get back on the right point of direction. Then we'd go into the powerdown.

So we did all of that, and got into powerdown, and then we just watched it. I think they got down to 300 watts or thereabouts as the power level after we got as much stuff off as we could. So after that it was wait and hope that nothing else went wrong.

Other things happened. I think the descent propellant system had a supercritical helium source, and it had a burst disk, and at some point, because we didn't burn that much out of it, that pressure kept building up and building up. They said, "Flight, this burst disk is going to go." It's supposed to be non-propulsive. Well, of course, it wasn't. It made the docked vehicles twist around or get out of attitude or something like that, although it was in a sort of a wobbly rotational thing, because most everything was off. They didn't leave the thrusters on. They just let it rotate and wobble.

Of course, they had to turn that [thrusters] back on to get back into an attitude. Somebody conjured up a procedure by which you say if you look out this window and you see the Moon, and this window and you see the Earth, and this window and you see the sun, you're lined up about right to do something. So people came up with pointing things like that to avoid—because we had lost the platform when we turned it off.

In the meantime John Aaron and his team were working on procedures to get the CSM powered back up, because if we didn't get it powered back up, the crew couldn't survive. So that's what was going on, and me, I was essentially watching the batteries deplete, and the water; they had plenty of water and so on; oxygen, plenty of oxygen. Then the MER or somebody, the crew procedures guys, crew systems guys, anyway, they came up with that procedure to use one of the hoses and make use of the CSM lithium hydroxide. Once you got past that, as long as nothing else bad happened, we had it made, we thought. At least we had a chance.

JOHNSON: Were you aware of any procedures that were in place before Apollo 13 to use the LM as a lifeboat?

KNIGHT: Well, there's been a whole bunch of e-mail on that subject. Bob [Robert D.] Legler, who has passed away now, claims for sure there was, that we had thought about it and that Hannigan had been very much involved in that, because somebody like Bell Corp. or something like that took some kind of credit for that, and Hannigan went ballistic. He said, "That's baloney. We did that." But finding evidence of that, it was difficult. But apparently, he said on Apollo 10 sims, they simulated something like it. I think they [sim guys] did it in a different place [in the trajectory].

But we always knew, yes, we could get the LM powered up. We got it powered up once you got into lunar orbit. The CSM provided power through a little circuit that kept the heaters going, certain heaters that had to be kept going in the Lunar Module. Otherwise, you kept power off. So that little circuit, we ended up using that circuit to provide power back to the CSM [on Apollo 13], and Legler made a big thing about that. But anyway, getting the LM powered up was not a problem.

The trouble [with developing specific procedures] is what are the circumstances, and what do you do? If all you're talking about is getting it powered up, we already had procedures for that. We had procedures for that even if we didn't have that little power source from the CSM. You just had to bring the ascent batteries on first, because they had a direct link [with the battery terminals], and then you could bring the descent batteries, because you had to have another circuit enabled. So we knew how to do that, but all the rest of it depended upon what the circumstances were.

So I think after the flight we went back through and said, "Do we need to have any real solid documented procedures?" I have a vague recollection, although I may be making this up now, that we looked at that, but what you did was very dependent upon what the circumstances were. Yes, you could define an infinite number of circumstances. So what procedures do you want to do? We said, "So what we know how to do is get it powered up, and we can get it up to some minimal power level. Now, what you do after that depends on the circumstances." So you just have to simply be aware.

The Lunar Module could it align itself if it didn't have anything from the CSM. What happened on Apollo 13 was they real quick copied, [the IMU alignment numbers plus other information to use in the LM] because I think nobody was sure they could use the telescope of the Lunar Module in a docked configuration, because it wasn't designed for that, to get stars. So all I'm positive of, is we could not find any documented procedures after Apollo 13, and we didn't have them going in. But I do think we found some sort of scenario, one- or two-pages, that says, "If this, do that," kind of a thing. But nothing that would be real specific documented contingency procedures like we've got for Shuttle.

After Apollo 13, though, we did look at a lot of other things, and so did Engineering, For example, we had pyro [pyrotechnic] batteries. If that didn't work on the lunar surface, we couldn't get off. So do we have procedures for that? What if an ascent engine doesn't start? So, people looked at what you could do, and we did do some thinking about that.

The pyro battery was in the descent stage, and if you looked out the front, the way the thing was built, it had the front hatch opened out on the ladder, which opened out on one of the legs, and then there was a leg back here and a leg over here and then a leg behind. Well, this leg over here [right side], where it was attached to the descent stage was where the pyrotechnic battery was and the wiring that went to those pyro devices that separated it.

Also right in that vicinity was a main bus power, so we had a procedure where the crew could get out, then they'd have to climb down, partly down the ladder, and then climb around on the struts and get to that point and rip off the insulation and go jump [power] across to fire the pyros.

