ORAL HISTORY TRANSCRIPT

GEORGE W. JEFFS
INTERVIEWED BY ROY NEAL
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NEAL: Let's begin, if we can, by getting a little of George Jeffs' background: education, how you got into the whole field of space engineering.

JEFFS: Well, let's see. My background is that I have a bachelor's degree and a master's degree in aeronautical engineering from the University of Washington in Seattle. In between those degrees, I spent about 5 years in the Navy—4 or 5 years in the Navy. I'm still a pilot, and I have great *empathy*, of course, for flying, pilots in general; and flying in particular is one of my great loves and always has been.

NEAL: Did you ever want to be an astronaut?

JEFFS: I tried to see if I could get into the astronaut slots after I was working on Apollo. But, George [M.] Low was not convinced that I wouldn't do more for the program where I was than trying to aspire to be an astronaut.

NEAL: Now let's talk about where you were and what you did when first you came aboard NASA. Can you describe what happened?

JEFFS: Well, my first interfaces with the NASA are back in the early part of the sixties. The Space Division, at the time, of North American Aviation was running into a number of technical problems and program problems on the Paraglider Program [part of the Gemini Program], and they were looking for strengths, additions to keep that program moving.

NEAL: You know there maybe those, George, it suddenly comes to mind, that might not even know that once upon a time there was a paraglider and that there was a chance that Gemini might land on dry land instead of the ocean. You might want to spell that out.

JEFFS: That's right. I really should say that that was associated with the Gemini Program. The Program Manager of the NASA at the time was Jim [James A.] Chamberlin; and Jim Chamberlin felt that it was not the right thing to do to land man on the ground on Earth. He wanted to land them with *dignity*. Landing them on the Earth, on land, like the Russians do, is not very dignified; and the water is just a little bit more dignified, but not much more. So we were trying to provide a Paraglider Program that permitted a little more dignified landing, a little more controlled landing, and one that was more accurate and would place us closer to the recovery ships.

NEAL: Would there be any relationship between the paraglider and its design at that time and the sort of winged spacecraft that eventually the Shuttle became?

JEFFS: I don't think there's too much of an association with winged spacecraft. There's a lot of association with the people that fly the so-called maneuverable wings—the Rogallo wings [named for Francis M. Rogallo, a Langley engineer who developed the initial design]. So, Rogallo was behind the wing that we were trying to fly on the Gemini.

NEAL: The Rogallo wing. Okay. Let's talk about it then. You had problems in trying to develop that wing, didn't you?

JEFFS: Yes, we did. We had a lot of problems trying to develop the wing, and I won't get into the detailed, technical problems with it. I think there are some interesting aspects of it, from a program point of view. You asked me for my association with the NASA. I found that the NASA hierarchy got into the depths of a lot of these programs and program problems, which was very refreshing to me. I thought that was an excellent thing to do. I think, on industry's side, there should be more of that, on the top management side, of getting more deeply into problems—particularly where there are critical problems. For example, Bob [Robert R.] Gilruth and I spent a lot of time together on the paraglider, as did some of the people that were surrounding him at the time like Walt [Walter C.] Williams and Jim [James C.] Elms and others that were really trying to participate and help with the program. I thought that was excellent from the *ideas* that they brought forth technically; it was also great for the troops, with respect to seeing that much interest on the part of a high-level customer.

NEAL: Do you think that today, with privatization, NASA perhaps has gone even one step beyond that?

JEFFS: Beyond that? I'm not quite sure how you mean that.

NEAL: Well, I mean by that, that NASA now seems to be relinquishing control of some facets of its space program to private industry, turning more and more of those controls over to industry, which, of course, was the role that you played earlier on.

JEFFS: Well, I think that trying to commercialize space is excellent. I don't think there's anything wrong with that thrust. I think the *timing* of it is critical. You can't hurry it too fast. I think the NASA did try to hurry that too fast in the case of Jim [James] Beggs and the Shuttle processing activities at the Cape, for example. Good idea but too early, I think. I think that the groundwork for really commercializing space—things like space vehicles—

hasn't really been laid yet with the government. I think we've got a long way to go before it's clear how industry can have the freedom and the flexibility to operate these machines while at the same time making a profit without losing sight of the safety factors.

NEAL: Back in the days of the paraglider, of course, you were trying to create something new—a different landing system for spacecraft. Were there opponents to what you were trying to do within NASA?

JEFFS: Oh, yeah, there were opponents, and particularly as we experienced technical difficulties with the system; as you might expect, that always occurs. We were trying to do a very *difficult* thing of packaging a very large inner tube in a very small bottle, if you [will], like a genie in a bottle, and trying to get it extracted with a tumbling, bowl-like spacecraft that was heavy compared to the wing loadings. So, we had a difficult time trying to make those deployments, a number of which were successful; but to make them *repeatable* in the same fashion each and every time. Not too different—dissimilar to parachutes, but with a little more vigor I'm afraid [*laughs*], in some of the deployments.

NEAL: As you look back on it, what was the greatest technical issue that you had to face? And were you able to overcome it?

JEFFS: I think the greatest technical problem that we had with the thing, it's really not too deep a technical problem. The deployment's pretty difficult. Getting the wing packed and getting the control cables and whatnot packed in such a way that they don't damage the inner tube-like structure, as I said—the wing beams, for example—and packed at the *densities* necessary to get them in the containing volume that we had available to us, was extremely difficult. And to provide that system with the long life that would be necessary in a stowed configuration, so you didn't have seams come apart and that sort of thing; it was really a kind of a materials problem, a life problem, and, clearly, a deployment problem—a number of which have been addressed and solved in a little less dynamic fashion with the controllable parachutes that you see today. And as a matter of fact, some of the NASA people—Bob [Robert R.] Gilruth, among others—were suggesting that we give a lot of consideration to the steerable parachutes at the time; the controllable parachutes. But the parachutes at that time weren't as far along; and, of course, like every major program, space program, we didn't have much time. And we were already pretty well embarked along a given course, so we really didn't have the flexibility to move much in that regard.

NEAL: You were facing the deadlines of: How do we send men to the Moon and get them back alive?

JEFFS: Well, and the fundamentals of the Gemini schedule, which really had bigger problems on its hand than just the paraglider. And the paraglider was an interesting adjunct to it, but not a *necessary* one. In other words, parachutes would still do the job for Gemini, so they could always fall back on that when times got tough and when dollars got tight.

NEAL: Well, eventually, NASA decided *not* to use the paraglider in its spaceflight program.

JEFFS: That's right.

NEAL: That must've created some problems at North American, didn't it?

JEFFS: Well, let me say about problems. Two things about the paraglider at North American. It created a problem, but it was a small program. It didn't create large layoffs or anything like that, that a big program would. The program was concurrent with the Apollo Program; and the Apollo Program was experiencing a lot of growing pains at that time; and it turned out, interestingly enough since both were in the same Division, that the Paraglider Program broke some ice for the Apollo Program, all the way up and down the line, when it came to inspection systems, when it came to procurement systems, when it came to control systems. Paraglider was finding the problems in those systems before the Apollo was, because the Apollo hadn't reached that stage of hardware that the paraglider had. So, when I was running the Paraglider Program, we were really being a scout, so to speak, in cleaning up some of the basic problems we had in our fundamental process systems at the Division. And I think that was very helpful to Apollo, albeit painful.

NEAL: Matter of fact, didn't North American continue with the paraglider on its own after NASA dropped the program? According to my notes here, after NASA stopped the funds, North American continued with some testing and demonstrated a successful landing.

JEFFS: Oh, I think that's right. We carried it on to complete the landing ourselves. We had some outstanding people beginning to work well as a team together that enabled that to happen. Not the least of those was [John] Jack Swigert [Jr.]. You know, Jack was a test pilot for me on the Paraglider Program.

NEAL: A well-known astronaut.

JEFFS: Yeah. And would-be congressman. He didn't quite make it.

NEAL: [*laughs*] Yes, indeed. As you've just defined, George, the paraglider was a logical step on the way to the Apollo command and service module, and you wound up being tremendously active in that—from beginning to end. Can you describe some of your Apollo experiences from the beginning? And we'll just follow it sequentially with you as you went through those growing pains and developments, and from what you remember.

JEFFS: All right. Let me leave the paraglider with saying that: You're right; you jogged my memory. We did complete at least through the landing of the Gemini, and we kind of left that in the record book. We did a great deal for the Apollo Program in breaking the ground on the overall systems that were necessary—management systems that were necessary—to make the Apollo happen. And thirdly, as far as me personally and a number of my people, we gained good working experience with the NASA. We met a lot of NASA people in working clothes and in management clothes, all of us; and we worked together as a team; and I think that that certainly helped me later on in my Apollo activities.

A couple that I bring to mind there that later were key players in Apollo on the NASA side were people like Scotty [Scott H.] Simpkinson from the inspection side—although you could hardly call Scotty just an inspector; he went far beyond that—and a guy named Marty [Martin L.] Raines, who was the reliability leader down at NASA. And, of course, we worked a lot with the contracting people, which enabled us to better understand where NASA was coming from insofar as later interfaces with Apollo were concerned.

NEAL: Well, in Apollo you were a prime contractor. You're talking now the subs?

