ORAL HISTORY TRANSCRIPT

OWEN G. MORRIS
INTERVIEWED BY SUMMER CHICK BERGEN
HOUSTON, TEXAS – 20 MAY 1999

BERGEN: Today is May 20th, 1999. This oral history interview with Owen Morris is being conducted in Houston, Texas, as part of the Johnson Space Center Oral History Project. The interviewers are Summer Chick Bergen, assisted by Sasha Tarrant and Tim Farrell.

We are so delighted that you're allowing us to come speak with you.

MORRIS: My pleasure. My pleasure.

BERGEN: I'd like to start by just asking how you began your interest in aeronautics.

MORRIS: Probably as a result of [Charles A.] Lindbergh's flight across the ocean and the great interest that everyone had in aeronautics for the few years after that. When I was a young boy, I started building model airplanes and I've been interested in aviation and space all my life.

BERGEN: Did that cause you to go a certain direction with your education?

MORRIS: Yes, it sure did. I wanted to do something in aeronautics and I wanted to be an engineer, so I put the two together and became an aeronautical engineer at the time.

BERGEN: You went to several different universities for postgraduate work.

MORRIS: The postgraduate work was mostly in residence at NACA [National Advisory Committee for Aeronautics], Langley Field [Langley Research Center, Hampton, Virginia]. The University of Virginia, Virginia Poly Tech, and the College of William and Mary all offered courses there, which were taught by the research scientists at the Center. That's where most of my graduate work, after the master's degree, most of the graduate work was done there. My master's degree was from the University of Oklahoma.

BERGEN: I noticed you were in the Naval Reserve. With your interest in aeronautics, how did you end up in the Navy?

MORRIS: Well, during the war I was in the Navy, a Naval Reserve officer, and everybody was in one of the armed forces at that time, just about, so I wound up being in the Navy, but I had nothing to do with aeronautics at that time, during that period of time.

BERGEN: How did you end up at Langley Field?

MORRIS: It was an interview at the University of Oklahoma as I was getting ready to graduate, they had an interview session, and I went to that. I had read and heard about NACA for a long period of time and so it was kind of the top of the line, as far as I was concerned, and someplace to go where I could further my education as well as do interesting work. So when they offered me a job, it was very easy to accept.

BERGEN: When you got there, what did you do in your first job?

MORRIS: First job I had was in a very small group of three engineers, two computers. In those days, computers were usually ladies with a calculator that they punched the keys on.

We had two computers and a secretary and we were designing a very large, high-powered supersonic wind tunnel, which was later built and still is running at Langley, as a matter of fact.

BERGEN: Why were you building this wind tunnel?

MORRIS: At that time we had not really broken the sound barrier in flight, in free flight, and there was a big push on supersonic aerodynamics to understand how you design vehicles to operate supersonically. This interest was all over the world. Congress passed a bill sponsoring three wind tunnels for NACA, one at Langley, one at Ames [Research Center, Mountain View, California], and one at Lewis [Research Center (now Glenn Research Center, Cleveland, Ohio].

The one I was working on, of course, was the one at Langley. It was a four-foot-square test section that went from Mach number 1.5 to Mach number 5. It had a drive horsepower of 100,000 horsepower [hp], which at that time was a lot of power and we could only run it from midnight to about six in the morning. During the day, other users of electricity used so much that we couldn't get on the line and operate high power.

BERGEN: Did you actually do some work in that tunnel after you helped—

MORRIS: Yes, I was in charge of the calibration of the tunnel when we initially put it into operation. Then I was a section head of a group of aerodynamacists working on the Century Series fighters that were coming along at that time, and other advanced military programs, as well as the very early workings on the supersonic transport.

BERGEN: After you worked on this wind tunnel, what other projects did you work on at Langley?

MORRIS: I was in the wind tunnel until I transferred over to the Space Task Group [STG] in 1959. I went to work at Langley in 1948. No, it was actually 1960 I transferred to the Space Task Group, which was at that time just starting to think about the Apollo Program. At the time I transferred, John [H.] Glenn [Jr.] had not made the first orbital flight yet. That occurred shortly after I got there. But we were already working on the Apollo Program, thinking about how we could get to the Moon and what was the best way to go at it.

BERGEN: While you were working on the wind tunnel, then Sputnik was launched. What kind of impact did that have on you and the people you worked with at Langley?

MORRIS: Well, we were all very chagrinned, of course, that we weren't the first to get one up. NACA did not really have a real active interest in space up until the Sputnik was launched. We did support work for the military, for the Air Force and Navy both, as well as the Army, but there was very little active activity within NASA itself. Far different than the X Series airplanes when we were trying to first go supersonic, Langley had a very leading role at that time in making the early supersonic flights. The interest in space was much, much less than that.

BERGEN: When the Space Task Group first formed, what did you think about that idea and that direction?

MORRIS: Well, when it was first formed, I thought it probably was just a—for a short period of time it would be a year or two years they would make a flight and then it would be all be over. Of course, it turned out to be a lot more than that. But that was my impression at the time, that it was probably just a transient thing that they formed a special group to go do, and once they did it, then it would probably be disbanded and that would be all of it.

BERGEN: You said in 1960 you joined the Space Task Group.

MORRIS: Yes.

BERGEN: What caused you to join that? Was that a voluntary thing or did someone ask you to?

MORRIS: No, it was voluntary on my part. Project Apollo had been announced at that point in time and the President [John F. Kennedy] had committed the country to make a lunar flight, and I wanted to be a part of that. Also being initially from Oklahoma when I found out the Johnson Space Center was going to be in Houston [Texas], that was getting back closer to home, so I volunteered at that point in time to transfer over.

BERGEN: So did you continue to work at Langley for a period of time?

MORRIS: Yes. We moved down here in 1961, among the first people that came down to form the Center here. But between the time I transferred and the time we moved, I worked in the task group there at Langley.

BERGEN: When you first came to be part of the Space Task Group, what were your responsibilities?

MORRIS: I was, again, a part of a relatively small group at that time that was starting as the project office for the Apollo Program. There were not too many of us and a lot to do, so we didn't really have very much of a formal organization. Everybody just pitched in and did whatever was needed. One interesting thing I did was to make a cost estimate for the entire Apollo Program before we even knew how we were going to get to the Moon. We had a period of about a day and a half to get the final answer and get it back up to Congress.

BERGEN: How did you go about estimating something like that that had never been—

MORRIS: We just started thinking about—two of us did most of that work for the day and a half. We just starting thinking about the kind of things that you would do, about how many people would it take, about how much would it cost to design and build the kind of hardware. They were just wild guesses at the time, obviously, because we didn't even know what hardware we had to build. We knew we had to build a great big rocket, but as far as the spacecraft goes, we didn't really know how we were going. So we took the experience from Mercury and a little bit of Gemini that had gone on at that time and went away from that and developed what we thought might be a reasonable estimate for the cost.

BERGEN: Did it turn out to be close?

MORRIS: No. [Laughter] No, it wound up costing a lot more than we thought at that time.

BERGEN: It's not surprising, there was so little known at that time.

MORRIS: Yes, and we didn't spend very much time on it, because we had to get an answer back out for congressional committee, so we just did it. But that was kind of one of the interesting things we did at that time. Looking back on it, it looks pretty darn foolish for two people to go try to do that.

BERGEN: It was a start.

MORRIS: It was a start, and that was typical of the program office at that time, where everybody just pitched in and did whatever was needed to be done at that point in time.

BERGEN: That's great. What are some other things that you did?

MORRIS: We laid out a tentative flight program. We were using the direct ascent as the model at that point in time of the way to go to the Moon, and we laid out what we thought would be a flight program that would lead up to the lunar landing. Interestingly enough, at that point in time our program ended with one landing. We made one landing and came home and the program was over, as far as our flight program went. Of course, it turned out to be a lot more than that at the end of the day.

In laying that program out, we were a lot more conservative than it turned out later on we really had to be, so we got a lot more flights to build up the experience to go to the Moon than we actually took in the real world later on.

