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INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is February 11th, 2010. We are honored today to be with Dr. Christopher Kraft, former Flight Director and Center Director for the Johnson Space Center [JSC]. He's speaking with the JSC History Office staff of Rebecca Wright and Jennifer Ross-Nazzal about the Space Shuttle about Shuttle design, development, and testing.

But before we do that, I thought we could lay out on the table what your role was as Center Director in relationship to the [Space Shuttle] Program Manager Bob [Robert F.] Thompson and then your work with the various project managers for the major components: the Orbiter, the external tank, the SRBs [Solid Rocket Boosters].

KRAFT: The organization was constructed in a—I don't want to use the word strange. It wasn't strange. It was constructed so that it paid lip service to having various elements of the manned spacecraft organizations, that being Marshall [Space Flight Center, Huntsville, Alabama], JSC, and KSC [Kennedy Space Center, Florida]. It was constructed so they could all maintain great face, and at the same time trying to make it such that decision making could be done in a pyramid fashion as opposed to spread out and nobody being in charge, because that's what you get when you have Marshall, which didn't want to answer to the Johnson Space Center.

The organization was constructed such that Bob Thompson wore two hats. He worked for John [F.] Yardley as the overall Shuttle Program Manager. Everything, both from a budget preparation and the overall decision making process for making top Level I decisions, was Bob

Thompson's responsibility to the [NASA] Headquarters [Washington, DC] organization of John Yardley, director of Manned Space Flight.

At the same time, Bob Thompson worked for me, so he wore two hats. He worked for John Yardley in this branch of the organization, but in the Center part of the organization he still worked for me. All his people were mine, or the Johnson Space Center's. I don't want to say he reported to me, because on the organization charts it was a dotted line, so that was a surreptitious way of still having him work for me. Now I didn't exercise that kind of a management scheme, but he did report to me weekly. I had the worst organization, people say, in history, because I had 23 people reporting to me. Everybody says that's a crazy way to run any organization. You can't have that many people reporting to you. It's the way I wanted it. I did have 23 people reporting to me.

The reason I make that point is that every week I had about 7 to 10 of those folks in my office giving me at least a 30-minute-or-more briefing on what they were doing, what their problems were, and what I could do to help them. Bob Thompson was one of those, so that's a diffused organizational sketch for you. If you go to the charts and many of these guys over here came to me when they started the Constellation Program and said, "Here's the organization chart." I said, "Don't pay any attention to that." It took them a long time to figure that out, because we did not work as the organization chart said. We did it the way we always did, i.e., we did it as a team. I was the team leader, so now that's one decision path. On top of that we had the Management Council.

ROSS-NAZZAL: What is the Management Council?

KRAFT: The Management Council was run by the director of Manned Space Flight in Headquarters. Depending on the intensity of the work that was going on or the decisions that had to be made, we met monthly as a top level organization to make overall Level IA decisions. Yardley ran that. Well, initially Dale [D.] Myers ran it, and then Yardley came in after Dale Myers went to the Department of Energy. George [M.] Low hired John Yardley to take his place, then Yardley ran the Management Council. The Management Council was also run by George [E.] Mueller in Apollo.

All of the Center Directors were the voting members, so to speak, of the Management Council, so it acted as the top level board of directors with a CEO [Chief Executive Officer]. John Yardley being the CEO. Now as Bob Thompson once said—and I think he was right—"We let them make 3 percent of the decisions; we make 97 percent, and it makes them feel like they're running the program." That was probably about right. I don't want to discount John Yardley, however, because I think he was absolutely the guy that ran the program. He did run the Shuttle Program; there is no question. I don't want to leave any doubt in anybody's mind that I would think differently. He did run the program. He did a darn good job of it. He was one of the best engineers I've ever had any contact with.

He respected me, and I respected him. We argued on many occasions, and he gave me hell on many occasions, but it was always a rational discussion or a difference of opinion which we solved, 99 percent of the time. I could tell you some where we didn't. The Center Directors then, with the program managers, Bob Thompson and his program manager, i.e., John Yardley's—John Yardley had a top level program manager under him. Anyway, Bob Thompson reported to Yardley, so that was another hat that Bob wore.

Bob prepared the total budget and submitted that to Yardley. Yardley submitted that to the Comptroller, who was Bill [William E.] Lilly. Bill Lilly, in a business sense, would have been the CFO [Chief Financial Officer]. In government parlances he was a Comptroller, and he was responsible for the total NASA budget. All the NASA budgets were his. He was the primary interface with the OMB [Office of Management and Budget].

Below that Bob Thompson was responsible as I said—I'm going to repeat myself here—for preparing the total budget that went to Headquarters. Now where was Kraft in this? I was responsible for the budget too, because he [Thompson] worked for me, right? Again I didn't exercise that in any sense that I would veto it, but it did come through me. That budget always came through me, and the Orbiter budget was under me directly.