JEFFS: No, on Apollo we were prime contractor. But we were running the Paraglider Program directly with the NASA. We weren't running it through any other company. So, in other words, we didn't run it through McDonnell [Aircraft Corporation]. We weren't subcontracting McDonnell; we were contracted directly to NASA.

NEAL: Right. Well, I was referring to the Apollo Program. Apollo, you had it.

JEFFS: The Apollo, we had it.

NEAL: You had the command and service module.

JEFFS: Well, that's right. We had the system.

NEAL: And you were working with the subs throughout that?

JEFFS: Yeah. Now what happened on Apollo was that I went back to the corporate office after the Paraglider Program and I became what they called an Executive Director of Engineering; and I was spending more time with other divisions and other programs than I was with the Apollo Program, for a lot of reasons; too deep and too many to get into at this point. But anyhow, that's what I was doing. And it came along, Apollo began to run into some problems: technical problems; fundamental requirement problems; basic data problems; system problems; design, engineering, manufacturing; all kinds of problems. And a number of investigative teams reviewed the programs, not the least of which was, I think in the 1965 era—something like that—Sam [Samuel C.] Phillips, had a team review of the Apollo Program at the Space Division. The Command and Service Module Programs is what I refer to and should, in all these discussions; that's what I was involved in. CSM. After the Sam Phillips review, it was very clear that there had to be some fundamental changes in the way we were doing the program if we were going to get there from here. And that was 1965.

And I was after that—we conducted our own review in parallel with the Sam Phillips review, and we found a number of the same kind of problems, and probably a few others here and there that didn't get into the Phillips Report that we ourselves found. I had built up a good rapport with Stormy at the time—

NEAL: Stormy?

JEFFS: That's Harrison [A.] Storms [Jr.], through the Paraglider Program. Stormy was delighted to have me tear up, in a way—if you can call it that—the overall systems of the Division because of the positive input impact that that might have on the Apollo Program, among other reasons. And so, when the Phillips review was completed and North American sat down to figure out what the actions would be to make changes in the program, Stormy requested that I become the chief engineer of the program. And so, I left my corporate nest—or whatever you want to call it—over there and went to work as the Chief Program Engineer for Apollo.

NEAL: From what I see here, you implemented some rather drastic changes—reducing the number of engineers, eliminating unnecessary tasks—is what these notes say. Can you describe any of that?

JEFFS: Let me say a couple of things about it; because I guess these kinds of discussions, if they're going to be meaningful to people in the future—if they ever have the same kind of problems—at least these are checkpoints to look at and look for I guess. A lot of good work had been done on the CSM when I got there; it was not starting from a zero base. Some very good work had been done. And, also, some things had been done that we really had to redo and change, even in the early phase—even in the 1966 period. And the things that were happening on Apollo were across a broad spectrum. In the technical arena, I think the guys got so focused on "lightweight for space" that a lot of decisions were made to save weight that, in fact, shouldn't have been made that way. And, we made those throughout the program. As a matter of fact, we did those downstream in the Shuttle Program. Sam Phillips and I later used to comment to each other about, "There we go again," because what we do is, we just put a blanket "save weight" edict across the program, so everybody tries to save weight. And what you've really got to do is, you've got to balance them from the risk point of view. Where the risk is pretty high, don't try and save weight as much or as vigorously as you might want to save some weight over here, where it's not as risky if you do have any problems because of the weight reduction.

I'll give you a couple of interesting examples. One of them was—on the Apollo Program was the systems involving liquids: the hydraulics, the ethylene—you've got me. I've almost forgotten the materials. But anyhow, it was the hydraulic fluids, the water systems, all the *tubing* in the spacecraft had gone to aluminum tubing in order to save weight. Well, there are two things about it: aluminum tubing, especially with water or derivatives of water, there's nothing more corrosive. So the system easily corroded; and through the years, the system started to corrode, number one. Number two, you have to *really* know how to put the V-nuts together on those joints and get them lined up just right or they leak. So what we got into with very early spacecraft, as a result of that kind of a decision, was we had to build special devices—they were *sleeves* for V-nuts of different configurations—in order to try and close off those V-nuts so that they wouldn't leak; and that was a development program unto itself. You can imagine, with tubing running all different kinds of directions and what have you, trying to develop *sleeving* for that so you could essentially do the job without the V-nut, even if the V-nut did leak. Little things like that were—that just caused all kinds of havoc downstream because they weren't put in stainless steel in the first place. Those are the kinds of development problems we got into.

We got into problems with fabricating the pressure shell, just from the point of view it could be done once; but if you tried to do it a number of times you had to have special design tubing—special design tooling, not tubing, tooling for the pressure cell. So we ended up with some outstanding tool designers that designed the welding equipment in order to put those damn modules together in a *repeatable* fashion downstream. Little behind-the-scenes problems like that just tore all kinds of hair out and caused all kinds of consternation, I'll tell you, throughout. We had a number of *technical* problems like that.

Another thing in the technical side that we had was, we had a lot of effort that was going into, well, kind of like—basically it was research. It wasn't basic research, but one basic problem was: "How is the man going to react in zero g? So let's do everything we can to try and analyze that problem, build any kind of devices necessary for that problem—in zero g or during the boost g's—with respect to switch throwing and this sort of thing, centrifuges, and what have you." All kinds of research programs going on. Another one was there were all kinds of people spending time out the kazoo on hypervelocity guns to try and simulate the impact of high-energy particles on windows or on the heatshield. And, as a result of this, they became massive development problems unto themselves, each one of those things. And even then, you had to extrapolate the results to wherever you thought they might apply on the closing velocities of particles in space on the spacecraft. So, the requirements from those researchers were not coming out; they were *delaying* the program.

The program was skidding along, waiting for results from these kinds of things; before somebody specified the windows, for example, and what the hardness had to be. Before people would specify the heatshield; it wasn't only from the heat transfer point of view, it was also from the damage point of view from particles and stuff like this. So when I got in, I said, "Okay, time's run out, guys. We've only got about 3½ years to go to the Moon, and we're not even off the *ground* yet! Time now is to take our best shots. Between ourselves and NASA, let's take the best shots on these things and see what we can do. It's time to stop cutting bait, and it's time to go fishing." So that's what we did to the whole organization.

We had another major problem where the engineering forces were kind of going across like the Indians after Custer; they were all over the place. They weren't that well-coordinated; the engineering groups weren't that well-coordinated. The engineering planning was getting overrun; there was no single focal point to try and pull all this together except engineering planning, and those guys were swamped. And so, each design group was kind of doing its own thing in a fashion. It wasn't that much of a Brownian motion, but it was not well coordinated, let me put it that way.

So, what I essentially did was that we lined up the engineering organizations with the spacecraft and the systems on the spacecraft. We knocked out peripheral groups, and we put them where they were most related within those disciplines. We put together a strong Project Office, and we integrated the engineering planning into the Project Office so that the two were handling not only the control of the input/output—requirements in and output drawings, EOs, etc., out from the design groups—they were handling the scheduling, which the planners normally do. So, they became a single controlling team. And then we also took a look at the system engineering, which was really, kind of, almost a separate organization. It was just kind of flying along in parallel with the rest of the organization; sometimes screwing up the organization; sometimes helping it. We got those—we took the system engineers and put a lot of the system engineers into the engineering design groups, with the designers, design people, where it was appropriate, had them to work together across the board from the inner design groups. We left a single corps of system engineers that handled the interface control requirements between elements of our own system and between outer elements, such as the LAN and the SLA, etc., etc. In other words, we just squeezed the system engineering group down, we put it where it should be in the design groups, we made it coordinated, and we made it part of the process; and it hadn't been before. And that, with the advent of a strong project engineering group to control the whole process, was a great big step.

Another problem we had in the whole process was that we had a confrontational activity going on between our forces and the NASA forces; and that confrontation was because people weren't quite sure of the role they should play, I think, on either side. We had too many engineers playing the sea lawyer and arguing and fighting with their counterparts. We had too many of the NASA folks that were directing from their own position without going through a central control point, and that was kind of like a Brownian motion. That was out of control. So what we did—what the NASA did to help the situation was to put strong people in charge of their own activities down there. So, technical direction was handled by the Program Manager; and they got guys like Kenny [Kenneth S.] Kleinknecht and Aaron Cohen, and guys like George [W. S.] Abbey, moving through the system that really helped—along with, and I really can't leave the George Lows out of this—really helped put discipline in the system from not only our side but also from their side. So, we ended up with a strong control from the Program Office within our own organization to strong control of their directions to us, with TDs, technical directions, being signed by their Program Managers; and, slowly but surely, a process began to come under control.

NEAL: Was it at about that time that the Apollo 1 fire suddenly brought everything to a roaring halt, and you realized that all these things you had been working on required a little reworking? A *lot* of reworking, in fact?