BERGEN: If you were working on Apollo during this early period, were you confident that we'd be able to make it to the Moon by the end of the decade as the President had announced?

MORRIS: Well, definitely in time. Of course, it was very early in the decade, so you know, ten years was a long time to me at that point in my life. [Laughter] Yes, I thought if it could be done, it could be done in ten years. The real question was, could it be done reasonably. As with a lot of research, you just don't know until you go try it and see, see how it turns out. So we were optimistic and we thought it was worth giving it a real try, but we weren't really confident. As in most research kinds of programs, you're not really confident of the outcome. If you knew what the outcome was going to be, it wouldn't be research.

BERGEN: That's true. Are there any other things? I know you eventually became Chief of Reliability and Quality Assurance. Were there any other things you did before that?

MORRIS: Well, when we first moved down to Houston, one of the things that we decided for sure we wanted to do was to test the launch escape system and the parachute recovery system very carefully, and to do that, we needed another launch vehicle. So I was in, again, another small group of a couple of guys, three guys, I guess, at that time that put the Little Joe II launch vehicle under contract. Again, typical of the rapidity with which you could do things at that point in time, we wrote the specification, got bids, evaluated the bids, and made a contract award in less than a month for that. Now that would probably take two years to do.

BERGEN: Did you participate in the launches?

MORRIS: Yes, I worked on both the Little Joe II launch vehicle and I was also head of operations for the Command Module part, the spacecraft part of that test program. I was mission director at White Sands [Proving Ground, New Mexico] for a couple of the early launches, before I became head of reliability.

BERGEN: Did you do all the things simultaneously or were they at different points?

MORRIS: They were more or less simultaneously. The Little Joe II, the Command Module [CM] that was going on top of it, and the operations force at White Sands that we had to build up. We had no people out there, so we had to start hiring people from scratch to get a work force out there. All that had to be done essentially simultaneously, yes.

BERGEN: Did you spend a lot of time at White Sands?

MORRIS: Yes, for a year I was there almost every week. At least three weeks out of every month I was there. I would be back in Houston either usually on a Friday or a Monday to tie things together here, and then back out to White Sands for the rest of the week.

BERGEN: Are there any of those test episodes or anything that stand out in your mind from that period?

MORRIS: Well, the most famous one, I think, was the first guided flight of the Little Joe II launch vehicle. I was not there for that one. I had gone over to reliability at that time and I was actually at Grumman [Aircraft Engineering Corporation], designing and building the Lunar Module [LM]. We were patched in by telephone to the people at White Sands so we heard what was going on for that flight. That particular flight we had one of the control fans lock hard over just right after liftoff, and so the thing started spinning, and it finally spun up to the point that the big solid rocket motors came out of the side of the case. It made for a pretty exciting event. [Laughter] I can still remember the commentator that was on the telephone saying, "It's liftoff. The vehicle is rolling, it's rolling, it's rolling, it's rolling. It blew up!" [Laughter] That's all we heard at the other end of the line.

BERGEN: The Little Joe tests were successful in the long run?

MORRIS: Yes, that was the only major anomaly we had in that whole program, actually. The people that did that, it was mostly other people, because I left to go to reliability fairly early. But the people that did that did a very, very good job.

BERGEN: You went to reliability at around 1964?

MORRIS: Sometime around there, yes. I've forgotten exactly when.

BERGEN: In the Apollo Program, what was the roles and responsibilities of reliability and quality assurance?

MORRIS: Well, at that time the Center did not have a reliability organization. There was no formal reliability program, and the program manager, Dr. [Joseph F.] Shea, felt that we really needed one. Since the Center did not have a resource we could draw on in that field, we created it within the Apollo office. Another fellow, Bill [William M.] Bland [Jr.], started the reliability effort within the program office and then he moved over to head of Test Operations, I think, anyway, another job, and I stepped in and took the reliability program and built it up for the whole Apollo Program. Later, that whole organization was transferred over to the Center and it became a Center resource rather than just one program office.

BERGEN: So as chief of this organization within the Apollo Program, what were your objectives as far as assuring reliability and quality assurance?

MORRIS: Well, we had numerical objectives and we did not want any single failure to represent more than one chance in a million of causing failure. Now, there were a lot of different failure modes, so you added them all up and it was a lot more difficult than that. But we would go in and analyze each of the vehicle systems, each of the electrical circuits, look for different failure modes, look for the likelihood based on part reliability or whatever other information we could get as to what the likelihood of that failure would be. If it was high, then we would offer suggestions for a redesign to make the system redundant, add more high-reliability parts, or whatever it took to make the system more reliable.

When we ran the numbers and looked at the probability of getting all of that vehicle, including the launch vehicle, the Marshall [Space Flight Center, Huntsville, Alabama] people were doing the launch vehicle work at the same time we were doing the spacecraft work. When we put it all together and ran the numbers, we found that we had, according to the calculations, about a 7 percent chance of getting there and getting back. It was not very high at all.

So we immediately, of course, started looking for ways that we could improve that. The big thing we did was establish a program to very, very carefully look at each failure of the hardware in test or in operation, wherever it occurred, and determine the cause of that failure and then fix it, put something in so that that failure wouldn't occur again or had a very, very low probability of occurring again.

I think that was one of the real hallmarks of the Apollo Program, was the attention that was paid by everybody to detail, to look at each and every piece of hardware, to look at each and every failure and to make sure that we were doing things which would improve the program, improve the reliability. Some of the failure investigations were really extensive. We might have one failure and maybe have a hundred people working on it for two or three months to track down exactly what caused that to happen and how can I prevent that from happening in the future.

BERGEN: Were there any particular situations that stand out to you?

MORRIS: Well, there were a lot of them. I was the co-chairman of a safety group that had both the Houston people and the Marshall people on it, a Dr. [Joachim P.] Kuettner, from Marshall. He was one of the original German scientists that came over with [Wernher] von Braun that was in charge of their operation on reliability, so we worked together for quite a while. We would, of course, look at the launch vehicle and look at all the problems that we could see in the launch vehicle and make them go fix those. They would look at the spacecraft and look at all the bad things in the spacecraft and make us go fix those. We used to have a lot of fun doing that, and I think it really helped the program a lot to have that kind of friendly competition. And it was friendly competition.

There were just any number of failures. I guess one of the biggest ones that I can remember occurred just before Apollo 11. It was about two, three months before Apollo 11. I was chief engineer on the Lunar Module at the time and all of a sudden the cooling system, which was a glycol loop, much like a radiator cooling system in a car, all of a sudden started developing crystals within the liquid that we had never seen before. These crystals would get on the filters and would start clogging the filters up, and we couldn't find out where that was coming from. It never happened before, and we had been all the way through Apollo 10, all the flights leading up to and including Apollo 10 and never seen it.

We had people from all over the country analyzing that fluid, looking at what was in it, looking at the crystals, breaking the crystals down to determine what they were, and it was glycol primarily. We just couldn't figure out why all of a sudden this started happening. Where was the problem? We would drain the system down, flush it very carefully, refill it, and within a period of a week all of a sudden we were getting crystals again. That repeated three or four times.

Finally, we found that there was a company in New York that supplied the glycol to Grumman to put in the Lunar Module and, without telling us, they had found out that this glycol was going to the Moon, it was part of the Apollo Program and it was going to the Moon, and they had historically mixed in a chemical with the glycol that helped prevent rust in automobiles and, of course, our parts were all stainless or aluminum so they didn't have that problem. So they said, "Well, we will give the Apollo Program pure glycol." So they quit adding that particular component into the coolant, and that was what caused the crystals to grow. As long as that component was in there, there were no crystals. When you took the component out and make it pure stuff, all of a sudden we grew crystals like crazy.

So we went back and said, "Hey, give us some of that old stuff." [Laughter] And it worked fine. It worked all the rest of the program just fine. But it was kind of typical of the sort of thing you went through to track down a problem, find a solution, and then fix it.