Now, if you were in that situation, you've already thrown the PLSSs out, so all you had was a secondary oxygen pack, and you're going to have to climb around this thing [descent stage]. You had thirty minutes or less, because it's thirty minutes from the time you started blowing it [secondary oxygen pack], so you weren't out of the hatch yet. You had to climb out around and pull this [procedure] off and when you did this, you were going to fire the pyros. One guy was outside, and one was inside, and the pyros would fire.

Now, they [engineering] had determined that this thing [ascent stage] would just go up like that [gesture] and sit back down again, and so then the guy would have to quickly crawl back in, get into the hatch, close it up, and fire off the ascent engine to get off. They didn't have a lot of time. So we built semi-procedures for that scenario, but you'd have time to execute it, because you'd know this isn't working. You'd push the [abort stage] button [for the planned liftoff], and—uh-oh, nothing happened. Then you had to stop and say, "Okay. Oh, Lord," and then you'd go back [and plan and execute the procedure].

Then we had another one [contingency procedure] where on the commander's side right up above and then to his rear, there was a circuit that you could jumper across, and it would fire the ascent engine, bypassing a switch or some other thing. Well, that would have been sporty, because you had this wire in this hand, and you had this other one. This one's hot, and this one is attached to the ascent engine. So as soon as those things touch, that engine fires. Now, if you lose it, the engine quits.

So pulling off something like that, we said, "You know, if we're really going to do this, we ought to be serious about it. What we ought to do is have something [so] we could wrap this wire around something here and have it real solid, and this around something [else], and then have a switch, because you can close that switch and hold it." Fortunately, we never had to do any of that.

But yes, we did work several contingency kinds of things like that, of course, after Apollo 13. And we did it big-time in Shuttle. Shuttle has a ton of those IFM [in-flight maintenance]-type procedures. But again, it's more complicated, and the LM, there were only so many things you could do.

But it was reliable. The LM was reliable. The power wiring was bigger, just because you really didn't know how to do things, really. The thing you compromised on was weight, and so you did everything you could to reduce weight, but there was generally a margin, they did a good job of wiring it up, I'll give them that.

JOHNSON: How do you feel that the movie portrayed the actual experience of Apollo 13?

KNIGHT: *Apollo 13*? The one with Tom Hanks?

JOHNSON: Yes, the more recent one.

KNIGHT: Well, of course, they had a lot of human-interest stuff, talk to the wife and talk to this, that, and the other thing. Then I thought that the little maneuvers they tried to show were overdone, because I don't think they had those kind of accelerations in it. But I cannot say that for sure, and somebody can, because the data is available to say what the accelerations were. Movies tend to exaggerate things for show purposes. So I thought that, from my technical perspective, it was overdone, but from a human-interest perspective maybe it was okay.

JOHNSON: It was dramatized, anyway.

KNIGHT: Dramatized, yes.

JOHNSON: Was there anything significant on Apollo 14 and the missions after that?

KNIGHT: Yes. Apollo 14 I remember, because that one in particular—to be honest, I have forgotten. I did powered descent on one flight, and I've forgotten which one it was. I think I did, anyway, because Glynn S. Lunney was the Flight Director. But anyway, on Apollo 14 we came around; they had separated, gone around the Moon. We had come back—or I guess they had separated—and for some reason or another, the abort stage bit got set, because the Control guy said, "Hey, it looks like this ascent program is running. Why is that?"

I saw a light on my panel, because I had the abort stage light, and it was lit. I thought, "Uh-oh, that's not good," because if it lit off the descent engine, they'd abort stage right then. So I think Bob—[the "Silver Fox." I think you interviewed him] [Robert L.] Carlton. I think he was out there, too, standing by, and he said something like, "Have them [the crew] tap the panel," and then they tapped the panel, and it [the light] went away. Then it came back. I remember remarking or thinking to myself, because I was out there, too, when it happened. I said, "You know, I think what's going to happen—[is that when the ullage maneuver starts, that particle will settle to the bottom of the switch and we won't see it again as long as there is an acceleration on the vehicle]."

This situation was a no-go for PDI. Well, immediately Engineering was on the line with Draper. We did— a one rev wave off. Two hours. In two hours those [Draper] guys sent out a procedure [software patch] to bypass that abort stage switch, and we implemented it, and decided to press ahead. Now, that is undoable today, absolutely. We've got so many people that want to plan these kinds of things. Well, anyway, I suspect they [Draper] had known how to do that in the past, because they had probably thought about those things.

What that did, though, is put you in a little bit of an awkward position, because if you were in powered descent and had to abort, you had to take that thing [patch] out so it [PGNS] would recognize that signal, or you had to do it all manually, which would not have been too good, or would have been sporty.

