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EDITED ORAL HISTORY TRANSCRIPT

CHRISTOPHER C. KRAFT, JR.
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is August 6th, 2012. This oral history interview is being conducted in Houston, Texas with Dr. Christopher Kraft, former Center Director of the Johnson Space Center. Interviewer is Rebecca Wright, assisted by Jennifer Ross-Nazzal.

KRAFT: The [Space] Shuttles were made in those Management Council meetings. What brings me to that is that in the latter part before we flew the Shuttle, there were X number of Criticality 1 problems. Well, I shouldn't call them problems, but Criticality 1 means that if you had a failure of that particular function or system or part, you would lose the spacecraft. During the latter phases before we flew we reviewed in detail at the Management Council every one of those. I mean in dirty detail, total detail. I would like to ask, "Where is that recorded?"

At that point in time, of the Shuttle accidents, [Space Shuttle] *Challenger* [STS-51L] and *Columbia* [STS-107], nobody ever talked about that in anything I've ever read since then. All these reviews, all the oversight that was made of the program, nobody ever talked about the fact that those things were reviewed. That's number one, but number two is I don't believe anybody remained in the top management of the program that knew what those decisions were. That's very very dangerous.

The Space Shuttle was like any other space vehicle. Weight, performance—that is power, liftoff capability—always a major issue, always will be in any space vehicle. You're always fighting weight. I tried to find a piece of paper written by Caldwell [C.] Johnson. He

wrote a paper that said spacecraft grow like babies. Regardless of what you do they're going to gain weight, so you're fighting weight all the time. Therefore, trying to do certain things that you would like to do sometimes can't be done because you just don't have the physical capability of overcoming the mass.

You have to make critical and judgment decisions as to what you can do, what you can't do, and when you can do it, when being the better of the evil and the good. Somewhere along the line you have to say I'm going to build it. If you keep saying I can make it better, I can make it lighter, I can make it perform better, yeah, you can do that. On the day you fly you can do that. Remember, that's a very important aspect of any kind of particularly aerospace design. You never ever get to the point where you're satisfied that you couldn't have done it better. But you're never going to fly if you have that attitude. Never.

As we were building the Space Shuttle, we knew we did not have an escape capability for the astronauts. We tried every way we could think of to overcome that, like you would in Mercury or Apollo, and in Gemini, which was terrible. Ejection seats. But the mass of this thing was so big, weighing 200,000 pounds sitting on the pad, the Orbiter, there was no rocket that we could jam up the tail of the thing that would allow us to get the whole spacecraft off, which is what you would like to do. You'd like to fly the damn thing as an airplane.

Secondly we then asked, "Is there any way we can build an escape pod?" Blow it off the end of the Orbiter if we have a malfunction of the engines that causes an explosion or solid rockets that fail. So we tried to build a pod. That was a failure because of two major things. Number one, it was extremely heavy to do and very difficult to separate it and propel it away from an explosion, overpressure or ball of fire that happens when the rocket might have exploded or the tank blew up. But secondly it's another spacecraft. It has problems of reentry, depending

on where it happens. It has major problems in control. You can't just let it spin. You've got to try to put it under control and guide it to where you want it to go, or at least try to guide it. As we investigated that we spent a lot of money looking at it. We spent a lot of money deciding that by God if we're going to fly this thing we can't do it. It's technically not feasible to do it.

Now I'll give you some background there. The Air Force with the B-50 something, think it was 50 something, in that time period, built a fighter bomber by Convair. They put a pod on that front end to save the crew instead of parachutes, instead of ejection seats. They couldn't make the damn thing work. They just flat eventually gave up on it. Took it off. They threw it away, because it was not practical. I give you that background. If we're going to fly the Space Shuttle, if we're going to go into orbit and carry 65,000 pounds with 1,100-nautical-mile reentry, we just physically technically don't know how to build an escape system for this vehicle.

Now what are we going to do about that? What is our answer to, "Well, are you just going to give up on trying to save the crew if you have a major catastrophe?" The answer was no we're not. Well, how do you say that? Number one, we've got two solid rockets on the outside of this machine on the pad. What is your escape system normally? Solid rockets. What's the reliability of the solid rockets that you use in the escape system? Probably 98 percent to 99 percent. What's the probability of failure of these two solid rockets on the side of this vehicle? Probably 96 percent to 99 percent. What can we do to make them 100 percent? Because if they are 100 percent or damn close to it, the solid rockets on the side are our escape system. That will push this vehicle to 150,000 feet, at which point we could separate the Orbiter if we have a problem and can't go any further and fly it back. As a matter of fact from 50,000 feet we could fly it back, if you could separate it. But separating it ain't no easy problem either at Mach something and high dynamic force.

So that was our answer to the question what are you doing to save the crew. Was that acceptable? It sure in hell was to everybody on the Management Council. It sure in hell was to anybody that asked us within the NASA management chain. It sure in hell was to anybody that asked us period. A lot of people didn't ask us I guess, but we asked ourselves. Now we also spent millions and millions of dollars on the software and those computers to be able to do that. We could fly that machine back to a landing at Cape Canaveral [Florida] or a landing in Africa if the machine was intact. We provided the software and the quad-redundant computers that would allow us to do that if the machine was intact.

That's what we talked ourselves into if you want to call it that, but I felt comfortable with that. Now I don't think anybody in the whole system thought more about the safety of the crew than I personally did or my people did, recognizing that we couldn't damn well fly that machine if we hadn't made that decision. Now the other thing we did, similar decision, was when we first started designing the machine we had a go-around capability; i.e., you could approach the runway at Cape Canaveral and if you weren't satisfied with the approach, wave off. We could start some jet engines, drop them out of the wing, fly around and try to land again. It didn't take us long to figure out we couldn't do that either. It weighed too much and it was very complicated and it added a whole fuel system, tankage, lines, all kinds of control systems associated with the engines, and the engines themselves, and the fact that they had to drop out of the airplane somewhere, carried in a pod somewhere. Add all that up. It's too heavy.

So we said can we land it dead stick, pilots call airplanes with no power, glide it, we got enough L/D, lift-drag ratio, to fly this machine as a glider, and how do we prove it. We proved it. We did the Approach and Landing Test. Pilots didn't have any trouble landing it. They landed it 135 times and didn't have any trouble landing it. Well, that was a pretty good decision

also, and allowed us to do the program. We couldn't have done it if we'd tried to keep those engines on. So the two, the escape system problem go together and the wave-off capability.

Now let's go back to Mr. [Michael D.] Griffin and Mr. [Charles F.] Bolden. Mr. Griffin comes into the program as the new NASA Administrator and says, "Space Shuttle is a flawed design. It has no escape capability and it is too dangerous to continue." He kept using that statement. He used it when he first became the Administrator. He used it with the press, used it with the Congress. I finally decided he ought to stop saying that, so I wrote him a not short e-mail. I said, "Stop using that term flawed design. It is not a flawed design. Here's what it is." I explained to him what I just did to you. Why and how we made those decisions and what you could do with what you had. I said, "I can't overcome the fallacies of man in my spacecraft design. I can't overcome the stupidity or the lack of knowledge or whatever that goes into making decisions, the decision-making process that people have. I can't overcome that. I can overcome systems problems, and I think we did." That's what I told him. I said, "I think the system works, has worked, and if you treat it properly will work."

Further, he and Mr. Bolden said it was fragile. Fragile. That's a poor choice of words for any spacecraft. I've never known a spacecraft that wasn't fragile. I don't give a damn what it was. Whether it was Mercury, Gemini, Apollo, Skylab or anything else, they were all fragile and proved to be so. That's what you live with. That's what spaceflight is all about. It's difficult. It's hard to do. It has structural problems, has thermal problems, has reentry problems, has control problems. It is fragile. But the Space Shuttle is probably the least fragile machine we've ever built.

Now let me prove that. When we designed that machine we did what we called—I think I've said to you before—we built it with a point design. What that means is that for every Mach

number and altitude and dynamic pressure that that vehicle is going to see on a specific trajectory within very narrow limits during launch and during entry, it's only designed to fly down that trajectory. Only. Get that. Only. It won't fly anyplace else, because we don't know how to do that. We still today do not know how to do that. This thing is not an airplane. It doesn't just go up and fly. It comes down a very very controlled trajectory. Up and down.