Now technical, financial, or other major decisions were made by the Management Council. As always those decisions came up through me to John Yardley, through Bob Thompson to John Yardley, through Bill [William R.] Lucas at Marshall. He answered to both Bob Thompson and Yardley, if that makes sense.

ROSS-NAZZAL: It's complicated.

KRAFT: That's about the way it was. If Marshall had to have a budget or KSC had to have something in the budget, [e.g.,] new consoles, new control center—which they did build during that time, Launch Control Center—Bob Thompson was really responsible for that, not me. I had little to do with that. I had little to do with those things that came up in detail through the other two Centers, only in the sense that Bob Thompson was responsible for it. I was knowledgeable of it, although I made no decisions associated with that.

Now to make it even more complicated for you, all the major decisions, however, on what any of us were doing were done by the Management Council. We, the Management Council, were knowledgeable of every major technical and financial decision that was made in the program.

ROSS-NAZZAL: Can you give some examples of those decisions?

KRAFT: Yes. Where, when, and how are you going to test the engine, and how many seconds of burn time are required until the engine is qualified.

ROSS-NAZZAL: That's a really detailed task.

KRAFT: We did that at the Management Council. Marshall was responsible for bringing that to the Management Council, but that's where we made those decisions. Now John Yardley really made most of those, but we did that. We reviewed that in the Management Council.

I'll give you a specific example. The qual [qualification] test for the solid rocket, which failed on [Space Shuttle] *Challenger* [STS-51L], was discussed and approved by the Management Council. Last year Arnie [Arnold D.] Aldrich came to see me, because he was the program manager at the time of the *Challenger* accident. I won't go into the details of that. I will sometime later if you like, but I was gone from NASA. He came to me, and we started talking about the solid rocket, how cold it was on that morning, and the icicles hanging off the pad, which I knew all about.

I said, almost offhandedly, "Well, the thing was only qualified for 47 degrees Fahrenheit."

He looked at me and says, "How did you know that?"

I said, "I knew everything there was to know about the Space Shuttle, because I sat in meeting after meeting after meeting and reviewed the Criticality 1 [resulting in loss of life or vehicle if the components fail] parts of the whole stack, not just the Orbiter, but the solid rockets, the engine, and the tank. We, the Management Council, reviewed that information in detail. That's the reason I knew 47 degrees qual test on the solid rocket."

It was burned in there [points to his head], so that's the level that all of us at the Management Council level did discuss.

ROSS-NAZZAL: How did you learn about these Criticality issues? Did you have the contractors come in and give those details?

KRAFT: No. We brought those up to the Management Council and said, "These are what we think are Criticality 1 aspects of the machine." The engine was one, and various elements of the engine: the pumps, the abort sensing system, the fact that we had subsynchronous whirl on the pumps. Subsynchronous whirl did this. [Demonstrates] The pumps were one of the major pieces of equipment, and it was a big thing, about that big about that round, and it was just like a turbine, like turbine blades in an aircraft jet engine. It stages, and either the hydrogen or the oxygen is flowing through this turbine as a pump to put fluid into the main head of the engine, which was mixed oxygen through holes in the head of this thing where it goes down in the engine and is burned.

Subsynchronous whirl means that it turns out anything that has a shaft that's about two feet long; it has a natural frequency where it goes up and down like this. [Demonstrates] That's normal, rational, but the problem is it wears the bearings out that hold that big shaft. This shaft is probably that big in diameter, and it has all these wheels to which the blades are attached that drive this fluid as a pump to the engine.

We discussed that till we got sick of hearing it. It took us probably three years before we got that thing to where it would run for a full cycle of the engine. Even longer than that, because we said it has to run for at least three cycles of the engine before we will say it's qualified to fly. Furthermore, every engine that is built has to go through the Mississippi Test Facility [now known as the Stennis Space Center in Mississippi] and do a full length burn. That's 500 and X seconds, which is what the Shuttle does today. Every engine still goes through Mississippi. Now when we first did that we were trying to get to three. We did get to seven. In other words you could use the engine seven times, but you had to check the pumps. You had to check those bearings after every flight, because you get the engines back fortunately. There was all kinds of tests that you ran on those pumps. All that I just went through is what we went through in the Criticality 1 discussion of the pump at the Management Council.

ROSS-NAZZAL: Did decisions have to be unanimous? How did you come up with your decisions? How did that operate?

KRAFT: It really didn't take that kind of a decision. We all agreed that these proposed times that the engine had to run to be qualified to fly was a good number. Now that was proposed by

Rocketdyne to Marshall to the Management Council, and I'm sure approved by Bill Lucas. Just like if you go over here and talk about the Orbiter the same way.