BERGEN: In your role in reliability and quality assurance, did you work really close with the contractors for the manned Lunar Module?

MORRIS: Yes, the reliability program, the part I was responsible for was the total spacecraft, so it was the Command Service Module [CSM], the Lunar Module and all the subcontractors were both North American [Aviation, Inc.] and Grumman. We had pretty large crews at both Downey [California] and Long Island, Bethpage [New York], working on reliability. We worked together, I think, quite well and quite effectively.

BERGEN: Shortly after you left reliability and quality assurance, Apollo 1 fire occurred.

MORRIS: Yes.

BERGEN: Would you share with us your memories of that event and how it affected you and the people?

MORRIS: We were all devastated, obviously. When it occurred, I was having dinner out at a restaurant with another fellow from the program office who was a duty officer at that time. In the middle of the dinner, he got a call, as the duty officer, and was told that there had been an accident down there. He didn't have all the details at that time. We had both driven separately, and so our wives took one car and went home, and we went into the Center. I guess we were there all night long, as a matter of fact, trying to understand what had happened and how it could have happened, why and how this could have happened to us.

I was not really a part of the long-term effort to determine the cause of the fire. I'd left reliability and I was working on the Lunar Module. I kept fairly close tabs on it, because everything they found in the Command Module and then we would go look at the Lunar Module and could we have that same kind of a problem in the Lunar Module, and in most cases, yes, we could. The problem could have occurred in the Lunar Module had it been a little bit further along in the development cycle at that point in time. So we had a lot of redesign in the Lunar Module, just like the Command Module and the service module had.

We were devastated by the loss of the crew, by the setback in the program. There was a change, I think, in the attitude of the people as a result of that, to give much, much more emphasis on crew safety and mission reliability than we had given in the past, and that went all the way down through the subcontractors. It wasn't just the prime contractors; it was all the way down through the subs [subcontractors].

BERGEN: So by this time you were chief of the Lunar Module Project Engineering Division.

MORRIS: Yes.

BERGEN: Where was the Lunar Module in development when you came in?

MORRIS: Well, I was very fortunate. On the Lunar Module Program I was able to see the whole program. I helped write the specification for the Lunar Module and worked on it off and on, well, all the way through its development, and helped close the contract out after Apollo was over. So I got to see that whole program from beginning to end. I was very fortunate in that regard.

BERGEN: Did you have any involvement in the decision of what method would be used to get to the Moon in deciding on Lunar Orbit Rendezvous [LOR]?

MORRIS: Yes. Another one of the jobs I had during the time—as I said before, we all just kind of pitched in and did whatever was needed. One of the jobs I had was being head of an organization called Mission Engineering. Mission Engineering was set up to basically look at the different ways to get to the Moon and decide which way should we conduct the mission, what was the most likely way, the best way, the optimum way, of conducting the mission.

I worked with and had a group of probably 15 civil servants and 300 or so contract people, both Grumman and Rockwell[1], Rockwell primarily at that point in time. We looked at all the different methods. It wasn't just us doing it; it was being done at Marshall, it was being done at [NASA] headquarters [Washington, DC]. Bell Labs, that was supporting headquarters, had a lot to do with that at that point in time. But we were contributing out of our organization. Of course, it finally wound up the Lunar Orbit Rendezvous was the best way to go.

[1] North American Aviation, Inc. became North American Rockwell Corporation in 1967.

BERGEN: What did you think when you first heard about the concept of Lunar Orbit Rendezvous?

MORRIS: I heard about that at Langley, actually, before I left, like just right after Apollo was formed. John [C.] Houbolt, one of the Langley scientists, had come up with the idea of, just by looking at the mass fractions, how much weight you had to carry how far, and determined that in his view the Lunar Orbit Rendezvous was the cheapest, lowest mass way to go. Generally, cost is proportional to mass, so if you make something lighter, smaller and lighter, it's usually cheaper, too.

The first Lunar Module that he thought of looked very much like a motorcycle. There's a guy in a spacesuit with some controls in his hands, and instead of wheels you had propellant tanks in front of him and behind him, a rocket engine right under his seat, and very rudimentary things. But that was his first idea. I thought that was pretty crazy at the time. [Laughter] Then as we worked on it, it got a little bit more sophisticated and a little bit more sophisticated and started looking like it really had a pretty good chance.

Also at that time, I was not part of it, but the Gemini Program was leading into the Earth orbital rendezvous exercises to demonstrate rendezvous techniques and docking. That looked pretty reasonable. Of course, as it turned out, when Gemini actually flew the missions, it was quite successful.

So after it was looked at in detail, it didn't seem too wild to me. A whole lot better than the idea of making a direct approach where you had to land everything on the Moon that it took to get back home. That would have just a terribly hard thing to do. The Earth orbital rendezvous didn't really save that much in terms of the total complexity and cost of the systems, so Lunar Orbit Rendezvous looked like, by far, the best thing to do.

BERGEN: Do you think if one of other team methods had been chosen, either direct ascent or Earth Orbit Rendezvous [EOR], that we would made it to the Moon before the end of the decade?

MORRIS: I seriously doubt—well, I think we would have made it. I think it would have been very difficult to make it before the end of the decade. I doubt seriously we would have hit the time scale, because it took a rocket, first stage, that was about five times the size of the Saturn V first stage. You've seen that thing out there, the size of that monster. At that point in time, this was 1962 and '63, we were working on that decision, they just had some back-of-the-envelope pencil sketches of what that great big rocket might look like. They hadn't built the engines, and it would have been extremely difficult to get that stage and get it working and get it reliable enough to use. The spacecraft would have been much more complex than the ones that we finally wound up with. So I think it would have been very difficult to hit the ten-year time period.

Now, at the time we thought we could. That was not a driver in the decision. At the time we thought that, yes, we could make it with any one of the three and make it by the end of the decade. We felt the Lunar Orbit Rendezvous was likely to be earlier and the probability of success was quite a bit higher. When I say that, that's the way we felt here. The Marshall people were for direct ascent, and there was a lot of contention going on by the big bosses to get that one settled.

BERGEN: So after that decision was made, we began working on the Lunar Module. You said you helped in developing the specifications for it.

MORRIS: Yes.

BERGEN: Could you take us through that process?

MORRIS: Well, in the course of deciding what mode we were going to use, we had fairly well determined that what we thought at that time the Lunar Module had to do, how big it had to be, what kind of propulsion it had to have. Well, in terms of size of the propulsion, there was a big debate there for a while there, whether it would be solid or liquid propellant. But the size of it we knew.

So the specification was not written in the way that it said, "We want you to build this design and build this Lunar Module that looks like this, that's this big." We said we want to land two people on the Moon out of lunar orbit, about fifty-mile altitude lunar orbit and get them down to the ground, keep them there for—I think the original specification was twenty-four hours, and then return them back to the Command Module, and left the design of the thing pretty much up to the contractor, the proposer, to come up with. We had nine proposals, as I remember, for the Lunar Module and they all were grossly different. They were not alike at all. We spent what was a long time then, we spent like three or four months evaluating those proposals and making the decision that finally wound up with Grumman being selected to build the thing.

BERGEN: How many of those original proposals did you feel were even feasible?

MORRIS: Probably seven out of the nine. Actually, the final Lunar Module contained many of the ideas that were in some of the other proposals. Another thing I think that denotes the spirit of the Apollo Program, a couple of the proposers, when they submitted their proposals, said, "If we are not selected, we hope the government will find things in our proposal that will help the final design of whoever is selected, and you're free to use it any way you want." That was just unheard of. That just did not happen that way. But, again, it's kind of typical of the support all across the country to the Apollo Program. It made our job very, very much easier with that kind of support.

BERGEN: That's great. So Grumman was finally chosen.

MORRIS: Yes.

BERGEN: Was that a unanimous decision?