We go to great lengths to keep it on that trajectory, or we did. We put up balloons for launch. We knew exactly what the winds were. We knew exactly what the dynamic pressure was as we went up, and knew that it was within the limits of our design. Same thing is true when we reentered. The computers kept that machine on the trajectory which was very very carefully designed. For those pieces of information going up and coming down, it is not fragile. It will withstand a safety factor of 1.4 minimum on every piece of structure, every piece of thermal, etc.

So to call it fragile is to say you don't know what the hell you are talking about. In spite of the fact that it is fragile if that makes sense to you. I can't take a hammer and beat the hell out of the thermal protection system, but I can tell you that it will withstand 2,300 degrees Fahrenheit without slumping. I can tell you that the nose will be at 3,500 degrees, which is almost the temperature of the surface of the Sun, and withstand that temperature. It's proven to be. There was never a failure of a tile that you would have called a Criticality 1 situation. Never in the history of flight. Never in test. We proved it by test.

To say it was fragile because of the tiles or fragile for any other reason is false. It says you don't know what you're talking about. You don't understand the design. So I say to you go get all of the decisions we made in terms of the fragility, in terms of the mass, in terms of the performance. You'll find that we were very careful about that. When we said the solid rockets have to have 100 percent and somebody abrogates that position, which the people that designed

the rockets said they didn't want to do, and yet NASA did it, that's fool's play. Not systems design. I can't overcome that. Same is true of the piece of trash that came off that tank that hit the wing. I can't overcome that. They should not have allowed that thing to fly under those circumstances, either the rocket or the tank.

Seventy-seven flights saw pieces come off of that tank, and they didn't fix it. The creed in Project Mercury was if you know of a known problem, you will not fly, or you must have technical sound engineering reason why you can. They abrogated that creed if you will. Don't know where to go from here. That's what I wanted to say to you.

You said, "Looking back on the Shuttle Program what do you believe to be the greatest strengths?" Well, it would do anything you would ask it to do. It would put up 65,000 pounds into low-Earth orbit at 28 degrees' inclination. It didn't matter what you carried up there. It would do the job. It would add beneficial help to you to check out the vehicle before you released it. You could bring it back if it didn't. You could go up and capture a satellite that had failed. Whoever thought you could do that and bring it back, fix it and fly it again, which they did? Whoever thought you could take the Hubble [Space] Telescope, which was totally useless because of failures of engineering judgment at the Marshall Space Flight Center [Huntsville, Alabama], and yet the astronauts fixed the damn thing for them? It was a brilliant piece of engineering to put something on there to compensate for the flaws in the mirror. That was a pretty good job, wasn't it? So I can say that the Shuttle did everything you could ever have asked for it from a performance point of view.

I don't know anything that you ever asked it to do that it didn't do, except for the two flights that failed. It ended up putting up 1 million pounds into Earth orbit and building the biggest monstrosity in spaceflight you've ever seen. What else could do it? It could have done

the same thing in going back to the Moon, and should have. You could just as well put things into orbit around the Earth and then go to the Moon, which is the right way to do it, because then you can build spacecraft that never have to enter the Earth. Just fly them back and forth from low-Earth orbit to lunar orbit. Translunar spacecraft. Don't ever have to come back to Earth unless you want to put them back in the bay of the Space Shuttle and bring it back. They can just stay there. Have an assembling point. Have a fueling point. You could do all of that with the Space Shuttle.

No, that's not good enough. NASA has got to have a new project. I did ask Mr. Griffin. "Well, why did you give up on the Space Shuttle?"

"Well, I had to make a decision," he said. "The [President George W.] Bush administration says you can only have so much money, and so I figured that the only thing we could do was give up the Space Shuttle. Take that money that it cost to operate and fly the Space Shuttle, and build a project to go back to the Moon."

I took him to task about that. But that was his answer. Now he would later say, "I have to agree with Dr. Kraft. That was not a very good decision. We should have kept the Space Shuttle. I would have done that, had I known that we were not going to get the money to build the lunar mission."

He would say today, "Yeah that's the right way to do it," because I forced him to say it. I got that on e-mail if you want to read it. But he says, "I decided that in this political world I'm going to go for the gold." Which is the big SLS [Space Launch System]. It's the wrong way to do it. Nevertheless that was his decision making process.

Now I said to myself—not being a party to any of this anymore—well what could I do to maybe overcome that objection. Maybe I could get USA [United Space Alliance] to take this

machine over commercially and fly it themselves. They could use what's left over in terms of flights for their own purposes. Sell it. I couldn't get them to do that for a long while, but eventually I did. Eventually they made a concrete proposal to Ms. [Lori B.] Garver and Mr. Bolden, that USA would take it over. We will absorb two thirds of the cost and if you give us the facilities initially, you give us the vehicles initially, we will eventually pay you for them, and eventually all you'll have to pay is the cost per flight. They refused.

They refused to even report it to the Congress that they had such a proposal. Mr. Bolden and Mr. [William H.] Gerstenmaier who now is a chief technical guy in [NASA] Headquarters [Washington, DC] would not take it forward.

Further, about six months later a group of financiers in Great Britain, in conjunction with George [W. S.] Abbey and others, proposed to buy the damn thing. NASA refused to accept that proposal, said they didn't want it. So I go back to the point. With the Space Shuttle, with the Atlas V, with the Delta IV, you could go back to the Moon easily relative to Apollo in about a decade.

Further, we had the Europeans agreeing to do exactly that and be a party to the program and build those parts of the vehicle which NASA did not want to build or could not afford to build. They still want to go. You read in the newspapers today that Russia and the Europeans are talking about doing it without the United States, without an SLS. SLS would probably be a great vehicle, but you probably won't be able to afford to fly it either. Even if you had it you probably couldn't afford to fly it. What else do you want to know?

WRIGHT: Well, Dr. Kraft, let me ask you since you're talking about cost. Sometimes when people have referred to the Space Shuttle Program as being flawed they refer to also the cost of operation.

KRAFT: Good point. Let me talk about that. People will say today, Bob [Robert F.] Thompson will say today, that we never really believed that we could fly 40 flights a year. We never really believed we could turn around [the Shuttle] in two weeks. That was just a salesman pitch. I'm here to tell you that's bullshit because I worked my fanny off to try to do it. You could do it.

Now why couldn't you? Because the culture of the system wouldn't allow it. Cape Canaveral engineers, Kennedy [Space Center, Florida] engineers put more hours of tests in the hangar than they ever put on flight, probably the first X number of flights. Why? That's their culture. They didn't have to do that. The machine had quad redundancy. We didn't put that on there to say that all that stuff had to be working on the pad. We put it on there to allow you to have malfunctions of various systems that would still allow you to fly. Called it FO/FO/FS, fail operational/fail operational/fail safe. Now had we known how they were going to use it, had we known that we couldn't overcome that culture, we wouldn't have done that. That was a damn fool thing to do to put that much redundancy in there. If you have to have that much going for you at the time of launch you can't launch it. I don't mean that literally, but it's very difficult to do that when you have that many systems that we put on there as redundancy backup.

Four computers, three APUs [auxiliary power units], should have had four, four IMUs [inertial measurement units], you can go anyplace you want in that vehicle. It had quad redundancy. You had valves. You had power systems. You had anything that was in the line of criticality had quad redundancy. That was built for the purpose of doing quick turnaround, of

having quick performance, of having high reliability. We used nothing but highly reliable parts in the machine. They cost money. Because you prove that the things will work. You don't buy transistors that fail and have infant fatality or something like that.

Everything we did was done on the basis of trying to get quick turnaround, trying to say just bring it back, look at it, follow the trends of the system with all the instruments. Again 1,000 points of instrumentation on that machine so you could follow the performance of the systems and see how the trends were that those things might fail and replace them before they did fail. That's what we asked for. You could say this is what it was doing when it landed, this is what you have to check out, go back to the pad with it after you've done that, and now you get on the pad and launch it again. Well, there might not be something working. That's what you got the quad redundancy for.