Anything that was done about the [Shuttle] tiles or the APU [Auxiliary Power Unit] was the Orbiter Project responsibility. There, in my organization, two people were responsible for that. The JSC program manager was Aaron Cohen, and whoever was the program manager at North American, then Rockwell. They had a program manager. He was equivalent to the NASA program manager. He made the decisions in the company. Aaron Cohen approved those decisions, and I knew about it through Aaron all the time.

We also then, once a month or whenever needed, had a similar what we call a CCB [Configuration Control Board]. Aaron had those weekly and sometimes daily, but then I would go to the program management review at Rockwell once a month. George [W.] Jeffs, who was the company president, with their program managers, with their top engineers, depending on which system you were talking about, made presentations on the whole program.

So that's how I was intimately involved in every one of those discussions and decisions. I didn't have to make them. They were already made, but I was involved in it and NASA expected me to be. I went to every one of those subcontractors on the Shuttle at least once, and many of them 20 times. We would get in a Sabreliner: Mr. Cohen, Mr. Kraft, Mr. Jeffs, and depending on who their program manager was—their program managers changed quite a few times—but also their chief engineer and the top engineers. If we were going to review the APU, they met us in Illinois. We went to that place where they built the APUs at least 20 times because we couldn't get the material to work. We had trouble with the poppet valves, and etc. Changed the material and they just changed it again in the last year.

That's the level that I worked at. Again, I didn't make any decisions relative to the pump. I was just there. The engineers made those decisions. The guy that built the APU made the decisions, but I was there and so was George Jeffs.

ROSS-NAZZAL: You were very intimately involved and immersed in that whole process.

KRAFT: Every system in that machine I was involved with. Now I was also involved in the total Orbiter budget. I approved it. My people assembled it with Aaron Cohen, bringing it to the budget people, bringing it to me. Me to Yardley, but through Bob Thompson. Now I know it's a complicated thing. It was complicated because that's the way we had to do it from the internal politics point of view.

ROSS-NAZZAL: It's good information to know for historians in the future looking at those org [organizational] charts.

KRAFT: Yes. If you looked at the org charts you'd say well this is the way you ran it. Didn't run it that way at all. If we had, we'd have never gotten there, because you wanted this thing to be integrated across all the brains you could get. Let's put it that way.

When we started having trouble with the tiles, John Yardley was at Rockwell helping us, demanding we make those decisions. That's one of the things I was going to tell you. He got so mad at us because we kept putting them on, taking them off. Schedule was eating us alive. We'd put them on and find out something was wrong with them. We have to take 1,000 of them off, redo it, and put them back on again. He got really upset with that. He said, "Nobody shall

ever take any tiles off this machine again until I approve it." You couldn't run a railroad that way. We made him think he did. He once found out that I and Aaron Cohen had decided to take 1,500 tiles off the machine and put them back on again. He was livid. He gave me holy hell, he called me a dummy; he called me every name in the book. That didn't bother me any.

ROSS-NAZZAL: You said the Management Council made about 3 percent of the decisions.

KRAFT: Well, that's the way Bob Thompson described it. No, it wasn't that way at all, but you cannot run a program by having a big management group up at the top level make decisions. If you did that the whole thing would bog down and fall down on itself, so Bob Thompson would make most of the Level I decisions on a daily basis, and then he'd summarize that to the Management Council.

Now on the major major decisions, we'd have these telecons: Yardley in Washington and his people; Thompson in Houston and his people; wherever I was. Sometimes we'd do it with the Orbiter, sometimes we'd do it with the other pieces. George Low started that. Every day at noon he would have a telecon with all the major players in the program on the telephone talking about the top 10 problems, and any other problem that had to be a decision made on, so we continued that. Bob Thompson had a meeting every day at noon. Some days if I thought something was going on I'd just show up at the meeting and listen in, because Aaron would tell me, "Well we got this problem, I'd like to have you come today."

I'd just mostly go listen, because Aaron would be making these decisions relative to his noon discussion with Rockwell, and Bob would be having his noon discussions with his people

in Washington and his reps from all of the elements of the Shuttle: tank, engines, rockets, Orbiter.

ROSS-NAZZAL: Looking back, what were some of the major decisions that you discussed on a regular basis?

KRAFT: God, I couldn't tell you that. Thousands of them. Literally, I'm not kidding, literally thousands of them.

ROSS-NAZZAL: What about the discussion to get rid of the fly-back booster? Was that a major discussion?

KRAFT: No, I don't think so. No, that was made for us. You picked the wrong one. That was an easy decision to make. What happened there was we submitted a—I think I told you this—a proposal, sort of a preliminary proposal I suppose, on the top level configuration of the Shuttle where we did have the fly-back booster. We had a model of it, presented it to President [Richard M.] Nixon. The process that that went through was we presented the configuration, but we also presented a top level budget and a top level schedule from the OMB to the White House. Who was that? I'm not quite sure I could even describe that, but it was the OMB and other representatives and the White House that had responsibility for that aspect of the President's decision making process. We said it was $14 billion. Within days they said, "You can have half of it."