JEFFS: Let me say two things before I leave that phase, but you're exactly right. You know, the problems with building big systems and managing big systems is—How shall I put it? Let me put it this way: There was a fellow that worked for Rockwell North American Aviation a long time ago named Joe Buer [phoenetic]. And Joe used to say to me, he'd say, "You know," he said, "when I first got in this business, I thought it was 100% technical and 0% people." He said, "That's really why I got in this business. And then," he said, "as time went on, I figured, well, maybe it's 50% technical and 50% people. And after about 25 or 30 years," he said, "I decided it was about 100% people [*laughs*] and very little technical in this whole thing!" I think that that moved Joe Buer so much that he eventually became associated with the cloth someplace; I think he did go into the church somewhere. But anyhow, the building of a team has to lead the building of the system. They've got to go concurrently, but the team's got to be a little bit ahead of the system. It's just as big a job to develop a hard-hitting, good-communicating, make-it-happen kind of a team with sensitivity, judgment, and depth of thought in this whole thing as it is to build the damn hardware itself. And that in conjunction with the NASA on both sides, in the case of a NASA program. In the case of Air Force, the same kind of thing.

We finally got to that point where we just had the team starting to go together. We were just starting to work the kinks out of the team; we were starting to find the hard spots and the spots that were pretty well under control on the program, when the accident occurred. Before that happened, there were a couple of things in the spacecraft that were just surprising to me. One of them, we had an astro-sextant door and we had a pop-out door on the astro-sextant door; it was on the leeward side of the spacecraft; and people—heat transfer guys were still concerned about that backside, whether you could leave an opening on the backside or whether you couldn't. I got rid of that door as fast as I saw it. It was like a door on a cuckoo house; you know, what the cuckoo birds come out of, and that door was supposed to pop out in orbit and then pop back. I couldn't even get the thing back in on the ground with my hand, let alone how it was going to come back in on orbit. And that carried over into Shuttle, too, insofar as making sure that any doors that you have that open and close—especially open and close in space—you better have a door there's just no way it can fail. That's all. Period. And so, I got rid of the door. We just essentially left the hole in it, and we heat-shielded it down through the hole; it was on the leeward side, so it worked out fine.

NEAL: And as the contractor, NASA, the client, allowed you to do this.

JEFFS: We did that. The NASA, of course, got into it and concurred, finally, with what we did; but we took the lead in doing that. I might also say, when I talked about the V-nuts, I got a little carried away. But it turned out that Bob Gilruth and I got to be the—how should you say it?—parents of the V-nuts on the spacecraft, because we got to know *every one* of those darn things. I'm not kidding! We went through every one. We had "Betty" and we had "Ann," and we had every nut you can think on that thing; and he rolled his sleeves up and he went right through that with me, no question about it. So, he and I got to be V-nut experts. In fact, he even helped design some of the sleeves for them.

NEAL: He was Center Director at that time, wasn't he?

JEFFS: Center Director. You're damn right.

NEAL: Right down there with the troops.

JEFFS: Because it was a critical problem. He doesn't get down on every little problem on the system, but just those that have the potential of really knocking the system off the track.

NEAL: So, he was a boss and you were a boss, and you were right down there with the working troops in the field.

JEFFS: Damn right. It got everybody's attention, and it sure as heck got the problem solved in a big hurry. And then we finally sure as heck changed it to stainless-steel when we had a chance to do so; that's for sure.

I want to say one other thing about the NASA and this attitude of confrontation versus cooperation in combination of the forces. The NASA did an excellent job of changing the focus of their folks from one of just overview to one of rolling up their sleeves and working, too. Because the NASA had great facilities, and they had excellent people; and we worked out a system where the guys started to work together—our guys and their guys worked together—to go to the Moon. And where it was best to a job in their plant or their lab versus ours, it was quickly recognized and we quickly agreed. And we integrated that right into our plans. So they became an active, *contributing* participant rather than an overseer on the program, and that made a big difference.

NEAL: That's one of the tremendous coordination jobs. I'm thinking of the incredible number of *people*, just plain people, and the various *facets* of the program. You as the contractor—

JEFFS: We had 10,000 engineers.

NEAL: Ten thousand? Just you?

JEFFS: Just at Rockwell.

NEAL: Just Rockwell. Now add to that all your subs, and how many would you say the total number of engineers are you talking about?

JEFFS: Gee, I don't know. I think at one time we figured there must've been between 35 and 40 thousand people in the program, but that included everybody. I expect that the engineers were probably in the 15/16,000 category, something like that.

NEAL: Well, I guess we'd better spell out this as the building phase, having nothing to do with launching *per se*. This has nothing to do with flight *per se*, this is just the building phase.

JEFFS: No, no, this is just the R&D [Research and Development] phase of the spacecraft.

NEAL: An R&D phase that, now I think, we've come to a halt with Apollo 1. Because now all these things were beginning to go together. You were beginning to see some light at the end of the tunnel. Or were you? And suddenly, Apollo 1. Disaster.

JEFFS: Well, we thought we were starting to make some progress. I do say that. Since I'd been in the program it was only 9 or 10 months, something like that. So I had a lot of things that I was working on: organizing engineering forces and the subcontractors. Let me say one other thing we did with the engineering forces that relates to subcontractors. What we did was, in focusing the engineering organization on elements of the spacecraft, we took the responsibility for the management of the subsystems away from a separate procurement group and put that into the engineering organization; so that the engineering managers were accountable not only for the work that their guys were doing on the—let's say the—propulsion system, the SPS [spacecraft propulsion system], but they were accountable for what Aerojet was doing on the SPS. So, their manager, Bob [Robert E.] Field in that case, was accountable with his engineers for integrating into the spacecraft; he was accountable for everything that Aerojet did and for directing Aerojet; and he was accountable then not only just for the engineering; he was accountable for the contract; and that made a great, big difference. The accountability became clearer, as to who was accountable for what and why things weren't on time or what have you. That was *clearly* identified to the engineering managers, and that amalgamated the whole engineering forces, including the subcontractors.

NEAL: Once disaster hit, obviously troubleshooting was very much the order of the day. Sam Phillips once again looms large with the investigation. And finally, some answers came forth. You were playing an integral role with some of that investigation, were you not?

JEFFS: I was selected to peer—or whatever the word is—, I believe it was, the Thompson Board at the time? At the Cape, following the fire at the Cape.

NEAL: I don't remember the name.

JEFFS: Well, maybe I've got the name incorrectly. But I think that's what it was, I think. I've forgotten. It's one of those kinds of things that you don't want to remember any more than you have to about, because of the tragedy associated with the affair. But, I was put on the board, which was purely a NASA board—an investigative board.

NEAL: The Apollo Review Board, to give it its official title. That was it.

JEFFS: It was a review board. It soon became clear to the NASA lawyers that maybe that they had a perception of conflict of interest with me on the board, because I was North American. So, after the first couple of weeks of this activity, they changed that and make me an *ex officio* member of the board. My particular role in that was to try and bring the North American resources to bear to help with that investigation. We had no intention or idea of trying to cover anything up. We were trying to find out the problem just as much as anybody else was; that's for sure. As a matter of fact, during that first 9 or 10 months, one of the guys that I became very, oh, kind of technically close to was Chaffee.

NEAL: Roger [B.] Chaffee.

JEFFS: Chaffee spent a lot of time—we spent a lot of time late nights and otherwise, on things that were worrying him about the spacecraft, about the procedures, about the displays, the instruments, the panels, etc.; he and I talked over at great length or I'd get the right people in to talk them over with him that knew about it on into the night. Because those guys came out here and lived out here. Chaffee lived out here, you know, for that.

NEAL: As a member of the crew.

JEFFS: Yeah. Those guys understood their spacecraft, and he was accountable for the spacecraft side, so he really got into it. So, he was a tragic loss. They were all great guys, but he was particularly close to me in that respect. At any rate, we brought all the forces that we could necessary to try and lay out the timelines along with the NASA from the data we had available to identify any kind of areas that might give us clues to the cause [of the fire].

I was disturbed to find that, whether it had any role in the investigation or not—the cause—I was disturbed to find that things had been done to the spacecraft that I wouldn't have done. I say that easily in retrospect because I wasn't in on the beginning. But the wires, for example, were not really very well treated. They were kind of scattered around the floor of the spacecraft. They weren't in controlled racks. They weren't tightly tied and stuff. One of the reasons for this was that the guys were trying to save weight again. They didn't want extra rack weight in there to run wire runs and stuff like you've got in *some* airplanes—military airplanes; not too many commercial airplanes, but military airplanes. And a feeling that, zero g, there wouldn't be much of a load anyhow. A guy can jump around a wire; it's not going to hurt him; it's not going to hurt anything very much. I *guess* that was the rationale behind it.

But at any rate, the wiring was certainly something I wouldn't want to have in my own private airplanes or helicopters. And so that was kind of concerning to me. The other thing was, again in retrospect, that we had an awful lot of flammable material in the spacecraft; and by saying "we," I mean both ourselves and the NASA, because *we* had not made a special effort to keep the flammables down, the combustibles down, in the command module; and the NASA had Velcro all over the place. They had notes all over the place, you know; the crew had notes on procedures and stuff. It looked like a Christmas tree in the closeout photos. And so, the three things that we were obviously looking for were the ignition source, the combustible material, and the environment which would encourage or support burning; and we had all three. We never did find the real *initiation* point of all that, at least not to my satisfaction, we didn't. But, we fixed anything we could think of or find that *may have* been the cause. As a consequence of that, in about 1967, I think the earliest part of '67; is that about right? I think that's right—

NEAL: Yes, that's correct.