So if you said you were going to do that, you could have done it. Not inside the NASA culture. I wrote a report about it. Mr. [Daniel S.] Goldin—and a group of people—asked me in 1994. They were already taking quite a bit of cost out of the program. I have to admit that. They got the cost down from about $3.5 billion to $2.5 billion. He said to me, "I want to get another $1 billion out of the program in terms of operating costs. Can you help me do that?" I put together a group of people including George [W.] Jeffs, several people from Marshall, several people from the Cape including Bob [Robert B.] Sieck, and Frank Borman. We met and met and met, and we wrote a report that said here's how you can do it. That's what formed USA. That's a NASA report. Got NASA on the top. Not me. NASA. That said you could do that and here's how to do it.

As a matter of fact here's several ways you can do it. That's what I went back to USA with. Finally pulling eyeteeth got them to write a proposal, which NASA refused. So all I can say to you is I could not overcome the NASA culture.

WRIGHT: You mentioned that NASA at some point wants to move on to another spacecraft instead of utilizing fully the capabilities of the Shuttle.

KRAFT: I think it's probably that, but I think it's the politics. I think the recognition by the Administrator that he has to make decisions, and if I'm going to have a program I have to give this one up in order to have the next one. I don't disagree with that. I recognize that as a political problem. I'm not saying that you can run the program in a political vacuum. You cannot. You have to build the damn thing inside the politics. But that's possible. To say that we didn't have any politics in Apollo is nonsense. We did. We sell the program every day. The Shuttle was even worse. You had to persevere. You had to do it, do it and reduce the cost. You had to extend the schedule. You had to do everything you could possibly do to keep the program alive, and we did.

I don't argue the fact that it's hard to do. I don't argue the fact that maybe it's impossible to do sometimes. You have to give up. That's what happened on the new lunar program Constellation. [President Barack] Obama came in and his people said, "We're not going to support it." I thought that was wrong. That was the politics. [Norman R.] Augustine comes in and writes a report. From a technical literary point of view it's the worst damn piece of paper I've ever read. I said that publicly. It made no sense. If you read it, it says do this, do this, but if that doesn't work do this. What kind of damn nonsense is that?

Or he said you should never start the program unless you have a guarantee that the budget is going to be there. What the hell? Has he ever seen a national budget? It only goes for a year. How the hell are you going to figure that out? No NASA program has ever been run that had enough money. If you say I got to have the check in the bank before I go you're not going anywhere. That's what his report says. His report says build a big rocket. That was an MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts] demand on his board of people.

I realize that's an opinion. It's my opinion. It was opinion of a lot of people with any sense. He says do the commercial business. Well, what's commercial about what we were doing for God's sake? We just gave them another $1 billion yesterday, whenever it was. That's commercial? Mr. Elon Musk. He shoots his mouth off. I don't know how much money he's got in it. Maybe $100 million at the most, and that probably wasn't his money. Probably somebody else's money. That's politics. The politics. Lori Garver particularly decided they're going to push the commercial program.

I wasn't opposed to that, I was just opposed to the method. As a matter of fact, I consulted for one of them who was trying to build it, Orbital Sciences [Corporation]. They didn't win one of the contracts, but that's because I probably insisted it had to fly.

WRIGHT: Dr. Kraft, how much do you think the Shuttle's future was impacted or the decisions were impacted when the decision was made to stop taking commercial payloads as in the satellites that were going up prior to [Space Shuttle] *Challenger* [accident, STS-51L]? Do you think that had some type of impact on how the Space Shuttle was perceived?

KRAFT: No, I don't think so. We sold the Shuttle on the basis of the fact it would do all the NASA programs, all the DoD [Department of Defense] programs, and all the commercial programs. Bob Thompson said well, we knew it wouldn't be able to do that. That's partially true, but that isn't to say we couldn't have. That isn't to say that we shouldn't have. In my opinion we could have. Now you ask me could you have made the Shuttle better? Hell, I gave you that answer at the outset. Of course you could make it better. JSC had a list of about 40 items under Mr. Goldin. He was given $1 billion in budget to do it. He used the money on something else, because he couldn't build the damn Space Station the way it was going. I don't know what the politics of that was either. I've written a whole paper about that, by the way, the history of the [International] Space Station, how it got where it is. Very interesting. It goes from an $8 billion program to a $100 billion program. It goes from a program that weighs about 40,000 pounds to one that ways 1 million pounds.

WRIGHT: I'd like to see that.

KRAFT: The program management goes from poor to nonsense. I have a paper on that. A piece of white paper on that. Mr.—what's his name—came in at the request of the president, I guess it was George [W.] Bush, to take a look at the program. He totally ignored all that. I know him very well and I wrote him a letter and said, "How could you ignore the past of the program?" He said, "Because I was told to." So that's the politics. It's there. I can't overcome it. That's true. He couldn't overcome it either, and didn't choose to.

Tell you an interesting story, a sideline. I got a telephone call about six months ago from Mr. [Edgar M.] Cortright. Know who Cortright is?

WRIGHT: Yes.

KRAFT: He says, "I want to apologize to you," for something that took place when I was back there working on the Apollo 13 tank. Now if you read my book, you'll find out that on Apollo 13 the tank failed not because there was anything wrong with the tank, but because they used it improperly. Number two, they replaced the heater with a larger heater but they didn't replace the switch through which instead of a half amp now flows one and a half and the moment you hit it with that kind of power burned the goddamn points.

The heater is on all the time. It burned the damn insulation off the wire inside the tank as they emptied it. Now that didn't have a damn thing to do with the tank. Mr. Cortright comes in and says, "You got to rebuild a new tank and you have to put in all these new wires. Glass-covered wires." Very difficult to build. I know, because I watched it being built. It cost us $50 million to build a new tank. But the thing that I was ticked off about was that you're now going to fly a tank on Apollo 14 that's not qualified to fly in space. Whereas the tank that flew on Apollo 13 was qualified to fly in space, if you hadn't abused it. I asked him that—Dr. [Robert R.] Gilruth and I asked him that. His answer was "Well, I got my reputation to worry about."

I knew there was no way I was going to overcome that. Now when Neil [A.] Armstrong wrote his book later, 10 years, 15 years later, 20 years later, whenever it was, he was on that committee with Cortright, but he had to leave. He wasn't there when they made up their mind and said what they were going to do. He says in his book, "Well, if I'd stayed I would have agreed with Chris that we didn't need a new tank." So here's Armstrong saying we didn't need a new tank in his book.

[The Space Shuttle is] called the most complex vehicle ever built. What improvements could have been made to increase its efficiency and performance constraints? Well, to begin with, there were a lot of things you could do without doing anything. For instance when we put the Space Station up and with the agreements that Vice President [Al] Gore made with the Russians, we couldn't put it up at 28.5 degrees' inclination, which is where it should have been. I'll say a little bit more about that shortly. We had to put it up at 50 degrees because that's the only place the Russians could get to from their launch site with their launch vehicles.

The engines and performance were now not good enough for all the mass they wanted to put up inside the Space Shuttle, so they had to increase the SSMEs [Space Shuttle Main Engines]. You had to increase the performance of the SSMEs from 1.06, which was max, to something like 114 percent, 115 percent. Now that drives the temperature up, drives the requirements on the pumps up. You had to go redesign a lot of it. It cost a lot of money.

On the other hand if you flew the SSMEs at 98 percent performance, which you could on almost every flight, the reliability goes up so high, you would never have to look at it again. That's one thing you could have done.

The tank was too heavy now to get this performance, so you had to change the tank to aluminum. They had to add a material, [aluminum/lithium alloy]. Now let me tell you, you couldn't weld it with the weld process that we used. It's hard enough to weld aluminum, which they developed a whole new process to build that tank. Now they have to redesign the weld system. The cost of building a tank went from the initial estimates of $2 million, then $8 million, 40 million bucks per copy. So instead of making it better and more efficient, they made it better and more expensive. Now how could I have done that? Well, I could have gotten rid of the APUs. That was proposed. I could have gone to electric motors. I could have done a lot of

other things. I could have improved the electronics. I could have changed the computers. I could have improved the hell out of the thermal protection system by densifying all the tiles at the surface. I could have changed the material in the tiles. On and on. I could have modernized everything on it, and increased the efficiency and decreased the cost of operations, if the culture would have allowed me.