That's when it became a semireasonable machine. That's the way that decision was made. The President, I guess, or somebody up there said $14 billion over six or seven years. I think that was in '71. We said we were going to fly it in '77 or '78, something like that, which we didn't do. It wasn't our fault we didn't do it. Although it was probably a good thing we didn't, because I don't think we would have made it, but that's what Bob Thompson believes, and that's what I believe.

By the way, I think I told you before, Thompson and I were classmates in college.

ROSS-NAZZAL: I think you had mentioned that.

KRAFT: That decision was not really an engineering management decision; that was a political money decision. On the other hand, the size of the Orbiter was reduced once. That was an in-house decision we made because we wanted to see if we could reduce the cost. That wasn't a very good decision but we made it. Took three feet out of the cabin, trying to get the cost down. Dale Myers helped make that decision. I didn't like it at the time, but I didn't think we had much choice.

We had jet engines that were stuffed in the wing. They flopped out to give you go-around capability. Now that doesn't sound like a big problem, but you have tanks that have to have the fuel for a jet engine. We had four jet engines and all these lines that run from those tanks to those engines. Those jet engines had to be able to fly this 200,000-pound vehicle. This is a space machine, not an airplane. Frankly, we couldn't lift it. The rocket wasn't big enough. We didn't have enough performance to do that. We just bit the bullet and said, "The thing will

land dead-stick, so let's see if it will," dead-stick being without power. No go-around capability. Do you think we can do it? We decided, yes we think we can.

It was about like that too. We just said this thing is too big a job to do. It's too complicated. It's not worth the risk to the overall machine to keep these engines, both from a mass point of view, complexity point of view, and the fact that we think we can do it without it. Now you could ask the same question about not having an escape capability, which everybody talks about. Current NASA Administrator Charles F. Bolden about two weeks ago said, "The Space Shuttle is a flawed design because it doesn't have an escape capability." We made that decision to not have an escape capability—and I'll go back and talk about that—because we couldn't do it.

It was one of those things that we came up against in the program for various reasons, which I'll talk about, that we couldn't do. We couldn't put a big enough rocket up the rear of that Shuttle to drive it off of those solid rockets and recover it. In the first place we couldn't get it up to speed fast enough off the pad, and then we would have had to have a parachute system to have it descend. That was just out of the question. It was too complicated, too heavy, and therefore impossible to do, so we aren't going to do it. That's a risk we will take.

Now how did we answer that question to ourselves? That'd be a damn good question. How did we, as a collective group, all the way up to Mr. Yardley, decide that we can fly this machine without an escape capability? We might kill everybody on there, and that's probably an unacceptable decision to make as total managers of this program. If that's the conclusion we came to, maybe we ought not to build this machine. We rationalized this way. A solid rocket is a solid rocket. That's what we would use as an escape system if we could make one big enough.

That's what we used on Mercury, that's what we used on Apollo. Couldn't use it on Gemini, and if you want to know that story, I'd be happy to talk about it.

We said they are solid rockets. We use solid rockets because they are about 100 percent reliable. If you light the fuse, and the case holds the pressure, it's going to work. We've got two solid rockets on the side of this machine. They are our escape rockets, they will take this machine to 100,000, 150,000 feet. We can separate the Orbiter at that point and fly the Orbiter back to Cape Canaveral [Florida]. It's called RTLS [Return to Launch Site]. That's how we rationalized that we could use those two big solids as our built-in escape system as well as part of the launch system, and then fly the machine back.

Let me tell you, building the software to make that happen from any altitude, all the way up to orbital speed, is the way we designed that software. It will do that today. You cut off anywhere. If it's got flying speed, and it's high enough, it'll fly back to Cape Canaveral on its own. The software in that machine will do it automatically. That we could do. It was a hell of a task, hell of a job to get that done, but that's what it will do.

Now that's what Mr. Bolden says is a flawed design. Chris Kraft says that's bologna. Mr. [Michael D.] Griffin said that same thing. I got my papers out a couple days ago. In 2005 he kept saying to the Congress, when he was trying to get rid of the Shuttle, which he did obviously, "It's a flawed design." He kept saying that, so I wrote him a personal "eyes only" letter that said, you're full of crap and here's why—the explanation I just went through with you.

He got me an answer back, said, "Well, I don't agree with your ideas about keeping the Shuttle, but I won't use that term again." I got that piece of paper out the other day. If this whole thing sounds complicated, by God, it was complicated.

ROSS-NAZZAL: It is a complicated machine.

KRAFT: Darn right it is, but it is the best vehicle for space ever built. It'll be a long time before we build one as good as that again.