But anyway, so in one rev, [we had the crew] put that in, started PDI, and just as soon as they did the ullage maneuver, which is what you do to settle the descent propellant, exactly what

I thought would happen, happened, or what I've speculated, and a little ball, if it was, went to the bottom of the switch. The light went off, and everything stayed fine. And it stayed that way throughout the entire lunar stay, and it came back after ascent. When it [ascent stage] got back up into orbit, shut off the ascent engine. A few seconds later, blink, it [the Abort Stage light] comes on again. So that I specifically remember from that particular flight, and I think there was something else, but again I'm a little fuzzy.

After they docked and got things transferred and closed the hatches, closed the LM hatch and the CSM hatch, then they're supposed to depress the tunnel, but didn't, for some reason. Then they said, "Okay, we're going to jettison the LM." Then the next thing is the LM data went away, and somebody [a crewman] said, "Boy, that LM took off like a scalded dog." Then a few seconds later data came back.

In the aftermath of that, they [engineering] determined that what happened was—because I think we didn't figure this out until after they got back on the ground, from the camera, which was a 16-millimeter—is that when they [crew] left the tunnel pressurized and fired those pyros, there was a pressure wave, and that pressure wave bent the LM hatch in. When it bent it in, it didn't quite seal again, and of course, as it separated, all of this LM [cabin] gas comes out, and it [LM ascent stage] went tearing off thataway.

Well, what if it had bent the CSM hatch, because the guys weren't wearing suits. It was a sturdier hatch, the CSM hatch was. I don't know; who knows? The docking probe may have had an effect and attenuated it, or who knows? But anyway, that was interesting. Ever since then they, by golly, made sure they had depressurized that tunnel, and the crew was wearing suits from then on. The suits, they weren't clean; they were dirty, because they had that dust on them, lunar dust.

So that, I particularly remember. I think it was that flight; I guess it could have been [Apollo] 15, but I don't think so from some other things you were saying. But, wow, I remember that.

On one of them—15, maybe it was— we depressed the upper hatch when they had got on the surface, and Scott or somebody stood up and looked around and took pictures from the top there. Then we did the rest of the EVAs. Like I said, I was there for the EVAs.

Apollo 16 was John Young's and Charlie Duke's flight, —but the rover was on 15, 16, and 17, so I did a lot of rover work. Rover was my responsibility. The way they envisioned the rover originally, is it [Rover deployment] was supposed to be automatic, because they had some ground rule that everything that the EVA crew does, they have to be able to do with one hand. So as he backed down the ladder, he [EVA crewman] was supposed to reach over here. Now, he's facing back, so it's on the commander's side. But he's supposed to pull this D-handle, and this thing was supposed to fold out. The rover, it essentially was supposed to fold out and jump off and deploy itself onto the surface. That's the way I characterized it. My thinking at the time—like when we were going through design, was, "That is a recipe for something going wrong." And I said, "The crew's got to be out there. Let them do a manual deploy. It will be just fine." But, the designers argued back and forth.

Finally they did end up agreeing and designed it so it was a manual deploy, so that this thing [Rover cover/carrier] would drop open. Then the crew would get down, and then they would lift the rover off, and then they would let it deploy. Because it was all folded up, and its wheels had to fold out and flop out and so on. But we talked, and so, yes, we to some degree affected the design to make it simpler, and let the crew do this, because you've now left off things that can have something go wrong. It worked fine.

Obviously, they didn't anticipate the dust, because they didn't put enough fenders on it, and they had to make them [fenders] up out of a checklist or something to tape on. You know, those sorts of things.

On [Apollo] 16 I remember, the astronauts got into this—ever since Alan Shepard decided to do his thing—they all wanted to do something a little unusual. So I think Scott did the feather and the hammer, and Charlie Duke decided that he was going to do a backflip. Now, he's out on the surface, and he's got, all of this stuff on and this suit and everything. So the last EVA—either backward or forward, I forget which one it was—anyway, he didn't tell anybody about this.

John said something about, "Now, Charlie, don't do something stupid," or something like that. Anyway, Charlie, he's out here, and he decides to do this backflip, and he doesn't make it all the way over. I'm sitting here watching this thing on the tube, and I thought, "Oh, my." And he landed on the SOP [Secondary Oxygen Pack].

JOHNSON: Oh, no.

KNIGHT: Now, if you know what's in there, there's two bottles of oxygen at 6,000 psi. If they explode on you, it's deadly. I mean, that's the end of you. But they had a lot of margin, fortunately. But he landed on that thing and then bounced on over, and he's on his hands and knees. Fortunately—and I was watching my telemetry, and it looked okay. I said, "Flight, he looks okay, but I'd as soon he didn't do that again."