So the better is the evil of the good. Yes it is. But we could have brought the cost down. We could have improved the hell out of it, within the cost. That's one of those things that in the politics of NASA and the politics of the Congress, very difficult to do. NASA doesn't like to do things that way. In that regard going to the commercial world is the right thing to do. They don't have to abide by all these government clichés. I was a party to that. I think it was a good idea.

I wanted to get rid of NASA out of the Shuttle, period, and said so in this report I wrote in 1995. I think I told you that story. I went down to the Cape to look at it personally four or five times when I was writing that report. I'd go down there. George Abbey, I didn't have to do much, because he would always tip me off as to what to look for. You go look at the R&QA [Reliability and Quality Assurance] people, and you look at the list of things. Seventeen people have to sign off on a process that they've got. Seventeen people. That not only is expensive, it's stupid. Not only that, the 17th guy says all 16 of these people have signed off, why the hell wouldn't I sign it. You only need one. Only need one.

I said in my report, well you're spending $500 million a year on reliability and quality. You don't need to do that. Cut that down from 500 people to 100 people, you'd be just as well off, and maybe better off. When Mr. [Harold W. Gehman, Jr.] wrote his report on the [Space Shuttle] *Columbia* [STS-107] accident, he said Kraft is part of the problem because he said get

rid of all the reliability people. That isn't what I said at all, but that's the way he interpreted it. He said, "Kraft said don't make any more changes to the Shuttle." That isn't what I said at all.

I said the big problem you have at the Cape, one of the big problems, is that you're piecemealing changes, and therefore the procedures for checking gets changed every time you do that, don't do that. Do it in a block concept. Save your changes up. I didn't say that by myself by the way. Save all the changes up and make a block change, what we did on previous spacecraft. That's what we did. We didn't change it continuously. We saved up our changes and put them in the next spacecraft.

WRIGHT: You feel like some of those lessons that you learned in those early unmanned programs got lost along the way as part of the culture?

KRAFT: Exactly. Yeah that's the reason I was asking you about the chronology and the reporting of this thing. People have forgotten that. I'll give you another example. I got an e-mail three or four weeks ago from one of the top flight directors. He used to be head of the Flight Director's Office at JSC. Still there. Like to retire. He says, "I got a question from a pseudohistorian at Cape Canaveral. Says he's looking at Apollo 4, and he noticed that they did a skip reentry trajectory in that test to prove the thermal system on Apollo."

The question he asked was "Is that the way they did Apollo?" He, the flight director asked that question. He sent a note to me and several others. My first statement was "That's a damn dumb question. But I won't say it's dumb. Here's the answer. Of course we used the skip trajectory in Apollo. We dove it in, killed off part of the energy, took it back out, and then came in at the normal entry velocities, so the heat shield design did not have to overcome 36,000 feet

per second, only 25,000 feet per second, and we could design the thermal system to do this. Furthermore, we had a mechanical device on board which the astronaut looked at to make sure it was following that trajectory. Furthermore that was the reason we had to be damn careful when we came in to make sure we didn't skip out or dive in. Furthermore if you go to Google." I looked it up. "Here's a report written by Mr. Claude [A.] Graves and Jon [C.] Harpold that says Apollo reentry. It's got all kinds of lines and altitude and skip trajectories in there, it's got the note that describes this mechanical device. It's a 15-page report." [NASA TN D-6725]

WRIGHT: Jennifer encounters that a lot.

KRAFT: So don't tell me about the need to keep these things in mind. It's absurd that people don't remember things like that. What the hell are they doing in the business? I'm an old man and it's still all up there. I guess they're all dead. That's classical. That's what happened in the Shuttle. It hadn't been that long, had it? People forgot the decisions that were made, the reasons the decisions were made. The reasons why decisions are made are important because that determines how you're going to use the machine.

WRIGHT: That may be the piece that's missing; the reasons why those decisions were made. Not just what the decisions are.

KRAFT: Exactly. You deserve to ask, "Why did they do that?" And there is an answer. We didn't just pull it out of the air. We did that in excruciating detail.

WRIGHT: Since you mentioned SpaceX. I have to think you've been watching some of how that came about with their process to enter into the exploration business. Do you feel like they're applying many of the lessons that NASA and that you learned as you were coming through those early days?

KRAFT: I hope they are but I doubt it. But the technology is very superior to Mercury, it's very superior to Apollo. Doing it today is a hell of a lot easier. It doesn't require the detailed testing and design that NASA put into it in those early days, so it is easier to do. It has been done, so the test program doesn't have to be the same. That's what makes it less expensive. That's what allows you to be able to do it. You can hire engineers that can read. So yes, it is a lot easier for SpaceX to build a Mercury capsule because that's what it is, or an Apollo capsule. They haven't built the manned one yet.

WRIGHT: That was my next question.

KRAFT: Well, they're going to find out that in order to satisfy themselves, I hope themselves and NASA, that it isn't easy to prove that it's safe. I just think that's where the costs are going to be. That's where the rub is going to be. But I don't think they'll have trouble doing it if they are wise people. There's no reason why they can't hire some good wise people.

I was consulting for Orbital Sciences. I know Orbital Sciences was one of the best companies in the country compared to SpaceX, and they were not very smart. I'm no brilliant damn engineer, but I could tell them what to do. That's why I asked you about the Monte Carlo process. That's another interesting story. Bob [Robert G.] Chilton, very close personal friend of

mine, was up at Texas A&M [University, College Station, Texas]. He taught there for quite a while. After talking to you I said, "I'll call Bob." I said, "Bob." Same question I asked you. "Do you know of any documentation on the Monte Carlo process that we used for looking at the reentry dynamics of the Shuttle?"

The answer was "What's a Monte Carlo?" He was responsible for the goddamn thing. "What's a Monte Carlo?" You even know now what a Monte Carlo is. I had a lot of experience with Monte Carlo analysis because that's what John [P.] Mayer and Bill [Howard W.] Tindall and Emil [R.] Schiesser and others used to analyze the trajectory analysis back in those days.

WRIGHT: It is a very different and maybe somewhat of interest time in space exploration. Of course we're sitting here on the morning of the news that the new rover hit successfully on the Mars surface. It at least gives a little bit more excitement for NASA to have a success to talk about.

KRAFT: What they did this morning was fantastic. You don't really know how fantastic that was, because it's like the reentry of the Space Shuttle in that they had to design it with wide variations in environment to begin with. They didn't know what the density was going to be, what altitude was going to be. That makes a big difference then on the aerodynamics that you're going to have to use to slow the thing down, and how the parachute is going to open and on and on. So that means they had to expand the variables. To do it under those circumstances is pretty damn good.

WRIGHT: I believe one analysis person made the remark that it was somewhat reminiscent of Apollo. With the ascent engine and the parachutes and the whole episodes of having to figure out all those variables that if one didn't work nothing was going to work.

KRAFT: Right. Absolutely.

WRIGHT: That was a good analogy I thought.

KRAFT: Yeah. If you look at Apollo 11, if you had tried to do that automatically on Apollo 11, the landing on the Moon, I think you'd have waved off. The system would have waved you off. But we had some people on the ground saying it was still working okay. We had guys in the spacecraft that said it was still going where they wanted to go. That allowed you to do it. But that was part of the system too, wasn't it? Because that's what that damn control center over there was for. We had 5 million words of computer capability, which is peanuts today.

WRIGHT: The comment you made a while ago about SpaceX, that the technology is easier. But I guess the decision making process is the same.

KRAFT: Yeah. They must have some pretty damn good engineers. That's all I can say.

WRIGHT: Well, I think that's the history of space exploration, is having the engineering force.

KRAFT: Yeah, engineers are pretty good guys. They're not the smartest people in the world. I mean that literally. But they know how to get a job done. That's what you need. You need both. You need a Max [Maxime A.] Faget and Chris Kraft. We were the antithesis of each other, but you needed both. I and my people, not just me, but all the people that I had working together, we knew how to attack a problem. We knew how to look at all the ifs, ands and buts. Then we knew how to evaluate it, and where to take the risks, and within the risks, how to overcome them. That took a lot of effort, a lot of work, a lot of money to do it. Then I went out and tried to sell that idea.