ROSS-NAZZAL: What makes it the best, Dr. Kraft?

KRAFT: In my opinion, it will do everything it was set out to do, and it does it safely. Every major system on this machine is quad-redundant except the structure. Quad-redundant. If you recall the terms FO/FO/FS: fail operational/fail operational/fail safe, so we had four computers, four of this, four of that, four everything. We only had three APUs, but I thought we rationed that was enough, because we had three hydraulic systems.

We only had three IMUs [Inertial Measurement Units] and a lot of people were very upset about that, because you had to come up with a voting system as to which one was right, once one fails. When you have three, it's easy to vote. We had software on board that says if you got three working, then two can vote the other one out, but if you got four, you could do that twice, which is good, but it's also complicated. As a matter of fact, we did it with two. We could vote out the bad one even with two.

We had two failures, which were catastrophic. Both were the fallacies of man, not the fallacies of the machine. We were having burn-through on the rings on the rocket, and here's the system telling us. "I got a problem." Now they did have a fix in the works, but they decided they would go ahead and fly in spite of that. Probably not a terribly bad decision, but compound that with the fact that the rings were cold. The machine was not qualified for temperatures below 47.

Now there was a rationale for that too. That was, "Well, the core of the rocket temperature is higher than that." They convinced themselves it was okay to fly, forgetting the O-rings. I say they convinced themselves wrongly so. They made a deliberate decision to fly in spite of those known factors. That was a failure of the human brain, not of the machine. We should have fixed it. Same is true of the debris. Eventually they were playing Russian roulette.

So take what Chris Kraft says with a grain of salt. I say the machine has never really failed. There is no rocket, even with those two failures, that has the success rate of the Space Shuttle. It'll be a cold day in hell when that is improved on.

ROSS-NAZZAL: When you were working on designing and developing the Space Shuttle did you ever envision it would be flying for nearly 30 years?

KRAFT: Yes, that's what we built it for. We built each one of those vehicles to fly 100 times. We knew it would probably fly four times that.

ROSS-NAZZAL: You were anticipating each Orbiter would fly between 400 and 500 times?

KRAFT: No. We said we will design the machine to fly 100 times, then you need to recertify it. Take it apart. Now we also decided you need to take it apart after eight flights, look at certain level structure that you could see, etc. Then at the end of 100 flights we'd have to make some kind of new decision as to its capability and validity to fly, but I think probably because the way we did things in the system, it would probably fly 400 times. I can't remember how I would convince you of that, but we did that in a probabilistic study.

ROSS-NAZZAL: That's pretty amazing. I've heard some people from the Shuttle Program recently say that there was some discussion about recertifying the vehicles.

KRAFT: That's a requirement of the [Space Shuttle] *Columbia* [STS-107] Accident Review Board. That's a rational thing to talk about, that's what they probably should do. They would find that you can. That's recertifying it. Now I think that would probably be the right thing to do.

ROSS-NAZZAL: Last time you had told us some wonderful anecdotes about the thermal protection system. I was curious if you could talk to us about some of the other systems or structure of the Orbiter. Things like the wing, the midfuselage, or other systems or subsystems that you had your hands in.

KRAFT: When we started, we couldn't put the wing in any kind of wind tunnel or thermal device, because there just was no place big enough nor probably not enough electrical power to provide the heat to totally qualify a wing or even one wing on each side. We constructed various test articles which were pieces of the upper part of the wing, the total wing, or a section of the wing through the cord. We ran structural and thermal tests on those. When we did that with the wing the first time, we found out the design was incapable of carrying the loads. We had to go in and add these—I'll call them stringers. They were actually an L that we put on every stringer to increase the strength of every stringer on the wing. That was a heck of a job to do. Grumman

had the responsibility for building the wing, but we had to modify the wing based on that kind of a test.

I think when I was telling you about the tiles I told you that story about the people not believing that the tiles would stay on the machine. That test article was a special test article that we convinced ourselves, on the basis of combined loads—what you'd like to do is put all of the loads that you're going to experience on that test article. We couldn't figure out a way to do that, because you have aerodynamic loads, thermal loads, and the thermal loads turned out to be structural loads as well. Trying to put all of that environment that the machine is going to see at any given time just can't be done.

What we did was try to take the worst case for each one of the loads and design a test article that would allow us then to see what happened and then analytically take the results of those tests and combine them into what we thought were the actual loads at any given Mach number, up and down. Up being the worst case in some cases, reentry being the worst case in some cases, so we tried our best from a test article point of view to arrive at that kind of situation where we could take then those results as a worst case and add that to the case that we were going to see in flight.

These people didn't think that was sufficient. The best structures guy in the United States didn't think that was sufficient. He refused to sign the paper when we got ready to launch.

ROSS-NAZZAL: Who was that?