JEFFS: —the NASA sent two guys out as their leaders. One of them was Frank Borman and the other was Aaron Cohen. Borman from the astronaut side, Cohen from the technical and program side, and myself for North American Aviation. We went through that spacecraft in about 6 or 7 weeks, from A to Z, every system, every nut, bolt, rivet in the system; and we changed it. And we changed it, recognizing that we only had—what did we have? We had '67, '68, '69. We had 3 years to go to the Moon. And that was a big change; that was a big change to the program. But it also, interestingly enough, gave us a chance to clean up a few things that we were trapped into by prior decisions, such as some of these lightweight issues that I've talked about, and the aluminum tubing went to stainless-steel tubing, for example, that I'd referred to earlier.

Of course, the major changes were made in the hatch. I think the hatch job was a *beautiful* job done by a bunch of excellent mechanical designers in a short period of time; a very complex, double-door kind of a situation. That door was not easy to do in the first place, which was one of the reasons that it wasn't there from the beginning, to try and hold an outward-opening door and the seal against it. We changed all the wiring in the spacecraft. There were 25 miles, I think, of wiring; but I think 125 miles would probably be closer to it, seems like to me. That wiring all came out like you wouldn't believe; I mean, it's something you never see. It was beautifully combed, every wire bundle, every break-away, every limb was carefully structured so there were no pulling on adjacent wire harnesses; the ties were just right; the racks were put in to hold it; additional weight was put in to take care of all that. The parachutes were beefed up to take the weight. George [E.] Mueller, in one of the meetings, said to me, he said, "George," he said, "why are we trying to save all this weight in this command module with these changes? Let's just put the weight in there. We've got plenty of room in the booster. The trouble is, we don't have much room on the chutes; that's the problem!" [*laughs*] We were up around 13,000 lbs then; we were getting pretty close to the dynamic limits on the chutes that snap out at 15,000 ft. So we were getting kind of antsy there, but we put in new rip stops; and we put in new materials in the chutes; we built our own parachute lofts. We brought the packers over here. We packed them under our supervision. We came up with packing to densities that we hadn't experienced before; up to 100 psi, I think, were some of the packing densities we got into. I think we got—we were afraid that we might, over aging, crease the chutes; so we had to put age-life chutes aside to test them versus time.

NEAL: How would you describe the relationship in this building phase between NASA and North American? In other words, you've said "we," "we," "we." Was it truly a "we"? In other words, how did it work, function?

JEFFS: Yes, it was "we." It was "we." Because, you see, you know, in all this stuff the contract is always in the wings someplace. You've always got a contract with the government, and the contract has to be updated, and the funding has to be accordingly, and the meetings of the mind have to be accordingly, or it's not consistent. So, the NASA with the people that worked day and night just like we did—like the Aaron Cohens, in the case of the CSM, and his people. They hung in there, stayed with us, and everything. We'd make a change—all the changes were covered by technical directions which were then subsequently covered by proposals that we would give to them, and we'd go concurrently. We'd go and start the job before we'd negotiated exactly what the price was going to be for those things in order to not waste that time.

NEAL: And that was why you also set up—what did they call it? SPAN?

JEFFS: Well, no, I'll tell you. The SPAN is a little bit different. Now you're getting into the operational side. This is still *building* the spacecraft.

NEAL: Right.

JEFFS: Still building the spacecraft. The NASA moved fast, and they knew what was going on; but they had to know what was going on in order to be able to give concurrence in what was being done. So, *good* communications were established between ourselves and the NASA at all levels; and it was *unusual* if we didn't have calls through midnight and through the morning hours from different guys in the NASA, talking about these issues as we went along. I mean, the communication was that good; and yet the communication was *controlled* so that we weren't going off half-cocked. We'd document what we do. Now, let me add one other thing to that. In order to control this process, after the Borman-Cohen-Jeffs swath through the program, we set up a control bite, what we called MCRs, master control records, on the program. Master control records are a documentation of the job to be done. Let's say it's a hatch. They'll put together an MCR on the hatch. They might have a subset of MCRs for different elements of the hatch—the latch, the seals, etc.—but they'd have a total tree of that hatch. That goes into the drawing tree, by the way. But anyhow, the Program Office would put that together. They'd work with the design groups. They'd figure out the timing of the release of different parts of that in order to facilitate the fabrication. The manufacturing guys got into it at that time; they were *dragged* into it at that time. Not dragged, they *willingly* jumped into it at that time because they all started to work together. And the NASA would get into it on those MCRs. They'd see all those MCRs.

I reviewed every MCR in the program. I used to have stacks of MCRs. They'd come in a black folder, the MCRs; and they'd *have* to be written clearly, which is tough for an engineer. And the engineers started to learn to write when they brought those MCRs to me. And I'd go in there on—there was always something going on on Saturday morning, but on Saturday afternoons and Sundays, I'd go through those MCRs, and I'd read every one of those damn MCRs. I can see them in my dreams. I had *stacks* of them on my table; four or five stacks to the ceiling. I'd read those damn things, and go through them, and make some changes, and we'd cover those in the CCBs—our own change control boards, which I ran—and the NASA participated in our change control boards so they knew what was going on in great depth. So we controlled it that way, and that became a normal operation of the program. We had tables in those MCRs that showed that if *anything else* was impacted in the spacecraft when that change was identified—weight, GSE, checkout procedures, anything—all that stuff, the whole thing was included in those MCRs. And the NASA stayed with it. By them staying with it, they were able to support us contractually, because they kept their contracts guys apprised of their concurrence with the activity that was going on, and they *knew* what that activity was.

NEAL: You established a system—

JEFFS: And by the way, George Low, on their side, set up his own change control. So, all those things that had a higher level of impact to the program, and some that didn't—some of the lower-level items that he was interested in—would go to his change control board. And, I used to be—at least in the early beginnings, I'd represent us on those change control boards down there, because I was the one that signed all the MCRs back here. So, he did the same thing essentially across the program.

NEAL: You built systems, in other words, that really held up throughout the entire Apollo Program, didn't you? Systems in which the cooperation between the contractor and the NASA were at work, working *for* the program on a continuing basis. Obviously, you had to. And I guess this began to come to fruition when you flew with Apollo 7, the first time you went up there manned. What do you remember about that?

JEFFS: Apollo 7, we had—although time was short, we had built a lot of confidence in the system. Apollo 7 was not really that demanding a mission; you know, it was the short stack and not a 34, low-Earth orbit. We were concerned. It was our, you know, our first manned flight; so we were concerned with it. But, we had confidence in it; and the flight was a pretty good flight. It had a few chits in it. And one chit—as I mentioned to you earlier, off the air here—I mentioned to you that somewhere between our software and the NASA software, the axes got transferred 90 deg and so, instead of taking in the development of the passive thermal control system—the so-called "barbecue," as you call it for thermal averaging—instead of taking him around the longitudinal axis, we took him around the pitch axis! So we took him head over heels, and that kind of got everybody's attention; mostly Wally's. He reminds me of that from time to time. Who was responsible for that? I'm not sure yet. I'm not sure it wasn't somewhere down there in that flight controller's backroom somewhere. But anyhow, or we might have done it; I don't know. At any rate, nothing was really hurt by it. But, from our point of view, out of it didn't come any *major* changes we had to make to the spacecraft, as I recall, from that first flight.

We had done something else there. We had—again, it's a system of managing our resources. We had set up a system of kind of real-time reaction and participation for flight ops. We had our own control rooms back here at Downey, and the reason for that was that we wanted to be able to bring anybody to bear in the program any time of the day or night as quickly as possible that might be able to contribute to a problem resolution. We couldn't take *all* our forces down to Houston, so we had a lot of our people here, obviously, or we had them in subcontractors' facilities. We tied them all in to our net. We had real-time data presentation on our own CRTs [cathode ray tubes] here; the NASA helped us arrange for that transfer of data. They piped the data into us so we could do that here. And, we had a nucleus of our key people *down there*, working with them, in the Mission Support Rooms, backing the MOCR [Mission Operations Control Room], and in the SPAN, which was a management control room that was to help pull resources together from any place in the country. And, we participated with our key people in both those activities, throughout *all* the flights; and, of course, throughout all the flights, we did the same thing in the mission control rooms at Downey. And even in some cases where we had more classified material, we had them in a separate control room. It was a good way to bring the resources together throughout the world in real time on the program and have them play right into the flight controllers.

So, that was a system that worked out very well for us. We tested that on 7, too. It was kind of a test of that system to make sure that that system was working the way we wanted it to. And we learned a lot from that. It was kind of the foundation of the operating procedures for the mission ops support for the rest of the program while the program continued on into Shuttle and so on.

NEAL: I think you've covered the bases right through there. Now, other major decisions were being made during the entire program. We got you as far as Apollo 7; but think back with me on Apollo 8—a massive undertaking. They didn't have a LM [Lunar Module], and suddenly, "Let's go to the Moon!"

JEFFS: [*laughs*] The first thing that happened to us was that, "We didn't have a LM, so let's go to the Moon." It was basically, time was running out on us. One of the program foundations, of course, was to get to the Moon in the decade; and time was getting short. George Low, in his own offices with his own people and himself, how that transpired in this case, I don't know. But *he* was the thrust behind the cislunar flight of Apollo 8. I shouldn't leave [James A.] McDivitt and his troops out of there. Somewhere in that flight, on the docking system; you know, we were working on the docking system on the flight before that. I think I've got all that. I probably should look at those to refresh my memory here a little bit. [*Refers to his notes*]

NEAL: Sure. By all means.