I went to work for GeoControl as a consultant and tried to sell the mission control concept to the power companies. Nuclear power companies. That was a tough sell. They still had all the bells and whistles in their control room. You can't do that. Now they have all the things we had, but I couldn't convince them at that point in time. That was in the late '80s. They ought to get rid of all the Bourdon gauges and all that stuff they had in their control rooms and go to some software displays, etc., which were readily available. Here it is. Well, it's a good idea, but we tried to sell that to the Electric [Power Research] Institute in Stanford [California], who was their research group. They said, "Yeah it's a great idea, but we'd have a hard time selling that to the practical guy in the field." But today it's there.

If you'd had that, the thing that happened in Three Mile Island [Pennsylvania], [Eugene F.] Kranz went up and looked at that when they had the Three Mile Island [nuclear accident]. He was overcome with disbelief that they would do that. They turned the system into a system that wasn't there. Working on the pump and the cooling pump, so they had this one offline. The emergency system said turn it onto this system, and the pump wasn't there. Any modern display

system would have a big red light that would come on that hey that pump isn't there. That was pretty dumb.

You asked what were the weaknesses. The weaknesses, it did take a lot of turnaround capability initially, because you had to fix the tiles that were beat up by the damn foam coming off or the rocks coming up off of the runway. When we first flew it, smart us, we put these sod lines in the runway so that we didn't have to worry about the brakes and the tires skidding and all that sort of thing. Well, hell, it brought chips up off the runway when it landed. Ran all over the tiles and marred the hell out of them. So those kinds of things had to be done.

There was a lot of maintenance you had to do when we first started flying. The first time we lit the damn fuse, they got overpressure from the solid rockets, and knocked about 25 tiles off the back end of the vehicle. Fortunately they were all noncritical tiles. Max Faget figured that out on the back of an envelope, how to fix that.

How do you fix it? He went out there and looked at it and put a bunch of V-shaped canvases, filled them full of water and killed off all the overpressure. The pressure coming back when you lift the solid rockets came back up out of that trench and knocked the hell out of the back end of the Orbiter. Three or four psi [pounds per square inch] overpressure. So yeah, we learned a lot of things as we went along. That was the main thing I was going to talk to you about. I just remembered.

That piece of paper I sent you about the management team meeting and people criticizing the hell out of Ms. [Linda] Ham and the program manager at the time, [Ronald D.] Dittemore. That wasn't where the problem was. The problem started way before that. The culture did change in NASA. That woman that came and said the culture had changed on that review committee unfortunately is right as hell. I would never have admitted that, but it was true.

It started when [James M.] Beggs came to be the Administrator. We'd had these meetings on the intercom between the management in Washington and the management in Houston once a week, and talk about the problems, etc., etc. Beggs, when he got to be the Administrator, started coming to those meetings in Washington, and he started arguing with us over the intercom. I started telling him he was full of shit. That didn't go very good, not very well, he didn't like that. It was customary in NASA, I believed, to say it like it is. You're talking about people's lives, you're talking about the program, you're talking about things that if you're going to do something and don't do it right it's going to fail. That's the way I tried to run my organization, that's the way I wanted my people to be the same way. If I was wrong I wanted to know it. Don't tell me later that you were wrong. I want to know it right now. Tell me I'm wrong so I can change my mind and change the way we do business.

Anyway, because of that environment, it had become more and more difficult to make decisions as we normally made them. You could make a decision, and if it was wrong you could change it. Well, that came to a head on—I don't know if it was the first or second flight. But on one of the first Shuttle flights we had three fuel cells and the program had a mission rule that said in the first several flights, if you have a failure of one of the fuel cells we don't have enough batteries on board the space vehicle, the spaceship. We only got enough batteries to last about an hour, so that's not long enough to get to another landing site. So if you have one fuel cell fail, how do you know that's not a generic problem? We hadn't had enough experience on the fuel cells.

The mission rule said if you have one of the cells go out and you will therefore come down on the next available prime landing site. It happened. We did it. We announced we were going to do it. Well, Beggs got on the damn telephone. We were assembled. All the major

leaders of the program were in one of the rooms over in the Mission Control Center, including me and George Jeffs and Glynn [S.] Lunney and Ed [Edward P.] Smith who was chief engineer of the Shuttle. We'd all talked it over. Yeah, that's the right thing to do.

He calls us on the phone and says, "You can't do that."

"What do you mean we can't do that? That's what the mission rule says."

"You're ruining the reputation of NASA." He says this on the telephone. Gave us holy hell for doing it.

He got through talking, and I said to him, "Sir, this is what we're going to do, that's what we decided. We're going to bring it down." He was really pissed off at me. This group walked out of that meeting, and we looked at each other. We had another meeting that said from now on we're not going to tell that son of a bitch a damn thing.

Now we didn't put it that way exactly but that's what we did. We're going to make our own decisions in these matters and we're going to follow it through. If he wants to undo them, he's going to fire us. He did. He fired me. But that was the genesis of the *Challenger* accident right there, because people stopped being as forthright. People stopped reporting things. On the *Challenger* accident they weren't reporting properly. It was worse on *Columbia*.

The management process failed, but that's where it started. People started going underground with the process because they didn't like all that damn criticism they were getting from the management in Washington. They said we're not going to put up with it. Now that was okay as long as you had people like me there, or George Jeffs from Rockwell. It was okay because we knew how to deal with that. But we left. Now you got people over there that don't have any guts, so the system keeps getting weaker and weaker and weaker.

Eventually that's going to bite you. When you don't tell it like it is in our business, it's going to kill you, and it does. That's a very unfortunate thing. But it is true. Now I don't know that you would ever write that. I don't know that you would ever try to explain that. I don't know that anybody would agree with that. I know my friends would agree with that, but Beggs would never agree with that. He would say, "Well, they were recalcitrant."

I don't blame him for firing me. He didn't like the way I operated. He didn't like the way I told it as it was. A lot of other meetings after that. When they were trying to rewrite the contracts at the Cape to get rid of Rockwell, Beggs was the kingpin of that. Beggs didn't like Rockwell. He told me. The day he came into my office, the first day, he said, "I don't like Rockwell. I don't trust those people." I was overcome by that, because that's a stupid statement. But that's the way he operated. He was one of those kinds of people that operated that way. So when they wanted to change the contract at the Cape, eventually that's a good idea. I myself recommended that, and do it on a competition, because it brings the cost down, etc. But it wasn't the time. It was in the first days of the Shuttle. Even if you got rid of Rockwell you're going to have to hire them all back because they're the only people who know how to do it. You're going to have to teach whoever came in there all the stuff. I said it wasn't time. "Can't do that right now. I don't want to spin that contract." He really got ticked off at me.

Walt [Walter C.] Williams was in the office. There were three or four of us in the meeting, just that number. He said, "Well, Walt, what do you think?"

He said, "I think you better listen to Chris."

So then he looks at me and he says, "Goddamn it, Kraft, when are you going to be ready to make this change in the contract?"

I said, "Sir, I'll damn well tell you when I'm ready."

I'm sure that was the day he decided I'm going to get rid of that SOB. I'm sure. I had other people telling me you can't keep doing this or he's going to get rid of you. Hans Mark wanted to get rid of me anyway. So they did. They could, because what I did was retire, and then they rehired me as a rehired annuitant, because if I didn't do that I was going to lose all kind of money in my retirement, when they changed the retirement in the government. Jack [R.] Lister came and he got about 20 of us together, old heads, and said, "You better retire now and let NASA rehire you, because that way you'll be under the previous retirement system." When we did that we gave up all the civil service protection, so he had to rehire me every year. Best thing that ever happened to me, because I went out and made money.

WRIGHT: Got a few more rounds of golf in, didn't you?

KRAFT: Yes. I went to work for Rockwell. They paid me. Rockwell immediately paid me $200,000 a year as a consultant. I was worth every damn penny of it when I first went to work for them. I later quit because I wasn't. I worked for them, I consulted about 10 years for them, and I said I'm not worth the money they're paying me, so I just quit. Chairman of the board called me and said, "We got to have you." I said, "No, sir, I'm not worth the money you're paying me, I'm through." But at that point I'm now on four, five boards where I'm making a lot of money, so it didn't matter.