KRAFT: He just died. Holt Ashley, a professor from Stanford [University, Stanford, California]. He used to be at MIT [Massachusetts Institute of Technology, Cambridge, Massachusetts] and

then went to Stanford. The other guy was John [C.] Houbolt, who thinks he was responsible for lunar orbit rendezvous. Houbolt was a structures guy, by the way. He and Holt Ashley refused to sign the paper. They were on an oversight committee that we talked to continuously on what we were doing to validate the capability of the Orbiter. They didn't agree with it.

You remember that little nylon pad that the tiles are glued to? They thought the strain isolation pad would fail. We did all those tests that they insisted we do, but they didn't think that was sufficient. They didn't think that we had done a good enough job. I won't go into details what they meant, but they didn't think we'd done a good enough job to prove to them that all the tiles wouldn't fall off.

I told you Houbolt wrote me a letter T minus, I don't know what it was, six weeks or something like that. Said, "Would you please put a steel net around the whole Orbiter, because NASA is going to be embarrassed when it gets back from its first flight, all the tiles are going to fall off." That's what he said, got that in my files. You could get that letter from Virginia Tech [Virginia Polytechnic Institute and State University, Blacksburg, Virginia].

ROSS-NAZZAL: Be a good letter to have.

KRAFT: It's up there. We thought we were smarter than he was, and we were. I guess sometimes we might not be. John Yardley, Bob Thompson, Aaron, George Jeffs, and their guys, Tom [Thomas L.] Moser from our place, and Bill [William C.] Schneider, we all looked at what they wanted us to do, and we did what we thought was a response to what they wanted us to do. Then we looked at the results and convinced ourselves that it would work. We had done a lot of those things by analysis, from tests, but you don't have a perfect test. The only perfect test is to

fly the thing. I think I told you that. Somebody asked me, "How did you know you were ready to fly?" Well, I didn't know whatever else to do.

That's the way I looked at it. We had done everything that we thought was necessary to fly. Frankly, we thought we had done everything that anybody else had asked us to fly that was rational. Now who decides what's rational? We did. Somebody had to. We didn't do that lightly either. We beat some of these things to death from an analytical or test point of view. We overdid it, probably, in some cases. The big thing that convinced me about the loads was that they were always deciding their arguments on the basis of worst case on worst case. That doesn't happen in nature, not very often. Maybe it has once in somebody's lifetime, but worst aerodynamic loads, worst vibratory loads, worst thermal loads, worst structural loads, worst any kind of load don't all happen simultaneously. If they did, no airplane would be flying today, so you have to be reasonable, rational. In the end, take the risk. The risk sometimes being high, the risk sometimes being not very bad at all. That takes engineering judgment. That's what I got paid for, me and the rest of us.

I was talking to somebody the other day. I said, "I never was a very smart guy, but I was wise."

ROSS-NAZZAL: It must have been exciting being an aeronautical engineer and working on the Space Shuttle.

KRAFT: It was. It was the biggest challenge as an aeronautical engineer I ever had. No question about that, but I had an awful lot of good people that were doing the analysis. They may not

have been the best, but they were some of the best in the country. Particularly the thermal people, they were always changing their minds.

ROSS-NAZZAL: How so?

KRAFT: They would run these analyses and say, "Well, we don't think the thing is going to work, we think the tile will come off under certain circumstances, so we need to do this, that and the other."

I thought, "God bless, we already got the Orbiter built."

"Yes, but we think if we don't put this magoochie under the tiles in this particular place, the temperature here and there is going to be different than we predicted it to be and therefore the stress between this point and that point is going to change the elastic properties of the structure. It'll stretch this way instead of that way, and it'll pop the tile off."

You have to listen to that. You have to probe it and find out if they really know what they're talking about. Somebody's got to judge that. In the end you say, "Okay we'll do it, take the tiles off and put the magoochie there." We did that a lot of times.

[At] T minus three days, those thermal people came to us and said there are something like 200, 300 tiles on the nose that we think are going to exceed the Criticality 1 loads. I said, "You got to be kidding." "No, that's what we think." We put a scaffold up there, took them off, and put the tiles back on.

ROSS-NAZZAL: This thermal work that people were doing, was that being done primarily at JSC? Or were you also doing it at Ames [Research Center, Moffett Field, California] and Langley [Research Center, Hampton, Virginia] and at contractor facilities?

KRAFT: All of the above. They had the best guys at all of those places doing it, and using the test facilities particularly at Ames, because they had the one place in the country where you had enough temperature and power to run these tests in. We had an arc jet facility here, but it was not big enough nor did it have enough power. We ran a lot of tests here, but it took the facilities at Ames, with the best in the country, to run a lot of those tests.

ROSS-NAZZAL: What about the wind tunnel testing? You had mentioned that a little bit.