JEFFS: Oh no, that's right. You're right. The Apollo 8 sat in there before 9; 9 was McDivitt was after that—

NEAL: 9 was the real test of all the hardware.

JEFFS: Yes, right. 8 came along because Low called up Myers, Dale [D.] Myers, who was the Program Manager at that time, and in so many words said, "Let's go to the Moon with 8." Cislunar. And Myers and Charlie [Charles H.] Feltz and I got together in our own little huddle and talked about what that meant to us; and were we ready to do that; and what areas did we have of concern; and what was the risk? What hadn't been thought of that should have? And what have you on that flight. So we spent some time. We spent kind of an ugly weekend thinking about that. But, we couldn't find any good reason for not going to the Moon. And of course, with the space program; you know NASA encourages anybody who's got a last-minute EO to hold it up before you go. If anybody's got a concern, hold it up. Of course, that was a big step for us to go to the Moon. We spent the weekend thinking about that, and I think we couldn't see any reason why not to support him fully in doing that. I had a lot of confidence in Borman; Borman knew the spacecraft well, he'd spent a lot of time with it, and he was the key man on board the mission to do that. And the flight controllers were ready. In the meantime, we had people in the flight controller corps, too, and we had some great ones there in the Chris [Christopher C.] Krafts [Jr.] and the Glynn [S.] Lunneys and others that were going to help take us to the Moon and back. So, off we went. Of course, if we'd gone to the Moon and lost it, we could have had the company still rotating around the Moon someplace. [*laughs*] But, everybody was informed. Let me see, was that before Bob Anderson or after Bob Anderson? [*Refers to notes*] That was before Bob Anderson.

NEAL: Bob Anderson, the President at one time and later CEO and Chairman of Rockwell?

JEFFS: Yeah. I guess that was '70. Was that '70?

NEAL: Yeah, or thereabouts.

JEFFS: I guess [J. Leland] Atwood was there at that time. But at any rate, nobody found any reasons not to do that. Off we went to the Moon. I think on the Moon we ran into a couple of things that were surprising to us. I'd spent time during the flights at Houston; I'd go to Houston because I'd figure there was no point in me going to the Cape. If there was anything that could be done to help the CSM, it was going to be done through Houston and not through the Cape. So I used to spend all the time for every flight down at Houston. And one thing that did happen to us that still rings in my memory is that we got into the penumbra of the Moon, and we really hadn't thought much about it on the flight path, but we got into the shadow of the Moon, and the spacecraft temperature started to go down. And I mean, they really started to go down! We thought we'd lost a couple of pumps in the environmental control systems. We were having a terrible time; and finally it dawned on us that some of the additional temperature data that we were getting on external temperatures and stuff like that, pretty clear that that's what was occurring. We were in the shadow. And, of course, it was pretty clear to the crew that we were in the shadow, too. So that was resolved, but it was kind of an exciting few minutes while that temperature really fell off the wall! Outside of that, an excellent job was done. The spacecraft proved itself pretty well in the environment; and, of course, it had lunar entry velocities, which was a good test of the heatshield. And the heat shield—it was also surprising on that flight to me that the heatshield probably could have been flown about 2 or 3 times. It could have been flown about 3 times. We could have carved that heatshield off. We could have cleaned the charred portions off the heatshield and actually flown that heatshield again, and still had enough depth in the heatshield to handle a reentry problem a second time, and maybe a third time, with a given heatshield if we'd wanted to operate the spacecraft again.

NEAL: Would that have been true for others in the lunar series? In other words, would the heatshield hold up that well after each of them?

JEFFS: Yeah. The heatshield held up pretty well.

NEAL: You found out, in other words for the first time, that the heatshield was not a matter of major concern?

JEFFS: Well, it was always a matter of major concern. But it did have some degree of reusability in it that we, of course, never counted on with Apollo. A lot of those modules were flyable again. I mean, there was nothing wrong with flying some of those modules again. But, the system wasn't structured that way, so we didn't. That was just kind of an interesting resolution. We always got tests of parachutes under these situations and flotation systems and so on.

NEAL: You were moving up in the hierarchy, it says here: Vice President of Apollo CSM Program in '69; remained in that position until '73. That allowed you a broad play of your various talents. What do you remember of that era in particular? We've talked Apollo 7, Apollo 8. What others of the Apollo missions come to mind? What other developments were key?

JEFFS: Let me say two things prior to that. One of them was: one thing, you know, being an engineer and a pilot, I had feelings for both sides of the equation on these spacecraft. And one thing that I wanted to do was make sure that they had a spacecraft that I would be willing to fly in; that I'd fly it myself. And that attitude kind of was pervasive into the organization. I was *tough* as an engineering manager and on engineers, because I was an engineer; and I didn't want any foolishness. I was—we just didn't have time for foolishness. And so, I was pretty tough on the engineers. One group of engineers that I was particularly tough on that, in turn, I think, turned out to be a wonderful contributor to the program, were the analytical groups. And there are two particular analytical groups. There were three of them, really; three key ones. One of them was the aeronautics guys, and the trajectory guys; and another one are the thermal guys, the thermal dynamics guys; and the fourth one are the stress guys. These guys were all critical, but they were all analytical; and they don't have any hardware to call their own; but every time a change would come into the system that involved them one way or another, I wanted them to come back and tell me they'd gone and looked at the hardware and put their hands on the hardware, and that the change that was coming before me to be made had their blessing as a result of their *detailed review*, and not just analysis. And that brought the analytical groups, I think, into greater play. The spacecraft was more theirs than it ever had a feeling of being before. They didn't *like* necessarily getting up in the middle of the night and going out and looking at an interrupter or something on the side of the heatshield, but they did it. And I think, as a consequence, we got better hardware, we got better people participating, and it was extremely helpful.

Moving up in the hierarchy, I guess you'd say, in the '72 to '74 time period I was—we had the continual problems in big organizations of functional organizations versus project organizations, and I had a *powerful* project organization, *technically powerful* project organization. And I had a *technically demanding* program that overrode almost anything else from a priority point of view. And so I was tough on the functional guys, the guys that were the experts in this and this and this, aerodynamics, thermodynamics, etc. I was very empathetic with the guys that were on the program that were doing it, more so. So we had this kind of a battle. Then I had to put two hats on, because in—I think it was '72 to '74, something like that, I was the Executive Vice President of the Division at the same time I was the Vice President and Program Manager of the Apollo Program, so I had accountability for both sides of this mess. [*laughs*] And, of course, you had the Saturn Program going on as part of this same time; Saturn II. We tried to work out a good balance here to get more program accountability into the functional groups. So I tried to do some of that in the '72/'74 period. But my heart was still with the Apollo Program; and in the Apollo Program then, from '72 to '74, I was the Executive VP, so the Apollo was still kind of the primary one. I don't remember, when was the last flight?

NEAL: The last lunar mission was ’72. So you were on the downturn by that time and worried about Skylab, of course.

JEFFS: Yeah. Then we worried about the four spacecraft for Skylab and what we had to do to the spacecraft for Skylab. I guess you asked me what happened on all the flights in between.

NEAL: What comes to mind? You know, as I say, we got as far as Apollo 8. 9, 10, 11—these were all key missions, and then, of course, there was always 13, which is a whole world by itself. So I wonder what your memories are of some of those flights? What were some of the keys?

JEFFS: The EVA [Extravehicular Activity] activity was always exciting to me; I liked the EVA. I liked the role that the hatch played in facilitating the EVA operations. We spent a lot of time with EVA concerns throughout the flights, particularly on into the lunar flights. We had all kinds of minor little considerations there on hand-holds and foot constraints and all these kinds of things, many of which interlace with the parachutes and parachute operations, so you’ve got to be careful what you do. So there were a lot of interrelations with the EVA. But I like EVA because, after all, the whole thing is kind of man-in-space; and the more we could do with man-in-space, the more pleased I was with what the system had contributed. So, Dave’s [David R. Scott] recovery of the films on one of the lunar flights from the camera, the bottom of the service module, all these things were, I think, excellent steps toward increasing manned activity in space the way it should be evolved, so to speak, on into Space Station and other things, if you will.