MORRIS: Well, in the selection process, that's hard to find out. You start out working with a bunch of committees down at a low level looking at the nine proposals in one small specific area and you rate them. Then another group comes in and looks at all of the committee actions and puts it together and they then say, "We think this one is superior in this regard, this one is superior in that regard." Then it goes to a selection committee, and the selection committee takes those recommendations and comes up and ranks then not all the proposals, but usually the top three or four. I think it was three on the Lunar Module, if I remember right.

They rank them and send them over then to the selection official, who was the NASA administrator, and he makes the final decision. So how much better Grumman was than any other proposer, again, if you ask ten different people that worked on different parts of that selection process, you'd probably get ten different answers, because it depends on what part they were looking at. But as I said, I think from what I saw of them, at least seven out of the nine could have been picked and it then would have worked.

BERGEN: The Lunar Module was so different from anything that had really been developed at this time. What were some of the challenges from that perspective of making it successful?

MORRIS: Part of my challenge was that I, of course, had spent the time after I got out of college working on aerodynamics and the Lunar Module never saw the atmosphere to be flying. It just sat around only at the Cape [Canaveral, Florida renamed Kennedy Space Center (KSC)] and at the factory, but it wasn't flying. When it flew, it flew in perfect vacuum. So I had to forget all about aerodynamics. [Laughter] I'd been used to thinking in terms of streamline shapes and how you really make something that is the most efficient aerodynamically, and the Lunar Module just didn't care. So it wound up being what a lot of people thought was a fairly ugly vehicle, but it was designed to perform out of the atmosphere in the most efficient manner that you could. All you had to do was just put the stuff together and you didn't care what it looked like, as long as it was efficient. But a lot of the designers had to change their way of thinking a bit.

Another big problem that we faced all the way through the Lunar Module program was weight. The original specification weight turned out to be quite low, very low, much lower than we could have gone. There was still some flexibility in the launch vehicle and in the service module propulsion, and the program increased those so that we could accommodate a heavier Lunar Module and still get up there and get back. But every time they would give us a little slack, the Lunar Module would grow in weight, so we had two great big weight reduction programs trying—not trying, we had to get the weight down. Just no question about it, we had to get the weight down.

We spent a very large amount of effort in that regard. Much more so than if you're designing an airplane and you're designing it to fly 5,000 miles, if it winds up flying 4,600 miles, it's still a pretty useful airplane. But if you design a Lunar Module that will get down to the Moon and get nine-tenths of the way back, it's not a very good thing at all. [Laughter] So you have to make sure that you can, in fact, do the total specified performance capability. That was a little bit different way of looking at it, things that most designers in their past careers had done.

BERGEN: You mentioned that it was so different that people had to think differently to make it work successfully. What were maybe two or three of the things that came out of that different thought process as parts of the Lunar Module?

MORRIS: Well, there were, of course, just an awful lot of them. I was trying to think of what might be—one of the things that I remember turned out to not be as big a problem as we thought it was going to be, and that was the landing radar. It was a radar that looked down at the lunar surface as the vehicle got about 100,000 feet and started down from about 100,000 feet. It would give you your altitude and your altitude rate, the rate at which you were going down.

Of course, at that same time the descent engine was firing and the radar had to look right through descent engine plume. That plume was known to attenuate the radar signal grossly, and there was no way we could move the antenna out far enough to get out of that plume, so we put some baffles in, and did not have any real good way to test it. If you test it here on Earth, the atmospheric pressure makes the plume a much more confined geometric shape than it is in vacuum. Until Apollo 9, we really couldn't test it very well. We were quite worried about that thing and worried about it all the way through Apollo 9. Apollo 9 fired it up, and, of course, it didn't have a lunar landscape to look at, but it was able to pick up the Command Module and then give a closer rate on the Command Module in a very short test that we did there.

Then, of course, Apollo 10, which got down to about 50,000 feet, as I remember, from the surface, got a good look at that landing radar. It was supposed to start coming in at about 100,000 feet and it locked on at, I think, about 120, so it was really a little bit better than spec, even.

Another thing that was quite different was the crew station. Instead of putting the crew in seats, the crew was standing up when they were flying the Lunar Module. They couldn't just stand there, because they would float around the cabin, so we had to have some restraints that would come up and clip onto their belt and hold their feet down on the floor so they could operate the controls and have something to react against. It took a little bit of time to work that out and get that satisfactory. Those were two of the things.

The guidance system, I guess, was probably one of the big technical areas where we were doing things differently. In the Lunar Module we decided to have both an analog guidance and a digital guidance and then compare the two. That was the first time that that had been done on a flight vehicle. Again, it increases reliability to have two different approaches to get the same answer. If you go at it with the same approach two times, if you made a fundamental mistake in that approach, then both of them are going to give you the wrong answer. If you go at it two different ways, then very likely you'll not have the same fundamental error in both those programs because you started out from different places. On the other hand, it's much more difficult to compare going through the navigation process to compare the two, because they are coming from different places. Until you get the final answer, it's much more difficult to compare. That took a lot of work to make that thing, that process go, and it functioned quite well all the way through the flight program.

BERGEN: It's amazing to me, in our age of computers and technology, that we got to the Moon with as little advancement in those areas as we had at the time.

MORRIS: Well, there were great big advancements, but compared to what we have today, they were very, very archaic. If I remember right, the Lunar Module digital computer had a random access memory of like 32,000 bits. Now, you can go down and buy one to put on your desk at work or at home, and instead of 32,000 you're usually talking about maybe 10, 20, 30 megabytes of data, millions. Programming those computers was very difficult because of their limited capability. You really thought a long time before you put something new in that program, because that was just like weight on the Lunar Module, you only had so much memory in the computer and that's all you had.

Another decision you had to make was how far up the state of the art did you want to go to get the hardware you were going to use. If you got the very, very latest state of the art, it was not very reliable, because it hadn't been used. People hadn't been using it. So your chances of running into a hardware problem were much greater. On the other hand, if you took something that people knew a lot about, it was much less capable because it was two or three generations back in the process. Same thing is going on today. We were forced to go fairly far out in the direction of what can be done, not what's the most reliable and then make sure we did the things to make that reliable before we actually flew it.

The Shuttle, on the other hand, took a different approach, and they basically said, "We will use proven equipment." Their first computers were not state of the art; they were well-seasoned kinds of pieces of hardware that were quite reliable and people felt very comfortable with them. But again, they were very restricted on their capability compared to the state of the art. Of course, since then they have upgraded those computers and they've gone a couple of generations later in the technology.

BERGEN: You mentioned earlier some testing that you did on the Lunar Modules. Can you share with us a few of your memories of the testing that went through to prove the Lunar Module?

MORRIS: Well, let me go back to the Command Module. When I was in reliability, it's kind of an anecdote, one of the first times I went to North American or Rockwell—North American at that time—they were just getting ready to make a drop of a Command Module into a water tank to show how it operated dynamically when it hit the water and then how it floated after it got in the water. I was with the guy who was head of reliability for North American, and he said, "Hey, we're having a test out here, let's go take a look and watch it."

"Sure."

So we went out. The test went off just as planned. The thing hit the water, and it cracked a seam all the way across the bottom and it just went glub, glub, glub, glub, glub, right down to the bottom. [Laughter] Here this guy, I just met him, and he wanted to impress me with their test capability, and it was a total failure. It turned out that was a fairly easy problem to fix. They had a bad weld schedule and they found it, and that was easy to fix, but it was quite embarrassing for him.

The Lunar Module, like the Command Module, Lunar Module had a lot of different tests. We did propulsion tests at the White Sands facility, actually built the White Sands facility to test both the service module as well as the LM, engines and propulsion systems. Here in Houston we did tests in the environmental chambers, both manned and unmanned tests, did vibration and acoustic tests here. Did structural tests at Grumman and Bethpage. I did electronic testing at MIT [Massachusetts Institute of Technology], at Bethpage, here in Houston, and probably a couple of other places that we did integrated electronic tests to look at how the total electronic system would work together.