KRAFT: The problem there is that you can't get the right combination of what we aerodynamicists call Reynolds number, Mach number, and dynamic pressure. You can't get that in a tunnel. You try to do it with high-density gas like they did, they had a 16-, 17-foot tunnel at Langley, where you could build the pressure up and use a different gas instead of air to get the density up, to get the Reynolds number right. What is Reynolds number? Reynolds number is an equation made up of the length of the cord of a wing, as an example, the density and the velocity.

You can compute that very easily as you fly in or out, up and come back in again, but you can't match those conditions. Reynolds number particularly can have a profound effect on how the aerodynamics is going to respond. You can't match that for the trajectory which the Orbiter is going to fly, particularly around Mach numbers of 6. Above that we can do pretty well and

below that we can do pretty well, but in that range we pretty much had to guess what they were going to be.

When we ran the computations, particularly when we were dealing with the control capability of the machine, because the airplane is basically unstable, you had either the thrusters or the surfaces, depending on what altitude you were at. Thrusters, where you're out of the atmosphere, and you come back through the atmosphere, you use both, and you get a little lower then the thrusters aren't strong enough. It's all aerodynamics. The gains that you had between how you mix those forces, gains being how much of this and how much of that, you do that through the automatic control system electronically. You vary all those gains all the way from Mach 25 to touchdown. You have a whole schedule in the computer that says at this Mach number on this trajectory this is the gain you use. You vary those gains all the way down.

We would run what is called a Monte Carlo process. That's a mathematical technique. There are, in the case of the Orbiter, 35 major parameters which you can vary, so we put a range with those. We would guess what the number was, then we'd put a range around that as to what the probabilities it would be within that, then we put another X factor on top of that to say it could be this wide. Some of those went from positive to negative, then we put it in the Monte Carlo process. That's a random process where all 35 parameters are modified in a random way. You run 1,000 cases. It has to be stable in all 1,000 of the cases, or you have to run it over again by changing the gains.

ROSS-NAZZAL: How big were the models that you were using in wind tunnels for the Shuttle?

KRAFT: I think anything that big [demonstrates] to quarter-scale. Some wind tunnels you could get quarter-scale, but there you'd be limited in Mach number or in density, so we did it in a whole bunch of wind tunnels. We took all of the data from the X-15 flights and the X-vehicle flights at Edwards [Air Force Base, California]. We plotted all that data on a big chart for the Mach number range of the Orbiter. Threw all that data up there. Lines and dots everywhere. That's how we got the bounds of tolerances, etc. That's how we got the numbers at each one tenth of a Mach number in the critical range. The critical range was probably somewhere between Mach number 2 to 8. We'd do it every tenth of a Mach number. Got above that, you could use what we call Newtonian flow. Aerodynamics means nothing, it's just plain old physics above a certain altitude. You compute the forces, and they are correct; Newtonian flow, it's correct. Below that, subsonic, below Mach 2, 3, wind tunnels were fine. We could get that data.

ROSS-NAZZAL: How long did that process take to map out all those details?

KRAFT: Years. Years. You did the same thing with structures, by the way.

ROSS-NAZZAL: Tell us about that, because you mentioned there was another story involved because you couldn't test the entire structure.

KRAFT: Yes, that's where I said we needed to use these test articles. We put them in these devices where we could apply the loads. Pull on it or compress it or stretch it with the pieces. That's what we were doing in the control analysis. We used all the data we could get for the

shapes that we were flying, a lot of estimation going on there by a lot of brilliant people. You could compute it. Today you use fluid dynamics, that's a fancy name, but that's what we were doing. You could write the mathematical equations for these parameters.

In my day, as a young aeronautical engineer, you could work with about eighth-order equations. That means the eighth power. You take a quadratic equation that describes each one of these things, put it together, and you end up with an eighth power equation. That make sense to you? X to the eighth in the equation.

I could do that on a calculator, but I couldn't get above eight degrees of freedom. With computers you can do hundreds of degrees of freedom, 200 or 300 degrees of freedom, so with the computers that we had in the mid '70s we had the capability of doing a pretty good Monte Carlo analysis. Today you can do better because computers are better. That's what worries you about today's engineer. He believes the computer, forgets the physics.

ROSS-NAZZAL: Tell us about the OMS [Orbital Maneuvering System] pods. How much involvement did you have there?

KRAFT: Aerojet Liquid Rocket Company was responsible for the OMS engine; they were in Sacramento [California]. I went there many times. They had a very new process in the engine head. Had a sintered metal head, instead of drilling holes in the head and filling those holes with very special material so they were very true. They are little nozzles in themselves, and then you pour the fluid in there. That's what drives the LOX [Liquid Oxygen]. Some of them are LOX, some of them are hydrogen, and you mix the two. That's what mixes below in the throat of the nozzle.