I guess one of the things in all these flights that doesn't meet the eye, you don't hear much about, and that the astronauts walk away from—and I don't mean to take the astronauts down; it's not their business to do that—but it's the guys in the back room that are continually going through that flight, going through all the data, which we did with a fine-tooth comb, every one of these flights. We were having, for example, some interesting damage signs on the parachutes, and we couldn't figure out where this damage was coming from. You know, we went to great lengths to work out the jettison sequence on the propellants on the spacecraft so that, hopefully, the nitrous oxide and the monomethyl hydrazine wouldn't screw up the risers and stuff and knock the chutes off there, for example; but you've got to get rid of it before you hit the water, because you don't want a bunch of hypergolics on board when you slap down in the water, just in case of a hard slapdown or something. So, we were going through all that and we found some strange kind of marks on one of the chutes, and we couldn't figure out what in the hell was going on. And we step-framed; we step-framed all the on-board film we'd get because we had on-board cameras, so we could get films of the chutes deployed and stuff like that, you know. One night we were looking at this, and we saw something that we thought was a speck on the film. It didn't turn out to be a speck at all. What it was, was, it was the beanie cover. We call it the "beanie cover" on the spacecraft. Essentially it covers the tunnel. The tunnel goes up through the beanie cover; it's got a hatch on top of it. The beanie cover is a thrustro-conical section with flat top and bottom, tapered; and that thing is released to lay open the chutes so the chutes can deploy. So you've got to get rid of that. The chutes are stowed underneath that beanie cover and so are the flotation bags. So that thing was released, but it would get *trapped* in the wake of the spacecraft in the atmosphere. It released if the drogue comes out at about 50,000 ft, and the beanie cover is deployed. The beanie cover then would trail in after the spacecraft, right along behind it. So, when the main chutes would hit, of course, it would slow the spacecraft down and the beanie cover would run through the chutes. We could have *wiped out* a couple of chutes there without any difficulty with that beanie cover. So, we went into quite a tricky design problem of how to put a parachute on that beanie cover, because the parachute had to deploy after the beanie cover was released and all this kind of stuff; so, it wasn't easy. But, it was the kind of thing that shows that extra tender-loving care that you *have* to give to these spacecraft for any bit of data you can that's going to improve the next operation; and you just can't relax, even after it's on the water and subsequently on the ship. You've got to follow it all the way through.

NEAL: There was a continuing progression in the development of the Apollo spacecraft right through to the bitter end when suddenly the plug got pulled, Apollo was allowed to go away, which we'll get to in just a minute. But I'm thinking of the continuing progression you've just cited. You've mentioned some of the things that were done on the way. Were there more, for instance, with Apollo 9? You checked out the spacecraft. Was that just a perfect flight? Or did you learn something from that for future reference?

JEFFS: [*laughs*] Well, you know, when you talk about these mission operation rooms, we talked about those here and you talked about the same at Houston, at the Center; and, of course, you can't talk about problems and problem resolution and carryover to fixing for next spacecraft without talking about a guy like Don [Donald D.] Arabian on the NASA side, who was an excellent "sparkplug", in my view, for their application of engineering know-how and brains to problems, and our own. We all participated in those meetings. So, every one of those flights had chits—they call them "chits"; I won't go on the television tape and say what else they might call those things—but there are chits for every spacecraft; and every one of those chits might look minor, but every one of them is an anomaly of some sort. It's something that either is operating differently than what we expected, or it isn't operating properly, or what have you; and it, of course, is followed through in depth and understood and *fixed* on subsequent spacecraft.

So, every one of those flights did give us something that either a change was made to a subsequent spacecraft or we better understood the system and how to operate it. But one of the flights—you know, we *choose* to make it more exciting for ourselves. For example, the lunar orbital injection burns are always on the dark side. They're always on the backside of the Moon. We don't have data. We have loss of sight. There's no line of sight, so there's no signal. And we don't know, of course, whether the burn is satisfactory or whether it isn't satisfactory until we see them come around the other side of the Moon. And of course, we can tell, depending on whether they're early or late coming around the Moon, whether you had a successful burn or an unsuccessful burn. And that's both going into lunar orbit and it's coming out of lunar orbit. Of course, coming out of lunar orbit, there's even more of that breath taking, because if they don't come out they stay, you know, unless we can fix the problems. We had a problem with, I believe, a secondary rate control sensor on the service propulsion system, the SPS which is the big engine, the big bell in the back that does the job. We had essentially a loss of the backup system, and we had to go through our redundancies to understand it. You have the A side or the B side; which side was lost? And, how to operate the system in its crippled configuration to give us the best chance of having a successful control during the burn. We went out to the spacecraft on the stand—our engineers *and myself* and others—and we actually gimbaled the engine out there to try and see what was happening to us on the wiring harnesses that led to that transducer. And we could see that what was happening is that manufacturing was doing such a beautiful job on the harnesses that some of the harnesses were awfully tight, and it's something you can't show in a drawing. You can't really show it on a drawing; and you can't rig it too well on your wiring mock-up boards, which are big and detailed. But, they got smoother and smoother; and as a consequence of this, the harness was actually *binding*. So we could tell, when you gimbaled, which angles were the toughest on that interface with that transducer; and that was all added information as to how we could best accomplish that burn then, coming out behind the Moon to get us back to Earth, by looking at what had happened out here on the spacecraft—*sister* spacecraft—that was sitting in the stands out in building 290 out here, as to how to *tailor* that procedure then for the next burn. Those are the kind of things that come out of each flight. Consequence—on subsequent flights, we loosened up on those harnesses a little bit; so we had a little more flexibility in those harnesses at that engine interface on the gimbal.

NEAL: I would ask, what was your favorite flight of them all in the Apollo series? And give me a reason, of course, for your choice.

JEFFS: Well, I guess my favorite flights were the last three of the lunar series flights. In the lunar series flights, we had—what did I do with my glasses?

NEAL: 15, 16, and 17.

JEFFS: We had an improving spacecraft. The spacecraft was really maturing. The number of chits that I talked about, I guess, had gone down considerably. They were getting to be miniscule in number. The EVA activity started to increase; on 15, for example, [David R.] Scott was involved in quite a bit of EVA work for us. 15, 16, and 17, the series was starting to contribute more, I thought. It got a little bit beyond its sensational aspect and started to begin to show that we could do things with our instrumentation that would, perhaps, give us some clues as to where the space program, and *reasons* for the space program going further in the future. We had, for example, deep-penetrating radars on one of those spacecraft, which we had to go and help RCA finally build ourselves. We used to send guys out—teams of guys out—to subcontractors wherever they were having problems, and we'd work the problems with them. We did that on quite a bit of the lunar instrumentation. So I guess, the answer to your question is: The lunar series, you know all three of them were kind of my favorites; and they were more my favorites because they got the next step beyond just the sensational part of landing on the Moon, which was the favorite of everybody—including my mother. But we got more into beginning to start up that hill of doing things with space systems that might help point the way to where we might be going in the future and how to go in the future.

NEAL: You weathered many a storm in the course of it. I'm thinking now, of course, of Apollo 13, which was—shall we say, a great *strain* on any group of engineers, to say the least. What are your memories of Apollo 13?

JEFFS: [*laughs*] Well, Apollo 13; I think they've made a lot out of Apollo 13 for the public and what have you. I think Apollo 13 was interesting from a couple of points of view. First off, as you say, it was a *shock* to an engineering organization; a *shock* to the whole organization. It threw the organization into a mode of trying to see what they could do to improvise, and to try and get out of that situation; and it didn't take them long to figure that out, and that was done not by a couple of guys just in a simulator someplace; that was done by a whole bunch of people across the whole program, trying to figure out what to do with that. It quickly got into power-down procedures, power-saving procedures, utilization of energy sources, backup batteries. Everything that we had in that spacecraft kind of came into play with it. Where to put the crews. How to get the amps down to practically nothing in the spacecraft. And, how are you going to live with the freezing in the spacecraft, and the cold in the spacecraft? That's the biggest concern we had in the spacecraft was the chill, the cold of the astronauts.

Once the initial shock was over, once the eruption had occurred, we still had part of the mountain left so we had a chance to get back. As soon as that was clear, everybody just kept working hard to make that happen; and they did. Yet, you know, we tried to get rid of those fans in those cryo tanks a long time ago, before Apollo 13; but the argument of the pousse-café problem—that is, the different stratification layers of the cryogens in the tanks—was a concern that kind of put the fans on a "Yeah, you need them" and "Maybe you don't them," "You've got them, so leave them in." But it turns out that in doing that, you complicate the interface at the top of the tank. And see, when you go with those tanks like that, that can't stand any kind of thermal leaks, to speak of they're double-walled, you know, vacuum-jacketed tanks, and they all come through a glass plug—all the wires come through a glass plug on the top of that damn tank. So, the more wires you put through, the more complicated that damn plug is on the top—which we finally got rid of those fans and we still ended up with the heaters in the tank. But you've got to keep that interface as simple as possible. The fans were an output of—how shall I say it? a science concern more than they were an engineering concern, I think; and the engineers didn't have enough guts to get rid of them early enough, and we didn't. We should've gotten rid of them before we did. Now the argument whether the fans were the cause of the problem or whether they weren't, I don't know, but I've always suspected those fans, and I'm just sorry we didn't get rid of them before that.

But I'm damn happy with the way that everybody responded, and we did get the right kind of actions into the system in real time, which is a credit to the total system that we and the NASA had an operation to do that. And separation, everything else; power for separation, the whole damn thing was thought through, once those tanks had gone, to the very splashdown point.

NEAL: In a very peculiar way, it was a rather classic illustration of how far engineering could dive into the barrel and come up with solutions based on *exactly* what you knew. You had to know—you, a collective "you," had to know—everything there was to know about the spacecraft and the human factors to make it work. And you did.

JEFFS: And how they interacted. Every one of these factors interacted. That's right. And I think, frightening as it was, it was a good example to the total forces that things can happen to you *fast* and you'd better be ready any time for them in spaceflight. There's no room for a wrong answer. You've got to have the total right answer and *fast*!