That turned out to be a pretty big problem, because the facilities were brought up at different points in time, and the hardware they had, the vehicle hardware that they were using, represented the design at different points in the design life. So the two facilities would not be testing exactly the same hardware and they'd get different answers and then you had to figure out, well, is there something wrong with the test or is it just the difference in the hardware.

Later in the program, we were able to update the hardware in most of those facilities and get it where the flight hardware was the same module, the same maturity, and you could then much easier compare results as you went through.

BERGEN: Was there any test that you can remember that had failures that required major design changes?

MORRIS: Well, there's no major test, but one of the problems we ran into, we started seeing stress cracks in the aluminum structure of the Lunar Module. This occurred because of the temper that we were using on the aluminum. We were using as high-strength temper as we could get, that made the aluminum more brittle. When you then would rivet two pieces together, you would have to pull them together, and that would result in a residual stress, not necessarily high, but continuous. If you then combined that with some of the cleaning agents that we were using chemically, it would cause cracks to form and grow in the structure, and it threatened structural capability of the vehicle.

We had to go in and in many cases take rivets out to find out how much the structure had been deformed in pulling it together to get a determination of were we likely to have trouble with that part. This would be all the way down from major structural components down to little detail pieces.

Then we got into a three-P program, where we would shot-bream the parts to put a compressive stress on the outside layer of the metal, which would help prevent that. Then we would pot the two pieces with epoxy as they were riveted together, so that they had a bed of epoxy between the two, which gave them better bearing area. The third P was to then paint the final product, so that the cleaning agent wouldn't get down all the way to the metal. We spent probably more than a year going back through some of the first flight vehicles to get that program implemented and get the structure where it could work again.

As far as major failures go, one I can remember was the RCS [Reaction Control System] engine had a habit of blowing up if we would put it in a vacuum chamber and pulse it. Normally you did not require the engines to thrust for very long, and frequently you wanted just the smallest amount of thrust you could get. You would only then open the valves for maybe thirty milliseconds or so. After we did that for a while, all of a sudden it would go "bang" and the whole thing would come apart. We had a lot of trouble figuring out, understanding why that happened.

The reason, as it finally turned out, was the engine was not on long enough to get hot, get warm, and the propellant, as it expanded through the combustion chamber, would condense out and form an icy-like compound, which was still very reactive. Then when you turned the engine on for a longer firing, it did get hot, it would explode. That causes us to, well, actually do two things. We changed the material that the engine was made of, changed it to columbium, which was very difficult to work with, but much more forgiving in terms of its ductility. We also then increased the minimum impulse of the engine to the point that it would, in fact, heat the chamber a little bit and prevent that icy substance from forming. That caused us to use a little bit more RCS fuel in the mission than we wanted to use, but that was the best compromise we had. But, again, for a period of months we were blowing engines up and didn't know why we were blowing engines up. So it was a pretty big failure in the program.

BERGEN: Grumman was the contractor for the Lunar Module. How much direct interaction did you have with the people at Grumman?

MORRIS: I practically lived up there. For a period of probably three years, again, I was at Bethpage at least three weeks out of every month, and there at least four days a week, and usually traveling to one of the subcontractors' plants during the fourth week of the month, usually with some of the Grumman people, go to the subcontractor that was having trouble. So I spent a very large amount of time with them. Of course, they had a pretty large group here in Houston. Once in a while I was here in Houston. During the time I was here, I was working frequently with the Grumman people here in Houston. It was a good team operation. The contractor people and the government people were all trying to accomplish the same thing. They worked together, I think, pretty harmoniously.

I remember one time at Bethpage—another kind of interesting sidelight—we were running an integrative test on the first LM, LM 1, and trying to get all the way through an integrated test without a test failure. We had tried this for, I don't know, four or five times, and always had failures in getting through it. People were getting discouraged and we were trying again.

We were about halfway through the test, and we got a signal from our test equipment that said we had a battery problem on the Lunar Module. The normal procedure was then, of course, to shut down and go up and check the battery and make sure the battery didn't overheat or anything. So we had some other instrumentation that said, hey, that battery's all right. It's not likely to be the battery itself. So the Grumman guy, who was the test conductor, said, "We'll accept that and we'll go on and say it's a ground problem that we'll determine later, but we'll continue the test."

Of course, LM 1 was the only one we had at the time that was a flight-worthy vehicle and I just was not willing to see that kind of a risk taken. So I told him just to call a halt to the test, that it wasn't their fault if it was a ground piece of equipment that caused the problem, but we were going to go check the battery. We checked the battery, and he was right, the battery was just fine.

So later on, my boss said, "Well, how can you call that a successful test?"

I said, "Well, the piece of ground hardware we were using would not be there during the flight. The vehicle was okay. The battery was okay and everything went all right."

The Grumman guy was there with me and we were explaining this thing. We walked out of the room and the Grumman guy turned to me and said, "You really wanted us to succeed there, didn't you?" [Laughter]

I said, "Yeah, I sure did." [Laughter]

BERGEN: You had worked some with North American earlier. What kind of differences were there between working with North American as opposed to working with Grumman?

MORRIS: The two companies were quite different, I thought, and again, if you talk to different people I'm sure you get different answers. Aaron Cohen had a job comparable to mine where I was the chief engineer on Lunar Module; he was chief engineer on the Command Service Module. If you ask him the question, he might say exactly the same thing, only reverse the two contractors. I don't know.

But the North American people, I think largely because the Los Angeles [California] area has a lot of different aircraft plants out there, people did not have nearly as much company spirit at North American as they had at Grumman. Grumman on Long Island was the only aircraft manufacturer, and so if you worked for Grumman and you wanted to stay in the aircraft business, you either worked at Grumman or you moved your family to some other location.

Many of the Grumman people there were second-generation Grumman workers; their fathers had worked there, their mothers had worked there, and they were working there. There was just a lot more company spirit. One of the traditions at Grumman was that every

Thanksgiving, every employee got a turkey. That was just something that just happened. It wasn't much, but that was just part of the lore of the Grumman people.

Technically, the two companies were both quite competent. Their strengths were in somewhat different areas, but, by and large, they were both very highly qualified technically. I think, from my point of view, at least, the Grumman people had more programmatic responsibility and more programmatic outlook than the Rockwell people. They very frequently would be in a position where they had to do something that would hurt the fee that they would get, but to do it, to save that fee, they would have to do something they didn't really think was right. They were consistently making the decisions, "I want the program to be right."

BERGEN: Were there any specific people that you worked with more than others at Grumman?

MORRIS: Oh, yes. Don Marcarion [phonetic] was probably the fellow I worked with more the longest period of time, a Grumman guy. The fellow who in charge of the NASA office at Bethpage was Andy [Andrew] Hobokan. I worked with Andy basically all the way through the program. Andy was there for a long period of time. Don Marcarion from Grumman. A guy named George [F.] Titterton, who was the vice president of Grumman, also a very active kind of a guy, he didn't just sit up in his little pinnacle, he was down on the floor looking at things quite a lot. Joe [Joseph F.] Gavin [Jr.] was another one I worked with a lot. There were just a large number of guys. Over the years, as much time as I've spent up there, you work with a lot of different people.

BERGEN: In 1968, the Lunar Module was a little behind schedule and NASA officials decided that they were going to take it all the way to the Moon without the Lunar Module. Were you involved in any of those discussions and that decision?

MORRIS: Only to the extent that they asked me where I thought we were on the Lunar Module, when I thought we would be ready to fly the Lunar Module command. The idea was initially that we would have what turned out to be Apollo 9, a combined flight, a Command Service Module and a Lunar Module together, and then go and orbit the Moon. It looked like we would be late with the LM, we would have to postpone that flight by a month or two months to let the LM get there and be ready to go. So they then came up with the Apollo 8 idea of reversing those two flights. I think George [M.] Low was probably the big instigator of that. I don't know whether it was his initial idea or not, but he was the one that picked it up and sure pushed it like crazy. My direct participation was only to tell them where I thought the Lunar Module was, when I thought it would be able to fly. I thought they were out of their gourd, but they didn't ask me that. [Laughter]

BERGEN: Fortunately, they were successful.