I was on the board of a hospital company. I was on the board of the Park Plaza Hospital, board of governors. These people saw me there, and they asked me to be on their board.

WRIGHT: Did you work any more with Max Faget after you left?

KRAFT: Oh yeah. I was on his board too.

WRIGHT: That's what I thought.

KRAFT: Max was a great guy. A very interesting person. After he'd been the president for a while he asked me to go on the board. He said, "When you were the Director of the Center, I thought you were doing a terrible job." He said, "I've since learned how good you were."

WRIGHT: It's always a different perception when you're sitting in that "The buck stops here" chair, isn't it?

KRAFT: Like Mr. [Harry S.] Truman says. You can't stand the heat, better get out of the kitchen.

WRIGHT: Interesting time.

KRAFT: But I'm just reminiscing here. I enjoyed every damn minute of it. I wake up in the night sometimes thinking about all the great people I worked for and with, the things we were able to do together and how we did them. How we got them done. Absolutely phenomenal. Without somebody like Gilruth and George [M.] Low it would have been impossible for me to do what I did.

WRIGHT: What do you feel like their characteristics were that allowed you to be able to do what you did? What kind of leadership attributes did they have?

KRAFT: I've tried to think about that. My definition of leadership is the number one requirement is you have to be willing to accept the responsibility for the organization of which you are a part and the people in it. If you aren't willing to do that you can't be a leader. That's a hell of a responsibility if you do it right and do it well. That's where it starts. So I say I was willing to do that. But number two, I was willing to let somebody else do it. I always believed in giving people responsibility for doing the job, and letting them do it without interference. You'd find that they weren't doing it like you wanted it done half the time. But it was being done, and it got done, and in the end might have been better than what I was thinking about doing. So I think that's the two characteristics of leadership that you have to have. That's hard to do.

My mother used to say—I think it was my mother—she used to give me a lot of cliches. "You don't learn anything while you're talking."

WRIGHT: That's a good one. I like that.

KRAFT: I love that. You don't learn anything while you're talking. Second thing she said was "You put everybody's troubles in the barrel, you always choose your own." Part of my philosophy of life I guess.

WRIGHT: I remember you sharing that one before. I've used it often. People sit and think about what a horrible day they have, but if you think about somebody else's, yours almost always seems better.

KRAFT: Absolutely. Go look at somebody else's problems. They're big relatively speaking.

ROSS-NAZZAL: You mentioned that you were the antithesis of Max Faget. Can you explain that? I'm curious. Can you expand on that?

KRAFT: Yeah, I was good with people, he was not. I was willing to accept the idiosyncrasies in the system. I was willing to live within the rules. I was willing to make it happen in spite of that. He was not that kind of character. He was a perfectionist. He wanted to do the thing with the best technology. He wanted to do things that would extend the schedule or make it better or make it easier. He wanted a straight wing on the Shuttle. He was right. But sometimes being right is not the way to go. We were just two different kinds of people. Gilruth sure recognized that. He called me in. He said, "If George and myself can make it happen—" he had to say that—"we're going to make you my deputy because I want to retire, and I want you to be the Director." Scared the hell out of me.

I said, "Yes sir, I'm going to do what you tell me."

Fortunately it happened. But after he had done all that, then he called me back in his office. He said, "I'd like for you to consider having Max as your deputy."

I said, "Bob, I won't take the job if that's the case." It was that simple for me. He and I could not have worked together. The reason I gave him was I said, "Well, I don't think we're

very compatible." But I said, "Also he's more important to the organization where he is than he would be my deputy." That was my answer to him. I said, "No, I won't take the job though if that's part of the requirement. I won't take the job."

WRIGHT: Well, it seemed to work out pretty good. He was probably happier with that anyway.

KRAFT: I needed a special guy to be my deputy. He had to accept my way of doing things. I had 23 people answering to me at the Johnson Space Center. That's a terrible organization. You don't run organizations that way. That's the way I wanted to do it.

I thought it worked pretty damn well because I was willing to do what I said before. I was willing to have 23 people doing what they ought to do, how to do it, and telling me what they were doing, and how do I help you get it done. I was willing to make decisions. I was not afraid to make decisions. Somebody taught me early in my life I guess that you've got to make decisions. If you don't make them the system just won't work. The damn organization won't run. This machine won't go unless you make a decision. If it's the wrong one okay, you find that out and change it and do something about it and make it better next time. But the system has to have leadership. It has to have people telling them what to do. As long as you're willing to listen to how they want to do it. You got to be able to listen.

That was Joe Shea's problem. He couldn't listen to what other people wanted to do. He wanted to make the decision, he wanted to do it himself, he wanted to be the guy in charge of everything. You can't be that. Particularly in the business we were in. We had 400,000 people working on the job. How the hell do you get 400,000 people to do the job unless you can trust the others how to do it.

That's the reason I got along so good with Rockwell. I caught a lot of guff for that. You're too close to the contractor, they would say. On the other hand, I was in charge, I insisted that I be in charge of the award fee for Rockwell. Headquarters tried to take that away from me four or five times. But I used that to control the program. If they did a good job they got the money. If they didn't do a good job I didn't give them the money. In one case they did a horrible job and I didn't give them any money. They fired the chief engineer, and he never forgave me for it. Ed Smith was the chief engineer. That was an interesting story, because I told you the story. [Robert A.] Frosch, we were about to give up the Space Shuttle; turned into, as I told you, a research program. They had made that decision in the total NASA.

He went to see the president. The president said they got to have it, etc., etc. So he came back from that. That precipitated a supplemental budget through the Congress for us and a $2 billion increase in our budget to the next year. We needed $700 million immediately. We got it. Well, I went to Rockwell among all our contracts. They gave me a number that they had to have now to maintain the schedule and in the next two years. So I used that number. Two weeks later they gave me another number. I don't remember the numbers, but it was big. A $300 million increase in what they needed instead of what they told me they needed. I had to then go take that up the damn chain. I couldn't keep that under my hat, so I did. Congress gave us holy hell. Everybody gave me holy hell. Well, when it came to the award fee I said, "You get zero for doing it." So they fired Ed Smith, who was the program manager. Ruined his career I guess. Although he left Rockwell and became the chief engineer on the [Northrop] B-2 [Stealth Bomber].

WRIGHT: Yeah, that's not a bad job.

KRAFT: He wanted the B-2. He was chief engineer and program manager on the B-2 and did a hell of a job. So he made out all right.

WRIGHT: Maybe you did him a favor.

KRAFT: Maybe I did. But he was a damn good man as a chief engineer. He was one of the best I've ever seen in my lifetime. But he really screwed us.

WRIGHT: Yeah, that hurt.

KRAFT: Caused me a lot of pain. Caused NASA a lot of pain. Congress really tore us up not just for that but the whole damn thing. NASA had been in there two weeks before we resubmitted this thing and said, "We don't need any more money," because that's what the OMB [Office of Management and Budget] had told us, you got to say that. They wanted to give us more money as a matter of fact, the committees did, and NASA said, "No, we don't need any more money." Then two weeks later we told them we not only wanted more money, we want $700 million right now, and we want $2 billion added to our budget next year. Because we knew the president was going to say, "You could have it." So they got their pound of flesh and quart of blood from NASA and we got our money.

WRIGHT: Dr. Kraft, I certainly don't want to take up your whole day. But I wonder, since you're reflecting a little bit this morning, you made a comment earlier that if you don't mind

taking a few minutes and reflecting on it, you said that spaceflight is difficult. So the other part of that question is but why should we do it, why should we keep pursuing ways to explore space?

KRAFT: My straight off answer to that is in a lot of cases we shouldn't. I think that's the case about going to Mars, or the case of landing on an asteroid. It's too dangerous to land on an asteroid. There's no damn good reason to do it in my opinion that you couldn't do it remotely. Same is true of going to Mars. I see no justification for sending man to Mars. Now if that was the only place we could go, that might be a different story.