By the way, you know, in this whole development process, we ran across problems from A to Z that I think have resulted in better products throughout our commercial product areas. That we—I can't document all of them, but I can sure think of a lot of them. One of them was, for example, on bolts. We had bolt failures—high-strength bolt failures—and they'd fail at the V in the cut on the threads. So it was suggested that we go to rolled threads, which cost a hell of a lot more; but instead of having a V at the bottom of the thread, you've got essentially a radius at the bottom of the thread. So it cost a lot more money to build that bolt, but the guy that built those and figured out how he could do that for us, the bolt manufacturer, called me up later on in the program and thanked me so much for letting him participate in trying to help with that problem; and, furthermore, those bolts were now part of their standard line and he was selling them out the kazoo, you know! Rolled bolts. You see, they don't break that easy.

We had a guy, still do—each one of these guys is almost a hero unto himself in these engineering forces. There was a guy named Harry Horrey. You know, I mentioned Bob Field in the propulsion area. There was none to match Bob Field in propulsion. Harry Horrey was an electrical guy, and he carried through on all the programs. He went through all the Apollo programs, he went through all the Shuttle programs, etc.; and Harry was one of *the* top electrical guys around. And Harry was sensitive to ghosts; and we had ghosts on these flights, where you get a glitch somewhere—you get a computer glitch or you get a display glitch, you get some damn glitch, and you can't figure out what it is; and Harry was a guy that would hypothesize. He'd imagine a spacecraft that's got, you know, literally hundreds of switches in the spacecraft. Where in the hell that kind of a problem might come from, and circuits and everything else, and braces. But anyhow, he contributed, as a result of those searches, to a lot of switches that are a lot better these days. We had solder ball bounces, for example, in relays. And what had happened in zero g is, if you had loose solder balls in a relay, they'd bounce around in zero g and they'd essentially close the damn circuit for you! And the reason was the manufacturers of the relays, in one g, don't have that much concern for debris in a relay because it's not going to go anyplace. But at zero g, they float all over the place. So, new procedures on cleaning out relays in the process came about; and you won't find many relays now out there commercially that aren't cleaned of solder balls, whereas before they were. We had whiskers on switches, where the wiring would actually, when you'd attach it, there'd be miniscule whiskers that you couldn't see; and those damn whiskers could go across to an adjacent pole and actually give you an instantaneous short, is what they do, and give you a glitch. And those were what caused the ghosts. Most switches nowadays, they trim them up pretty well and you don't have those kinds of whiskers on switches.

We had *problems* that were happening to us that we couldn't figure out *what* was going on. It turned out that we were getting some of these glitches because of a corona effect; and the corona effect was occurring because, in the connectors—the potting compound, the RTV, which was used in all these connectors—sometimes when it was put in you'd end up with bubbles in the RTV; actual little gas pockets in the RTV. Corona occurs at 111,000 ft altitude equivalent, something like that you get corona. Once you get through 111,000 ft, you're in a vacuum, so you don't really have a corona problem. Interestingly, what had happened with these gas pockets was: How do you get corona in spacecraft in space? You know, you're not at 111,000 ft; you'd have to be at just the right density of atmosphere to do this. What happened was that the gas was actually leaking out of these bubbles after they'd been sitting there in space for an indefinite period of time, and the time that it took for the gas to come out was a function of how deeply embedded that darn bubble was in that potting in the connector. When it would finally come out, we'd have the equivalent of a corona effect, which would then go away because the gas would go away. So as a result of that, on all subsequent connectors, *every* connector in the spacecraft, they were *all* potted with hypodermic needles; special care was taken so there was *no bubble* in any one of those potting compounds in those connectors. And that—an interesting problem, an interesting ghost run down by Harry Horrey.

NEAL: So right at the pinnacle of success, just as Apollo was really rounding out and moving well along, this was the time when the NASA budgets began getting short and the program was being denigrated. I wonder what your thoughts are of that period of time, and how did you hold that team together as you had suddenly a lot of layoffs in the workforce? This would have been in that era, you remember, starting immediately after the landing on the Moon, we began hearing the stories and we began seeing the effects. So you're coming into an era, during the same time that the best flights were being flown.

JEFFS: Right, well, you're right. We had a workforce that was going downhill, obviously. We participated in the Spacelab Program with the provision of the spacecraft, 4 spacecraft, for the attachment to getting up there, and also for getting back; and we were worried about some of the systems that had to operate for long periods of time, like the environmental control system, where you might dry out the wicks and dry out the cooling system itself so it wouldn't operate properly. So there were things to do, but they were minor things to do. The support of the spacecraft in the flight, in the operations, was about the only major thing for the organization to do.

As you say, we tried to maintain the corps and keep the corps together. We tried to sell the idea of additional J-series flights—that is, the lunar flights—because they had derived so much data. But one of the problems with deriving scientific data is, it takes so long to analyze and you get so much of it that the results and reasons for additional spacecraft are too long and too far down the road to have helped us very much. So we did move our forces around to other Divisions, and we did disperse a lot of the forces. We did take up on the Apollo-Soyuz Program, and we had to make a number of modifications to the spacecraft to do that, to interface with the Russians; none of which were great; but there was a lot of work going on in the docking system, for example, in the docking module, which was the decompression or compression chamber between the two vehicles. A sidelight of that was that, that module was originally designed as a module with pressure-proof rivets in it. And you can build a skin stringer construction with rivets in it, but you have to—on the rivets—put a little rubber grommet on them, that's kind of like a washer, that seals them; makes it very complicated to do that, and it's not leak-proof; and it's getting very expensive. I got so upset with it then when the guys came to me I said, "Well, why don't we just roll it? Let's just roll it out of a solid piece of material, and we'll machine the side fittings out of it." And we did, and that's what it finally ended being. Because, see again, weight was not a problem. But everybody was so conditioned, like Pavlov's dog, to thinking about weight that nobody could think about, "Well, heck, you can put additional weight up there because it's not coming back. [*laughs*] You know, it's not going to be on the parachutes, and you've got plenty of room in the boosters" So, we finally did that. But it was one of those things that, "Gee, why didn't we think of that before?" you know. The only reason we thought of it was because I got *tired* of all this nonsense with this leaky skin stringer stuff.

But anyhow, I think they did an excellent job with Apollo-Soyuz. I was interested to be able to assess the Russian capability, to a degree, myself, doing that as part of those teams that went to Moscow, Kaliningrad, to do that. I found the Russians to be very prideful, moreso than they probably deserve, because *Apollo* did most of the work on Apollo-Soyuz. I mean, the control authority was in the Apollo, the RCS [Reaction Control System] control was much greater than Soyuz. The materials were so much better in Apollo. Although, I say that with tongue in cheek because, you know, one of the things we did, that I didn't mention, on Apollo was—and in the future, if we ever have to do anything like that again, we'd better figure better ways—we went to a latte coat on all those panels, where we latte-coated the panels. That's the same as taking a radio, an expensive radio, and just *filling* it with plaster of Paris to keep it from burning so there'd be no ignition source. Anyhow, we had a little of that; but the point was that the Apollo was a much superior spacecraft to the Soyuz, and by design. It had more things to do than the Soyuz did. It was a much more elegant spacecraft, and certainly the redundancies were much better: the wiring was better, materials were better, the control authority was better. They had a pretty good docking system, though. Their docking probes were pretty elegant, and so we learned a little bit from the Russians. They had a screw jack kind of a docking extraction system and retraction system, and it was pretty well done. They had some *good* docking people, and they've shown that in their *Mir* operations and stuff.

NEAL: Isn't that a remarkable parallel? We had the Skylab, the Spacelab; they had *Mir*. *Mir* stayed up there for 12 years; we allowed ours to go away. I wonder what your thoughts are on that.

JEFFS: Well, we tried to talk [James C.] Fletcher into boosting it up and keeping it up there. All we needed was some altitude. We figured we could boost it with a CSM; and I think they had other ways to boost it, too, but the CSM was the particular way that I recall. But, for whatever reason that took place in the Washington arena, they decided not to do that. They decided to worry more about where it would come down in Australia or what have you. But it seems to me, like you say, we had the makings of a pretty good station right there, and why we didn't take advantage of it is probably budgetary. Just budgetary, money, and support from the Congress.

NEAL: Well, of course, too, all of the Apollo technology was certainly not lost but was changed into something else: Space Shuttle. And you played a key role in getting that on the road, too.

JEFFS: I'd like to say here a few good words in the Apollo Program to some of the political people. We had political people that were instrumental in the Apollo Program and in subsequent programs like the Shuttle; it wouldn't have happened without them. Guys like [Olin] "Tiger" Teague were just invaluable to the space program. So whatever program you have in the future, the more allies you can get that understand the program, that concur with the program in the right places; the more allies you can get obviously the better off you are. But, we wouldn't have gotten there without Tiger Teague on Apollo.

And as far as the rest of the Apollo Program's concerned and on into the Shuttle, guys like Don Fuqua provided the foundation for it. They're not alone. There were some other excellent supporters in Congress, too. I took Tiger Teague, when he was dying, down to Cape Kennedy in a Sabreliner on a trip that I was on from Washington [DC] to the Cape. I took him down there and circulated him among the troops and got him into the Shuttle bay down at the support room there—the Orbiter preparation room—and stuff. He was overjoyed, and so were the troops. So, we shouldn't forget those guys. Nobody does in Washington [DC], because without them you don't have anything anyhow, so that's not a message for the Washington guys because they've already got that message. But, boy, a few of them like Tiger Teague in the future are just darned important in the space program!