MORRIS: They were successful. It worked. But the idea of going up there without having the Lunar Module propulsion system available for at least part of the time to give you backup did not appear to me to be a very attractive thing to do. It turns out they didn't need it, so then it was fine.

BERGEN: Was that part of the specifications, I guess, the Lunar Module, that it would serve as somewhat of a backup in case of a problem?

MORRIS: No. No, we knew it would and we designed to give it that kind of a capability, but it was not a part of the original spec. It was something that we came out fortuitously as a result of the way the vehicles were designed.

BERGEN: Fortunately so.

MORRIS: Fortunately during Apollo 13, very, very much fortunately.

BERGEN: Before we go into some of the later missions, I'd like to talk about Apollo 9. That was such an important mission as far as testing the Lunar Modules. Could you just share with us your experiences, your memories of Apollo 9 and the impact it had?

MORRIS: Well, let me go back a little bit further to Apollo 5, which was the first unmanned Lunar Module flight. First flight of the Lunar Module, period. We did a lot on that flight. It was basically an all-up vehicle that could have been manned, but we put in the automation that was required so that it would operate unmanned. We really had a tough time with that mission. We blew one of our RCS engines. That's while we were having trouble with RCS, and we blew one of those engines and the vehicle started tumbling. We were able to get off, though, I think 90 to 95 percent of the test objectives, but it was a pretty hairy mission.

Going from there to Apollo 9, where you put a crew on board to separate a fair distance, actually, and then rendezvous again, was, for the people on the Lunar Module, a big step. During that time period, we had found out what was causing the RCS engines to blow and had fixed that. We were quite confident that we knew we understood that. We had done a lot of ground testing that was successful. We hadn't blown any more.

Our software programs during that time were just reaching final maturity. They had not been exercised, of course, in flight. The difference between LM 1 and LM 2 that was on

Apollo 9 was quite a bit different in terms of the software. So it was a great big step for us to make that flight.

One of the things that I darn near had heart failure was we tried to start the descent engine and it didn't start. We had a failure. Thing started, the valves opened and the engine started to come up, and then it cut off and the valves closed. We couldn't figure out what in the world was going on. In real time, one of the software guys said, "Well, there is built into the software a check program that says if you don't build up the pressure in the combustion chamber at some minimal rate, it will shut down. Let's override that and let the thing go."

There was a way that you could override it in flight, and we did. It started all right. It turned out it had to do with the speed of the computers. The computers recomputed the pressure at set time periods. They were short. They were like 50 millisecond time periods. But if the engine started coming up right at the start of one of those time periods, then it could reach the right pressure very easily before the next time period. If it started up very late in a time period, it just didn't have time to do it.

So the engine was really fine and it was doing its thing, it just happened to start a little bit off on the timing the way the gates were and then it was not synchronized as intended to be, to come on just as it started the time gate. It was just a matter of happenstance. But when that engine didn't start, it got our attention real quick like. [Laughter] We thought a little while before we put that change in in flight, but we did, and it worked fine.

Most of the rest of Apollo 9, as I remember it, went relatively smoothly. Rusty Schweikart had trouble with zero G segments a bit, a good bit, as a matter of fact, but he overcome it in time to go out and make the EVA [Extravehicular Activity], and did that fine. The rest of Apollo 9, as I recall, was better than most of us had hoped for. [Laughter] The number of anomalies that we had were less than we kind of were afraid we were going to get.

BERGEN: So did that give you the confidence on Apollo 10 when they took it to the Moon?

MORRIS: Yes. After Apollo 9, the step going to the Moon, as far as the Lunar Module was concerned, was not nearly as great as going from Apollo 5 to Apollo 9. That was a big step for us, because up in lunar orbit we did roughly the same thing we did on Apollo 9. We got further away and we were actually in the influence of the lunar gravity, where we weren't on Apollo 9. But those were pretty well understood things, and so the step for us was not all that great.

The stress point in Apollo 10, as it was with every mission, was when you tried to light the ascent engine, would it really come up. If the descent engine didn't light, you could always get back to Command Module and you could always come home. If the descent engine malperformed during operation, you could always abort, using the ascent engine to abort with. But once you lit that ascent engine, for some period of time there, there was just no way out. The Command Module did not have enough energy to come down in lunar orbit to pick you up. You wouldn't have time anyway, because the Lunar Module would not have orbital velocity, so it would just arc over and fall back on the lunar surface.

So my stress point for all of the lunar flights was getting the ascent engine going and seeing that it worked right. Everything else could get you in trouble, but there were usually some redundancies, some alternate ways around. But the ascent propulsion system, there just was no way around it; it had to work. It was designed very carefully to be as redundant as we could make it to assure ourselves that, yes, in fact, it would work, and it did every time.

BERGEN: That brings us to Apollo 11. Tell us about your memories of Apollo 11. It was such a monumental mission.

MORRIS: Yes, it was a monumental mission, no doubt about that. Apollo 11, as I talked earlier, we had trouble with the Lunar Module and the crystallization in the glycol loop prior to launch. We felt pretty good about that, actually, that we really understood it, and it turned out that we did. We never, in the program never had any problems, but there was still some concern there.

There was one of the scientists just a few months before launch, it was after Apollo 10, so it was maybe two months before launch of Apollo 11, said, "When you get up to the Moon and you try to land and use the descent for your braking and landing engine, you're just going to dig a big hole in that sand up there and you're just going to go right down in the hole and it will cave in on you and the LM will just go away. It won't be there." He was a noted scientist; he was not just some kook out there. He got the attention of the National Science Foundation and other scientific groups.

We thought about that a long time and did as much testing as we could. We had done a couple of landings with small vehicles, unmanned vehicles. We looked at that data and we felt quite confident that, no, we weren't going to dig a hole, that there might be some surface blasting where some of the dust would be blown away, but below that it would be packed enough that it wouldn't. Still, there was some concern there, so part of the radio conversation that we got during the landing process was Buzz [Edwin E.] Aldrin [Jr.] saying, "We're picking up dust. We're picking up dust." So everybody all of a sudden got—after they got out on the lunar surface, it looked like right underneath the engine they had blown dust maybe two inches thick out. The landing pads on the Lunar Module had gone into the lunar surface less than a half an inch, so it was really no problem at all. But when Buzz said, "We're picking up dust. We're picking up dust," it really got a lot of people's attention because of what had gone on prior to flight.

We had a panic on the Lunar Module right after touchdown. Deactivating the propulsion system, the pressure started going up in the descent tanks, and we couldn't understand why. It was getting to the point where we were thinking about aborting and taking off to immediately get away from it. Then all of a sudden it dropped, the pressure dropped, and it came back to normal again.

After the flight, we went back and looked at all the data we had and convinced ourselves that in a heat exchanger in the vehicle we had liquid helium going through the heat exchanger cooling the propellant down before it hit the engine. In shutdown, there was enough helium in there to freeze the propellant in the heat exchanger, which then blocked the pressure in the tank from getting out. It couldn't get to the relief valve and then blow a relief valve.

So we made a change in the design of that heat exchanger and put a bypass around it for later flights. That worked fine. I guess we started picking that pressure up maybe thirty seconds after touchdown, and that lasted for a period of forever, it seemed like. At the time it was probably two or three minutes that the pressure was building up and got above the relief valve setting. We were really getting concerned about aborting coming back. Evidently what happened was when the pressure got high enough, it blew a slug of that propellant on through and allowed the pressure to relieve.

The ascent part, as far as the Lunar Module was concerned, went without a hitch. We had no trouble at all. All the systems worked okay. There were some minor anomalies, but nothing significant or worrisome at the time that I can remember.