In my opinion there's so much to be gained by going back to the Moon and so much to be learned, not only science, and not because of science do I want to go back to the Moon, although that is there. I think the Moon has all kinds of natural resources which can be utilized on the Earth, and eventually will be. That's utopian, but I think it will be. I think there's a great utilization that can be made of the Moon. We could live there, you could find out how to live in another planet without atmosphere. Lower gravity. You could have a scientific observatory on the back side of the Moon. Be protected from the reflections of the Earth, etc. Could mine, could produce water, could produce fuel there, you could produce power there. All those can be done on the Moon. You wouldn't do that on Mars. For God's sake it's 270 million miles away. So I say there's a lot to be learned. But the main reason for going into space is what you could do with what you learn here on Earth. That's the main reason for going into space.

Doing it with man requires an order of magnitude or increase in the technology as compared to doing it unmanned. That is where the ROI [return on investment] is from going into space. Space is wonderful for science. It's wonderful for us kids that want to do something. But

it's even better for the man in the street. Or our way of life in the United States philosophically. So that's the reason I think the space program is so important.

The space program is as important to the country as the Department of Defense is to the country. Why do you have a Department of Defense? Obvious. Why do you have a NASA? Not so obvious. But anybody in their right mind looks at what happened in the '60s to the change in the state of the art. The whole damn United States manufacturing capability and process has changed because of the space program. Nobody had ever heard of a clean room. Nobody had ever heard of a transistor. We had a fuel cell but nobody would use it, etc. We didn't have telemetered instrumentation that allowed us to look at a human being in a spacecraft flying around the Earth. Today every [hospital] ICU [intensive care unit] in the country has telemetry.

A guy at Methodist Hospital said, "We're going to have remote medicine." I said to myself, "I did that in 1975." We had vans running all over the state of New Mexico, had NASA on them with doctors in them. But we found out that we could put, not trained doctors, but we could put technicians in them, and we could bring those Indians and the people out in the desert into that van and the doctors in Houston could look at them. I said to myself, "You just figured out you're going to do that again. Well, why didn't you keep doing it?" Anyway all I'm saying is that the benefits of the NASA-developed technology—[previously] the biggest changes in technology took place because of war. We had to go kill people. NASA was the first time we'd ever done that without killing people. The communication satellite which NASA developed changed the whole world. Changed it. The world was no longer the same place, was it?

WRIGHT: No.

KRAFT: Russia could no longer say that they did something and not tell you. We could take a picture of them doing it because of NASA. The computer industry was revolutionized by our demands of going to the Moon. Not only on the ground but remotely. Because we were able to build small, at the time high capability, low-powered devices that would compute. Now I got a damn thing I carry around in my hand. Bigger [more powerful] than my whole first floor of the Mission Control Center.

The photographic circuitry, you know how that's done? You draw a circuit on a big thing like this. Artists do it, engineers do it; they draw all these lines on there. Those are wires, and those are all the software that goes with those AND [logic] gates and NOR gates, etc. You put that on a big thing. You photograph it and you shrink it and then you stack them and make the thing this big instead of big as this room. That's NASA money right there. So that's where it is. I don't know what it's going to do, where it's going to be tomorrow. I don't know what the invention is going to be that allows me to totally change my way of thinking or doing. That's what NASA is worth.

Now you can say well, there's a lot of other places to spend the money. Okay, do it. But spend it that way. Spend it on applied—get that—*applied* technology. Why do I use that term? Because it has a schedule and a budget associated with it. That drives the answer back to the better is the evil of the good. You have to come up with an answer in six months, and I'll give you $100 million to do it. That's applied technology.

Regular technology is I'll give you the money, and I don't know when the hell I'm going to get an answer. I may never get an answer. I'll probably get 10 different answers I didn't ask for. That's wonderful. But it doesn't do a damn thing for the economy. It does eventually. But

applied technology, forcing you to do something that has to be used, has a purpose. Very big difference. Very big difference. Technological engineers will refute that. But they're wrong. You have to have schedule and budget and a purpose. Got to have a purpose.

We only landed on the Moon because we had to do it. If [President John F.] Kennedy had said, "We're going to land on the Moon," like Obama says, "I'm going to go to Mars in 2035," that's like saying they're not going. When you get there, probably change your mind 14 times, and should have. But Kennedy says, "We'll do it in this decade." That's a hell of a damn requirement. Hell of a damn different requirement than saying, "I'm just going to the Moon and I'll land there in 1990." Which he could have said.

So you have to have that incentive. You have to have that drive. You have to have the people that are willing to commit to it. You have to have people like me, George Low and Bob Gilruth that are willing to say, "God, I don't know whether you can do that or not but I'm sure willing to give it a run. I'm going to bust a gut to do it because it's important."

WRIGHT: I read a quote not too long ago about the difference between being committed and being interested is that when you're committed, there are no excuses. You're committed to doing it no matter what. I think that describes pretty much what you were able to do.

KRAFT: Right. When President Kennedy said, "We're going to the Moon," I was a flight director at Cape Canaveral. I hadn't launched John [H.] Glenn yet. He says, "You're going to go land on the Moon." I shook my head. Gilruth had called me and said, "You better listen to the radio today." Or the television. Whatever it was. "Man is going to make an important announcement." He said that. I'm just shaking my head. Bits around me and all these things

out at Cape Canaveral and countdowns and rockets on the pad. Guidance system to go this way instead of that way. The last Atlas we had launched went that way instead of that way. The last one blew up.

WRIGHT: Now you're going to the Moon.

KRAFT: Now somebody says, "You're going to go land on the Moon." That's pretty damn good.

WRIGHT: Yeah, it is good.

KRAFT: President Kennedy was in one of those buildings over there on Telephone Road [Houston, Texas, during his visit in September, 1962], and I had to tell him how we were going to go to the Moon. I didn't have the slightest damn idea how we were going to go to the Moon. I had to put a bunch of charts in front of me. Telling President Kennedy this is how we're going to do it. The senator who was with him went to sleep.

He woke up with a start. He said, "Young man, you believe all this shit you're telling me? How do you?" I almost fell out of my chair and so did the president. Because he was right. I didn't know what the hell I was talking about. President Kennedy, I had never seen anybody laugh so much in my life, and I was laughing right with him, because he probably knew I didn't know what I was talking about either.

WRIGHT: But you had a plan, that's what mattered.

KRAFT: That's right, I had a plan.

WRIGHT: You had a schedule.

KRAFT: Had a schedule and I had a check to do it with. I had the country backing me.

WRIGHT: That helps.

KRAFT: I had the Congress backing me. I had the greatest people in the world working for me, and I was working for the greatest people ahead of me. So that's a pretty good formula.

WRIGHT: That is. It's a good memory. A good set of accomplishments.

KRAFT: Yeah. I don't think we knew what the hell we were accomplishing when we first started. We were all flight test engineers. Gilruth was a flight test engineer, and that's what I was. How we get higher and faster. That's all we were trying to do. But you could see as it happens, and reflect on when it did happen, the impact that had. Having been a part of it, having watched it happen, going in there and seeing all that stuff. I bet I went into 150 damn machine shops in this country in that time period. All dirty, nasty-looking things. Now you go into them, they're all clean. They all had to have a clean room next to them where all the parts go. They work. They didn't work before.

Those transistors. Remember all the trouble we had with transistors? First time you put a transistor in zero g [gravity]. All those little balls of sawdust started floating around inside of them. Got jammed up into the points and they shorted out. You build 150 transistors, 10 of them would work. Or you forgot that you didn't hermetically seal them. You had some atmosphere in there, and they started growing—in a cave, there are things they call stalactites and stalagmites, we call these green plague and purple plague. Started growing. The stuff inside the can would grow and grow. It'd hit one of the points in there and short out. That was what we learned.

Just learned and learned and learned. Got better and better. First time we hooked up the environmental control system in the Command Module at Downey [California]. Within a couple weeks the damn thing is leaking like a sieve. All those pipes had holes in them. How the hell did that happen? They stacked the pipes outside in the environment of LA [Los Angeles]. Install them in the spacecraft, we put that liquid in there, and immediately it was like an acid reacting with all the impurities in the air in Los Angeles, and ate holes right through the damn pipes. That was a lesson learned, wasn't it?

WRIGHT: A good lesson to learn on the Earth.

KRAFT: On and on. On and on. On and on.

WRIGHT: All those little bitty pieces came together, didn't they?