We took the Apollo know-how and applied it to Shuttle. When I say "we," again, I'm talking about NASA because the NASA-Rockwell team was an operative element; it was an organization, kind of a seamless organization the way we worked on these programs. We did that with the Orbiter. We brought to the Orbiter all the know-how that we had on Apollo, and that's not just the *technical* elements of the system, but it's also the management systems; exactly how we worked together. How the engineers were structured. How the interface between ourselves and the NASA—how they were controlled. How the subcontractors fitted into it. How are procurement systems tied into the whole thing. The Air Force just recently, you know, they were talking about the integrated package stuff, the IPTs and stuff like this; and *seamless* organizations. Well, we essentially had a seamless organization on Apollo, and that seamless organization was applied to the Orbiter. And, I think, we did the Orbiter with much less time and money than the equivalent of the Apollo; and a good part of that was due to the know-how, the moxie, the people knowing how to get the job done and what systems to use in doing it. We attacked the problems just the same way.

One of the things the organizations do is when you get an excellent technical organization like NASA on the customer side that works as hard on a program as they do and in as much depth, then our forces can work much better with them and, as a consequence, the rapport is easier to build. You get to the point where you know each other's strengths and weaknesses, and you can rely on each other. So we did that with the Shuttle. If it hadn't been for Apollo, you wouldn't have had the Orbiter that you've had. The Orbiter was the foundation—I mean the Apollo was really the foundation for the longer-life Orbiter. As you say, you know, a lot of Apollo, we could have flown many times, many missions. Even the heatshield, a couple, three. But I think that we had those kinds of things in mind on Apollo, longer duration, more missions for a given spacecraft, usability. And I think the Orbiter is an *excellent* first step in the reusable system spectrum. I think it's proven itself; it's proving itself that it can do that.

NEAL: Time and again and again and again. Recently, the *Columbia* flew, I think it was, the 26^{th} or the 27^{th} mission. Did you ever think it would come to that, George?

JEFFS: Well, let's see, how do I answer that question? I guess, as far as the requirements are concerned, you know, everything that was done, was done with—take the heatshield. The heatshield was supposed to be designed for 100 missions with a factor of 4 on that. So, you've got to believe that at least the engineering effort was made to provide it with the capability of going on and on and on like that. You begin to believe it, that it can do that, and I think you're doubly—how shall I say it?—pleased or, whatever—satisfied that when you see it actually in action, happening, and it provides the basis for doing that, then I think it's gratifying that the engineering was well thought out in the first place. I was very surprised on the first flight of Orbiter, examining the tiles, for example, and finding that I had much less damage to the applied tiles than I thought we were going to have after that first flight.

So, it's got all the makings of reusability in it—except for the first stage, of course. The first stage-and-a-half or whatever. As far as the final stage is concerned, it's reusable.

NEAL: On a very personal level, do you think space, the exploration of space, really has a future?

JEFFS: [*laughs*] You know I laugh at that because, after Apollo—was it 8?—or after the cislunar, or maybe it was after the lunar landing, I can't remember which, Bob Gilruth and George Low called me into their office; and I really didn't know what those two were up to when I went in there. But, they wanted me to start thinking with them about, you know, what's space good for? What are we doing this for, aside from the follow-through on the Kennedy announcement? What can we do with space now to really take advantage of our ability to get there and operate, at least in a limited fashion, there? You've got a vacuum. You've got zero g. You know, what can you really do? And, I didn't have a good answer. You know, I had all the standard answers that everybody else does: the electrophoresis and all those kinds of things you can do in the way of processes to make better materials; but by the time you pay for the transportation costs, though, you're not so sure you've got that much of a competitive edge.

And so, it just seems to me that, you know, mankind's destined to go into space—sooner or later we're going to get there; we're going to have to get there, I think, one way or another. [*laughs*] We're going to be forced to do it. We want to do it anyhow. I think we're going to be disappointed that it takes longer to do it than we'd like to have it happen. But as the generations go by, it'll happen. We've got to learn to go faster, and we've got to learn to live longer; and those things are important. But the systems that we build and the more we learn about how to operate man-in-space, the more foundation we'll have to step off to go further; and I think it's going to take us a while to evolve into that. I think the Space Station—although I was not a great supporter of Space Station to start with—I think it probably is a logical evolutionary step of improving man's ability to operate in space, to work in space, to use space as a base, to use the Moon as a base, or whatever's necessary to, you know, investigate the planets and then gosh knows what, if we can, in the many generations ahead. So, I can't sell space on the basis of you've got a super vacuum, you've got zero g, you know a big facility that's a beautiful research-and-development facility, but I do think that it's in destiny. I think that you're going to operate there, and the sooner you begin to learn about how to do it the more useful it's going to be, and the more *critical* it might be as the generations go by.

NEAL: I think we've pretty well covered all the bases that I wanted to cover. Is there something, George, that you would like to have had me ask that I didn't ask?

JEFFS: Well, probably one thing that you didn't and I probably should have said was that: The people in this equation are so critical. The people involved in the operations played a very strong role in this whole process, from two points of view—more than that, but two key ones. One, the guys like the Chris Krafts and the Glynn Lunneys, the [Don] Puddys, the whole bunch of guys down the line, they exemplified the name of teamwork, of everybody working together in real time. They exemplified that. They exemplified that as leaders. And I think that that was pervasive; and it affected all the organizations, even the design organizations, with the rigor, the dedication, the discipline, the know-how, the knowledge, the hard work that went into operating. And that was carried over from the point of view of, "That's what we're going to do." For example, on Orbiter, guys like Chris and others exemplified that "We're going to fly this machine. This is not a briefing chart we're going to fly, fellows. You know, if aerospace could fly briefing charts we'd have been on Mars a long time ago!" [*laughs*]

These guys are *real*; they're for real. And they represent, they epitomize that, "What you're doing out there on the drawing-board is what's going to be flying in space not too much in the future, fellows. So, start thinking about it that way; start thinking about it that way. This is no longer fun and games. This is for real." So they brought that to the program. Those guys were so good that I tried to hire a bunch of them. In fact, I did finally. I hired guys like Glynn Lunney. I would have been delighted to hire guys like [Aaron] Cohen. I hired guys like—well, we hired Jim McDivitt, for example; Rockwell did. Chris consulted for a while for us. None of that has anything to do with what they did for the company. What that has to do was getting influx into our organizations of people that think like that, that make our organizations start to think like that; and that's the kind of thing that makes it happen.

I have high regard for all those folks. I wish that more of that would flow into the aerospace industry as a whole. I think the aerospace industry does itself a great disservice of not being more realistic and including that kind of thinking in what they do. I hear too many people promising things in aerospace on the basis of the contracts that might come out of it rather than on the product itself, if you will. So, I have trouble with that.

I have trouble with the Shuttle replacements, the X-33 or whatever you want to call it. I think that's a carrot-and-the-stick kind of a thing, relative to technology. But, I'm not so sure it's worth the kind of money we're putting into it at this stage of the game. To me it's something like propulsion that's going to be the key in that, in order to come up with a single-stage orbit kind of a machine. In the meantime, I think that we ought to take advantage of what we've got, like the Shuttle, and I'm not even involved in the Shuttle Program at all anymore. But the Shuttle Program, it's like you say: It's going to operate for many reusable periods. Whether it gets to 100 missions or not, I don't know; but it could well if you keep working on it. And you're paying a lot of money for it; and it *works*! You're not going to get a new one until technology takes you down there, and that's going to be propulsion, I think, not things like the X-33.

But anyhow, it's been for us—for me, personally, a grand event. Although like Chris and I have often remarked to each other, "Don't look at that. Don't look at that Moon. [*laughs*] There's 20 years of our lives" or whatever it was, 10, 15 years—"It's just *gone* up there!" But, on the other hand, it's probably the most exciting thing that's happened in my lifetime, getting there and what it means to where you can go beyond it.

NEAL: Leaving all that aside now, this is for something that will happen come this Fall, and I'm just sort of building a little bank when I ask this question: John Glenn is getting set to fly again. I wonder what your thoughts are about John revisiting space.

JEFFS: [*laughs*] Well, I have to give that some thought. I just got through saying earlier there's nothing wrong with making sure you've got excellent Congressional support of your programs. [*laughs*] And whether the NASA—I'm not at all privy to data that they may have had that would show the before-and-after comparison from a physiological point of view is a big contribution. I really don't know about that. But, I'd like to see as many *young* people in space as possible because you're not here many years in this lifetime, and the more you learn early about it, the better chance you have to contribute to it as the years go by. So the younger you are up there, I think the more of a contributor you're going to be to what happens downstream. Now if John brings to the table, because of the before-and-after uniqueness, that's something that the medics have to assess. But for me, I'd put young people up. I'd like to fly it myself. I fly helicopters myself; I fly them still, all the time. I own helicopters; *love* to fly! But, if I tried to get into space now, I think it would be more of a self-edification sort of thing than it would be contributing much to the space program.

[End of Interview]