[M. P.] Pete Frank was the Flight Director, and he said, "Yeah, me, too."

Anyway, I talked to Charlie about it years later, and I asked, "Charlie, how were you feeling about that time?" He said, "I was scared to death." [Laughter]

JOHNSON: And this was jus spur of the moment, he decided, or had he planned it?

KNIGHT: I doubt it was spur of the moment. I suspect that he had planned to do this, and maybe, for all I know, he had tried it someplace on—you know, we had some of these things that will tether you and so on. But I don't know. I didn't ask him that. But it was just—I don't know. I have no idea what was in his mind at the time, other than, "This would be neat."

But anyway, we got him through that, and that one [flight] turned out pretty well. That was it. I believe that was a delayed one, too, because that was the one where the SPS engine was—yes, that was the one we talked about earlier with Mattingly. The SPS engine was bad, so they were six hours late landing.

All of our lunar traverse stuff, that was a separate team. There was a lunar traverse team that worked on that, and they planned all of the stuff. They had a preplan, and then based upon what happened in this one [EVA], they planned the next one, and they'd tell the crew what to do. My responsibility was, is the rover working, is the PLSS working, is the suit working, and is the LM working. The INCO, Ed [Edward I.] Fendell, did a tremendous job with the cameras. Oh, just magnificent. Incredible.

In fact, a lot of that stuff is being used today to figure out what to do for Constellation; maybe how to better design suits and things like that.

Then [Apollo] 17 went [like] clockwork, I think, if I remember right. But it was sad, and it was the last one. But I stayed throughout the entire Apollo Program. Puddy offered, he said, "You ought to come up here and get to work on Skylab."

I said, "Well, I signed up for Apollo," and so I stayed.

JOHNSON: Well, a lot of people were moving on into other areas.

KNIGHT: Yes, people were moving on.

JOHNSON: Did that pose any problems as far as flight control was concerned, as far as getting people in there to work?

KNIGHT: I don't remember us ever having that much of a problem. Me and Bill Peters and Merlin [Walter M.] Merritt and Bob Heselmeyer, and that's all it really took for the front room. Now, the back room, I think most of those guys stayed, also. We picked up one or two. Harry Smith might have left, I guess, and we picked up a guy, Monty Taylor. He had a career in the Navy. He came for a while, and then he left.

But there was turnover. It's just that the program wasn't that long. I mean, it was five, eight, nine years. I'm talking about from when I got there. 1965 to '72, it was done. And they had a follow-on. They had Skylab as a follow on, and some of the guys moved over to Skylab.

I moved into Shuttle, and then they needed a fifth team for Skylab, Don Puddy's team. He did Skylab-1. I think it was [Neil B.] Hutchinson, Chuck [Charles R.] Lewis, and Phil [Philip C.] Shaffer, and they had a fourth team [led by Milt Windler].

Well, anyway, Puddy had done [Skylab-]one, and then he was slated to pick up and create a fifth team so they could have five-team rotation, because it was going to go on so long. So they looked for people that were not on any of the other teams, and so they pulled me back off of Shuttle and asked me to be a Biomed officer, and I said, "Okay, fine." It's close to ECLSS [Environmental Control and Life Support System] type of stuff and suit type of stuff. Bob Heselmeyer was a Biomed officer. John [T.] Cox, Bob [Robert] White, Lou [Louis A.] DeLuca, I think were the five there. Milt [Milton L.] Windler, he was the other Flight Director.

So I came in pretty late. In fact, I think they might have already launched Skylab-1, or maybe it was just before that, because I only had about 90 days, and then I worked sort of supporting on Skylab-1—Conrad's flight, which was Skylab-2. That was a 30-day, 28 days or something like that. Then I was on the console for the remaining time.

I got married during Skylab. They kept extending the flight. You know, I had it set up, and then we ran out of—shifted it two or three times, and then she [fiancee] said no more after that. So I traded off with a guy and went off and got married. Then I came back and worked shifts, picked up shifts again.

JOHNSON: A lot of the people we've talked to have talked about how those hours during Apollo and during those missions and everything affected their home life, so I imagine she was probably tired of waiting for you.

KNIGHT: Yes. Well, from the time I asked her to marry me, see, we'd been going together [for some time]. I bought a house over in Clear Lake; still there. We were in that house, and that was in August, I think, of 1973, and then we were in the house, and I asked her, "Let's get married."

Then we got married in January of ’74, so it was not a lot of time had elapsed there. But that’s another memorable thing about it; it was during the mission.

JOHNSON: Well, since we’ve gotten through Apollo, why don’t we stop for today?

KNIGHT: Okay.

JOHNSON: And then come back and we can talk about your experiences with Skylab and ASTP and that sort of thing.

KNIGHT: Okay.

[End of interview]