KRAFT: Yes. I remember we built those damn hydraulic actuators. They had redundancy in the wrong place. They had the O-ring seals. They called them Greene Tweed seals. Had a certain shape and you couldn't put them in backwards. Except they did. The first time we hooked that thing up it blew up. Not literally, but the damn hydraulic fluid going everywhere. Just a lousy damn design. We went to Moog, [Incorporated] over in Buffalo [New York]. "Build us an actuator with redundant seals on it." It cost us 50 million bucks. But we had a new actuator and it worked. Just learned all that stuff.

WRIGHT: Yes, and built upon it.

KRAFT: Yes, over and over and over again. First time we did metals. Why do you have to have these tags? You have a piece of metal, well, we had to have a piece of metal over here that we stored with a tag on it. This came out of that lot and it cost a lot of money. But when that damn thing failed because of some problem, we had this piece over here that we could run a test on. That costs you money but by God it makes it work in the end.

WRIGHT: Be interesting how much money, if you could figure how much money was saved by doing those types of testing and put those processes in place in the long run. Or lives you saved because of making sure those tests were done.

KRAFT: That's the only way you could have confidence in what you were doing. Took that knowledge, that testing, that belief that it had been done the right way, and the processes had

been followed, and this was the processes you had to follow. We had people checking to make sure those processes were followed.

You run a test on something, some piece of electronic gear, and it wouldn't work. What the hell happened to this thing? It worked before, but I got a new box, doesn't work this time. What did you do? Well, we made it a little better. Well, why didn't you tell us you made it a little better? Because when they made it a little better they moved this over to here and this over to there and the damn thing didn't work anymore. That happened in a big control box in the Shuttle. Process specs [specifications] were extremely important. But they cost a lot of money. That's what you had to pay. That's what SpaceX has the benefit of today. All of that I just went through, they have the benefit of all that. They didn't have to learn it.

There was a company down there in southern California that was building these big lines that go from the tank to the engine to carry the fuel, hydrogen in one, oxygen in the other, there were jackets on them, vacuum-jacketed to maintain the temperature. They couldn't get that out of the factory to save their life. We must have spent millions of dollars perfecting the process, the welding process. They couldn't do it. They had the contract but they couldn't build it. We could send our engineers in there, watch what they were doing, and figure out how to make it work. That's wonderful stuff. Couldn't have done it without them.

We built the Space Shuttle. We built all these special devices down there at Convair to make the structure lighter, and we had to build the machinery to make it happen. Put little strands of boron in the tubes. Weld it up like a cigarette. Learned how to attach things on the end. God, that was hard. In the end we saved a pound, and spent $10 million doing it I guess. But that's the only way you could land on the Moon. The Lunar Module. If you took your fist

and hit the side of the Lunar Module, you got a hole in it. It was that light. That's the answer to your question.

WRIGHT: It's a good answer.

KRAFT: It's hard to explain that to a congressman spending money. If they go see it then a lot of them did. That's what tiger teams was capable of doing. We don't have any more tiger teams.

WRIGHT: No we don't.

KRAFT: Well, I got out of you what I wanted.

WRIGHT: Well, I think we got more out of you. So we appreciate that.

KRAFT: You probably did but I want to make sure that somewhere there was recorded the fact that we didn't just haphazardly decide not to have an escape system on the Space Shuttle. There was justification for it and good engineering judgment for it. It worked pretty damn well. If you used it properly. If the red light comes on in your car and says stop the engine, it ain't kidding. If you don't stop the engine, you'll have to buy a new engine. You now know that.

WRIGHT: We definitely do.

KRAFT: If you don't do it, I can't make you do it.

WRIGHT: Circumstances will happen, won't they?

KRAFT: That's right. You have to suffer the circumstances. So you got to know where to take the risks. When we laid out the test program for going to the Moon, going to do this flight and do this, and we'll learn this, and then we'll go to the next flight. That might take us more than one flight. Here's A, B, C, D, E. That's what we called them. We'll do reentry tests. We'll do a test on the engine. Fly up there and do a rendezvous. Separate the Lunar Module and bring it back together and see if it'll dock. Have to have that. Have to know that before we go to the next step.

Got to Apollo 10 and George [E.] Mueller said, "Why are we doing Apollo 10?" Well, to tell you the truth, sir, when I get to the Moon, whenever we're going to land, I want to know that everything I did up to that point works. It's as simple as that. I want to know if it worked. I want to know when I come back off of the Moon I can rendezvous with that Command Module so when I go land on the Moon all I got to think about is landing on the Moon and getting off. Yes sir.

WRIGHT: It worked.

KRAFT: That's the way we're going to do it. I'm not going to change my mind. I want that test. So we did it. We learned one hell of a lot from Apollo 10 before we got to 11. We didn't learn quite enough because we put all the switch settings the same as we'd done on Apollo 10 in Apollo 11. That was wrong, because that's when we got the wrong answer in the computer.

Because we left the damn rendezvous radar switch on to make sure if we had an abort we could do the rendezvous and radar back to the Command Module and rendezvous. But we didn't need that when you're descending to the Moon. So it's taking in all that data and screwed up the computer. At least when we got to 11 we were able to overcome that, because we knew everything else around it was okay.

WRIGHT: Good judgment and good decisions.

KRAFT: Only based on experience, knowledge. Sometimes we had to break that. We did some things sometimes we didn't really know. Like the reentry of the Shuttle. I was not positive or sure that we knew what we were doing there. But I didn't know what else to do.

I was trusting in the mathematicians and the electronics engineers and the computer guys. They'd run all the tests I could think of. So we better go try it. Got to have a little nerve today. When we landed I said, "We just became infinitely smarter." So there we did do it without really being certain. We were reasonably certain, but we weren't certain.

WRIGHT: It turned out to be a good thing.

KRAFT: Yes, people don't understand how you go about that process. Just think. At every one of those tenth of a Mach number in the critical range there that we selected gains, as we call them, if you have this, you have X this. That takes place probably a million places in the Shuttle computer. We ran a test with enough margin in there that it worked. It worked no matter what the variations were, a random process. Let it all change. It worked. That's pretty good

confidence. If you can change the hell out of it and know the gains you got set there are going to work, okay, I'm ready to go to the next point. That's what we did all the way down.

I guess you'd have to say that there were some of us that had gained enough confidence based on experience that that kind of a rationale, that kind of testing was sufficient. We learned that as we went, didn't we? As we went, I think we began to gain that kind of judgment. Maybe we were lucky. I don't know. Maybe the Lord was with us. All of the above.

WRIGHT: All of the above.

KRAFT: We certainly had a lot of things happen that we got awful lucky about. When Apollo 13 blew up, it could have blown the whole end off of the damn thing and damaged the heat shield. Then it would have been Katie bar the door. That would have been the end of it. We just got lucky there. Maybe because we were so diligent about other things that we made the luck. Like the golfers say, it's amazing how your luck improves when you practice. It's true. I suspect that happened to us.

WRIGHT: You got a little more knowledgeable to be able to apply your luck a little easier, didn't you?

KRAFT: Yes. On the *Challenger* accident, we weren't lucky. On the *Columbia* accident we weren't lucky. But we had indicators, but we ignored them. Weren't smart enough to figure that out. The people at the time were not smart enough to figure that out. That's what happens. Probably happened to Amelia Earhart, didn't it?

WRIGHT: Might have.

KRAFT: Happened to Wiley Post over Alaska back when I was a kid. Or it happened to [Charles A.] Lindbergh going across the ocean. He got lucky as hell. Having all these hallucinations, going to sleep, etc. Persevered I guess.

WRIGHT: The golfer you were telling me about yesterday. He wasn't so lucky, was he?

KRAFT: No. Played 71 beautiful holes and then screwed up on the 18th and lost. He's done that twice now in the last couple months. Led the damn tournament. This one he led for 71 holes and lost. That's tough.

WRIGHT: It's a hard day getting up today, wasn't it?

KRAFT: I imagine it was for him. He said his son was crying. I think that really got to him. He's a hell of a nice guy too, [Jim] Furyk is. Well, get me out of here. You've had enough of me for the day.

WRIGHT: Well, you probably need a break. We worked you hard today. So we appreciate you coming in.

KRAFT: I appreciate it.

WRIGHT: We always enjoy it when you come in.

[End of interview]