The overall mission, the relief you felt within the decade and actually having put men on the Moon, actually having brought them back in a mission that was extremely successful, really, when you look at it, was a real sense, a real feeling, a real sense of accomplishment. We always had an advantage over the command and service guys, because once we got mated in lunar orbit from ascent stage and made it back to the Command Module and got the crew transferred across, we then jettisoned the ascent stage, so we were out of business. So we would start our splashdown party right after they kicked the LM off, and the other guys still had to get them all the way back home again. [Laughter] We always had about a day and a half jump on the other guys.

BERGEN: How did things change after you finally had a mission that proved the marketability of the Lunar Module?

MORRIS: I think everybody was extremely proud of it. I know I was, and also service people and the Grumman guys were also. To have worked on the vehicle as different in design and design concept from anything that's been built in the past and have it work that well in flight was a real good feeling. I think we were all very elated.

There were enough minor problems, both pre-flight and during flight, that we were not celebrating too long. We were back trying to get those things fixed so we could go on with Apollo 12. That went on all the way through the program. The crew had to make a turnaround, the guys at the Cape had to make a turnabout, but we had to basically take all the problems and make sure they were not going to be problems on the next flight, and convince the Flight Readiness and Review Board that we were ready to go. So it kept us busy all the way through the program just doing that kind of thing.

We were putting improvements in all the time. We were increasing the lunar stay-time capability. The Apollo 11 capability was about 24 hours. On Apollo 17, we were on the surface for, I think, 75 hours or something like that. It was a little bit over three days. Basically the same vehicle, we had changed some tanks around, changed the way we used oxygen, changed the way we operated the vehicle so that the batteries would last longer. There were a lot of things we had to do, but we were able to stretch that design to give us three times the lunar stay time that the initial spec called for.

We put the buggy, the rover, on Apollo 15, which was a fairly major job for the Lunar Module to incorporate that thing and still convince ourselves we had enough propellant to land it and get it on the surface all right.

BERGEN: We'll take a short break and change the tape.

[Break]

BERGEN: Now I would like for you to tell us about your experiences with Apollo 13. That was such an amazing, yet terrifying, mission that the Lunar Module played an invaluable part in.

MORRIS: Yes, Apollo 13 went quite well early on. One of the things we started doing after Apollo 11 was when we got about halfway to the Moon, we would make an entry into the Lunar Module, power up all the systems, get some telemetry data back down again just to make sure everything was working all right so that if we had a problem with any of the equipment, we could figure out how to work around it before we actually got at the Moon and had to do it in real time. A couple of the things on Apollo 11 we had to make real-time decisions. We said, "Gee, it should would have been nice to know that a day before."

We had just done that on Apollo 13, just made that entry. The Lunar Module checked out fine, and Fred [W. Haise, Jr.] and Jim [James A. Lovell, Jr.] were just in the process of getting back in the Command Module when the explosion occurred. I had been out there at the Center for, I don't know, twelve hours, I guess, getting ready for that entry, seeing the entry and then going over some of the telemetry data that was a result of that. I had just gotten in my car to go home. I lived about no more than ten minutes away, and when I got home, my wife met me at the door and said there'd been a problem. So I turned around and went back out there again.

At the time, it really looked bleak to me. I didn't see how in the world we were going to get those guys back. By the time I got back out to the Center, it was very obvious that the service module would not produce any more power. The Command Module had a very limited amount of power, it could last a few hours, maybe three, four hours at the most, which it wouldn't help at all. So as I said, the Lunar Module had to provide all the power to get us back home and there's no way, with our normal operating procedures, that we had enough energy in our batteries to get back.

In addition, the service module, prior to the accident, had been used to transfer the whole vehicle into a non-free return trajectory. Early on in Apollo 11, if we got to the Moon and the service propulsion system engine didn't work and put us into lunar orbit, we were in what's called a pre-return trajectory, which would bring us back to the Earth without any trouble. To be more efficient and to allow heavier loads to be carried, we had changed that by Apollo 13 to the point that we got into non-free return trajectories that were more efficient from a propulsion standpoint quite a while before we got to the Moon. That had occurred on 13.

So we had to use the Lunar Module propulsion system to get back to a free-return trajectory. The longer we waited, the more energy it took out of the Lunar Module system, so we had a somewhat limited period of time to do that. We had to change a lot of the constants in the guidance system for the Lunar Module before we could make that burn, because now we were pushing, Command Module the center of gravity was in a different place and the mass of the total vehicle was grossly different than just the Lunar Module which it was programmed for. So it was a crunch to get all that information up there, to verify the information, know that's what we wanted, and then to get it up there, get it verified on board.

At the same time we were trying to understand what we could do to the power usage to make the batteries work long enough to get back. In the environmental control system, we had the carbon dioxide removal part of the vehicle wouldn't accommodate three men for the period of time to get back. So we had different groups of people working on each one of those problems.

In the end, of course, the Lunar Module propulsion system worked fine. We got back into a free-return trajectory. Everybody breathed a lot easier then, because then just the RCS system would be enough to make the mid-course corrections that we needed to get us back.

We came up with a revised power schedule, which basically shut down everything except environmental control systems. We did a lot of things that we didn't want to do, put quite a few of the systems into an operating mode that we had not designed them for and had not tested them in those modes, and we weren't really positive how they would work. It appeared to us that they would, but there was a lot of concern there for the kind of thing we were doing.

The lithium hydroxide in the environmental control system that was used to take the carbon dioxide out, the fellows at the Center had come up with a way of using the canisters from the Command Module, adapting them to the LM, so once that was demonstrated, that took that worry away.

But we were basically inventing all the way back home, doing things we had not done before, operating in ways we had not operated before. It was pretty far down the road of return before I started feeling comfortable that the Lunar Module was going to last long enough. It was very uncomfortable for the crew, because we had to power down to the point that it got very cold inside and there was a lot of condensation on the walls, even ice formed, it was that cold. Of course, they didn't have overcoats and stuff. They were in flight suits or pressure suits without the helmet, but even that wasn't really very warm.

Then the real concern, from my point of view, I was concerned about the Lunar Module, but I was even more concerned about the Command Module, would those guys be able to fire back up again and make the entry once the Lunar Module was cast off. Again, if you talk to Aaron, he was probably more worried about whether the Lunar Module will get us back, than would the Command Module power up. But it came on just fine, and they came back in and we were all extremely elated.

I think we were all much more emotionally built up than we were for Apollo 11, because it had been a struggle. Many of us had been up there at the Center four days straight trying to make sure we were doing everything we could be doing. We had people all over the world working. Every time we would take a system and try to do something with it that we had not done before, the Grumman people would look at it, work on it, test it if they could, if they had a test rig that they could test it. They'd get the subcontractor that designed and built that particular part of the system in the loop. We literally had people all over the world working on different aspects of getting us back home again. It was another demonstration, I think, of a real team effort to do that. We had no trouble getting a response from anybody in the world that we asked for.

BERGEN: It was a great team effort.

MORRIS: It was, yes. It really was.

BERGEN: We found in our research the towing bill that Grumman sent to North American.

MORRIS: That was pretty cute. That was pretty cute. I was there when they handed that to the program manager from North American, and he really got disturbed about that.

[Laughter] To him that was no joke. So we kind of had our hand slapped about that. It was no time to get levity involved, but we thought it was a pretty good thing.

BERGEN: It's just fortunate that it worked out that the Lunar Module was able to fill in in that capacity.

MORRIS: Yes, if the explosion had occurred quite a bit closer to the Moon than it did, the Lunar Module just would not have had enough energy to get back to a free-return trajectory. We just couldn't have done it. So we were extremely fortunate as to when it occurred. We were extremely fortunate the way it occurred, as far as giving enough time to transfer the crew back into the Lunar Module and transfer the guidance information from the Command Module computer to a Lunar Module computer, which was probably not absolutely mandatory that that get done, but it would have been very, very difficult to reconstruct that in time to make the Lunar Module burn if we hadn't been able to have that transfer.

The guys had just enough time to do it before the—well, actually the service module power did go down. They had to shift over to the Command Module power to finish that transfer, so we used a little bit of the Command Module battery. We tried to recharge that through the LM. I don't guess we ever really knew whether that was successful or not, but we tried to recharge that Command Module battery from the Lunar Module.

BERGEN: It was a great engineering accomplishment bringing them back alive.

MORRIS: It was. It was. Again, as you said, it was a tremendous team effort to do that.

BERGEN: At some point in the Apollo Program, you switched from being the Lunar Module chief to being the manager of the Apollo Spacecraft Program Office.

MORRIS: Yes. Well, up until Apollo 11, I was chief engineer on the Lunar Module, and then after Apollo 11 through 16, I was manager of the Lunar Module, not just the engineering part, but the whole program. Then after 16, I was the spacecraft program manager, having both the Command Module and the CSM for Apollo 17.

BERGEN: How did your responsibilities change as you switched from just focusing on the Lunar Module to the whole Apollo Program?

MORRIS: Well, the responsibility, I was all of a sudden now responsible for the Rockwell. I think it was Rockwell by that time. North American name had been changed. So I was responsible for the Rockwell contract as well as all the subcontractors, as well as the Lunar Module. But I had very good people within the program office working on the CSM, and I don't think we missed a lick, because those people, most of them had been there through almost the entire program, as a matter of fact. They were doing their thing and it was going along quite smoothly. So it really was not a big perturbation in program management at all.

BERGEN: Apollo 17 was the last mission. Can you share with us your memories of Apollo 17?

MORRIS: Well, since I was program manager at the time, I'd have to say it was the longest mission we ever flew, the longest stay time on the Moon, the longest time out of the Lunar Module on the surface of any mission. More return mass of lunar soil, rocks than any other mission. So it was quite successful. I think, remarkably, by just the period from Apollo 11 to 17, the number of anomalies that we had, the number of problems that we were working during the mission were very, very, very few. We just did not have any significant problem the whole mission. As the program manager, you always worry about what's going to happen next, but the other shoe never dropped, it was just a very smooth mission, had a good crew.

I think the biggest thing, probably, was the emotional letdown after the mission was over, realizing that we were through, no more flights. Several of us were quite unhappy about that, because we had three more Saturn V launch vehicles, we had two more LMs that were basically built. They had been stopped earlier when the decision was made not to fly past 17, but they could have easily made the schedule to fly.

We had Command Service Modules that could have been there easily. We had the crew in place, not just the flight crew, but we had all the ground people that it takes to build checkout and operate the equipment in place. We felt there was plenty to be gained with two or three more flights from a scientific point of view. It was a big emotional letdown after 17 was over, but the mission itself was by far the least notable mission as far as trouble of the whole program.

BERGEN: Yet the most successful in terms of scientific.

MORRIS: Yes, by far.

BERGEN: And notable because it had the first astronaut scientist on it.

MORRIS: That's another story, yes. [Laughter] I won't get into that one.

BERGEN: Okay. Anything else that you would like to talk about in reference to Apollo that maybe we didn't give enough time or didn't bring up yet?

MORRIS: I don't think so. You know, you could talk for days, but I think your questions have covered quite well, really, the major points as we went through. We didn't spend very much time talking about the activity between Apollo 13 and 14.

BERGEN: We can go over that if you'd like.

MORRIS: Again, there was a very large redesign, rethinking activity after Apollo 13. It resulted in significant redesign of the Lunar Module, as well as the Command Service Module, although the service module is the one that had the problem. There were similar kinds of things that could have happened on the LM, and we didn't just look at that problem, we went back and looked at the entire design, because we knew we had time while they were fixing the service module to do some things. We went back and had complete design reviews of the total vehicle again to look at what could we do to improve the reliability and the operational capability of the vehicle for the remaining missions. That activity was almost as intense and as significant as the activity after the fire.

BERGEN: Oh, really?

MORRIS: Yes. It didn't get near the press or notoriety, if you will, because the crew got back and then the fire, the crew was killed, and there was a much different attitude and coverage by the press.

Also, another point we didn't discuss, the press really got very blasé rapidly after Apollo 11 and until 13. Then it was very heavily covering 13. But after the crew got back safely and everybody celebrated, for the rest of the program, the press coverage was very, very small compared to what we had earlier in the program. I always thought that really the harvest of the scientific information, the stuff we were trying to really accomplish, was the meat of the program later on. But the notoriety of it in the press was very, very small comparatively.

A couple of times we were remarking that we would have the guys out on the surface on an EVA, we'd be pumping it out to all the broadcasters, but the television would be showing soap operas, just in normal time. There was a big change, and I think that has continued to go down as time goes on. Again, there was a big flurry when the Shuttle first flew, but now the average man on the street, I don't think, could tell you whether there's a Shuttle flying or not, don't even know whether it's up there.

BERGEN: Another significant modification you mentioned just briefly earlier was the lunar rover.

MORRIS: Yes.

BERGEN: Could you go more in depth into the impact of that?

MORRIS: Well, for the Lunar Module it meant structurally redesigning a significant part of the descent stage to have, we called it a hangar place that you could put the rover when it was folded up, attach it to the vehicle, then deploy it down on the surface as it unfolded and get it down on the surface where the guys could use it. We were doing this on fairly, well, quite a short time period, really.

The rover, of course, was designed under the control of the Marshall people rather than the Center here, and that caused more coordination to have to be done to make sure what Marshall was doing and what we were doing with the Lunar Module was, in fact, going to all come together and work right.

So we worked quite closely with the Marshall people during that time, and that was partly done during the time between Apollo 13 and 14, we were doing the initial part of that activity. We worked with the Boeing [Company] people. Boeing designed and built the rover. We were fairly deeply involved with the Boeing people in some of the engineering decisions that had to go on to make the two things compatible.

On the other hand, from a scientific point of view, it gave us the ability to go away from the Lunar Module a very significant distance compared to what we could with the guys walking and pulling a little cart behind them. So the scientific return was way up. I think all the crew really enjoyed running that thing up there. We got plenty of television back that indicated they had a little toy they could play with and they really liked. But it gave us a lot of mobility on 17.

We landed in a valley with a big hill up on one side that had a slide on it, and by getting up that hill, we felt the crew would be able to get into an area that was much older, had much older rock in it than the surface that we had been into before. Of course, [Harrison H. "Jack"] Schmitt was very excited about that.

The operation of the rover, I don't remember having any significant problems between the Lunar Module and the rover during actual operation of the mission. I don't really remember the rover having any real major problems. They tore a fender off and did some stuff like that, but, by and large, the rover worked quite well.

BERGEN: You mentioned that at the end of Apollo 17 there was a sadness about the program ending. Did you at that time think we would be back to the Moon by now, or do you think we will go back in the future?

MORRIS: Well, yes, I thought we would. At that time we had—NASA, the big "we," NASA—largely under the direction of Dr. [George E.] Mueller had laid out a program which had the Space Station, the Shuttle, an orbiter transfer vehicle, all aimed at and being able to make quite routine trips to the Moon. Initially, they were going to do the Space Station, and, of course, they did Skylab, which was our first cut at a space station, but it was not permanent. Then during that time period they decided it would probably be better to build the Shuttle, the Space Transportation System, and use it then to help get the permanent station in place. The time scale they had laid out for this was, I think, to have the station in place by the late seventies, early eighties. Of course, we're just now starting to put the thing up, so it stretched out a lot.

Yes, I think we'll go back. I think there are things on the Moon, there's a lot more science to be obtained. But I think operationally as we go further out than the Moon, the idea of having the Moon as a way point when we really get serious about it, I think that's going to be a very big advantage.

BERGEN: I think this is probably a good ending point.

MORRIS: Okay.

BERGEN: We've been talking for about two hours.

MORRIS: Okay. Good enough.

BERGEN: Thank you for talking with us.

MORRIS: Sure thing. If you think of anything more you want, why, give me a yell.

[End of interview]