They had a bunch of plates, I don't know how many they had, 10 or 12. They were full of holes. You stacked those plates together and that's what took place. The little holes up at the top, and it used to be rocket engine, so the purpose of that is to get the ideal mixture. You're trying to mix the fuel as best you can possibly get it, because that's where you get efficiency out of the LOX and the hydrogen. If you can get all those little molecules of LOX and hydrogen to look at each other and explode, that's what you want to have, so they came up with this new head. That was Aerojet. They were bought by General Tire and Rubber Company, GenCorp. Anyway, they owned Marquardt.

Marquardt were the people that built the thrusters. That was a heck of a problem too, because we had to use a little nozzle that has that much power, has a hell of an explosion. We used the material called columbium. It had very high strength and impact load capability at those kinds of temperatures.

You have different size thrusters. You have either a 100-pound thruster or a 1,000-pound thruster. That's what you make the attitude control system with. The vernier thrusters are 100 pounds; main thrusters are 1,000 pounds. The engine was what, 10,000 pounds, I think the thrust of the OMS engine is something like that. You have two of them. You use that for orbit adjust and reentry.

ROSS-NAZZAL: Any challenges associated with those as you were working on them and designing?

KRAFT: Yes. When we first started that's what was happening. We put these things in their test facility out there, and the nozzles would blow up. We had a heck of a time getting, there again, a

proper mixture of the propellants, the fuel that you use in the rockets, therefore you always had trouble with the valving and the seats of the valves. They get damaged by the explosion that's taking place, or the fuel itself causes the valve seats to deteriorate, so when you close them they don't close. You eat the seats up.

That's what was happening in the APU. It's a shuttle valve like this [demonstrates]. That's an interesting system, too. It's dripping hydrogen peroxide onto a catalyst bed, which is charcoal and something else, in this enclosed area. It develops at a very rapid rate steam, which then drives a small impeller, which again is another turbine, at 72,000 rpm [revolutions per minute]. It pulses. It's not a continuous thing, so these valves are pulsing all the time. They get the feedback from the explosion that takes place plus the imposition of these highly corrosive fuels. They open and close very rapidly. It's either being eaten up by the propellant or the impact loads are causing fatigue failure. We kept having to change that seat material.

ROSS-NAZZAL: Tell us about your involvement with the Canadians on the RMS [Remote Manipulator System].

KRAFT: I never had much to do with them. I went there once just to show my face, but I had hardly anything to do with the arm. Had little to do with that.

ROSS-NAZZAL: What about the Shuttle Carrier Aircraft? How much involvement or discussion did you have with that?

KRAFT: I went to Boeing. [Robert R.] Gilruth was still here when we made that decision. He and I went to Boeing three or four times, listened to their modifications, particularly to the airplane. They had to modify the tail, because the lateral stability of the [Boeing] 747 was modified by having a big Orbiter up there, so they put two more tails on it. That's the reason you had two tails on that aircraft, because the plane didn't have enough lateral stability.

We looked at the structure of the attachments and how they were doing that. They had to redesign the upper part of the fuselage. I say redesign it. What they did was put a bunch of added structure to take those loads.

There were a lot of people that didn't think that we could drop the Orbiter off the plane. I don't know why anybody thought that. The Germans did it in World War II, all the time. They were flying their fighters up there on bombers. [John W.] Kiker and Owen [G.] Morris built a model of it. I don't know what scale model it was, probably a tenth-scale model of the 747 and the Orbiter. Flew it right out here [at JSC]. Proved to people that you could do it with a model. A lot of people thought we were crazy doing that, but that never bothered me. I said, "The Germans have been doing it for years. All you have to do is fly the thing off."

ROSS-NAZZAL: Was there any discussion about using other modes of transportation to move the Orbiter?

KRAFT: Yes, but that way you would have had to put it on a barge. You would probably have had to break it up in pieces and put it back together again. That's probably what you would have done. Either that or ship it by rail, which you could have done, or ship it in smaller pieces inside an airplane.

ROSS-NAZZAL: Sounds like a lot of work.

KRAFT: Well, that's why we bought the [Aero Spacelines] Pregnant Guppy [cargo aircraft]. You see it flying around here every once in a while, don't you? That's why we bought that, to carry big diameter pieces. It's not NASA's anymore. I think the government sold it to a company which they pay to use it when they need it.

ROSS-NAZZAL: Tell us about the assembly of *Columbia*. Once things started to come together, how closely were you watching that integration out in California, their putting together the various pieces?

KRAFT: All the time. I was in that factory all the time when they started putting it together. The rigging and the testing of the—the jigs they call it. The jigs themselves and then the tolerances that the wings had to be built to and the tail, because we had Grumman building the wings and Convair building the midfuselage, Rockwell building the back end and the front end, and Fairchild building the vertical tail. Somebody else building the rudder, I think.

We built jigs in Palmdale [California]. The Palmdale factory was owned by the Air Force, but we used the factory, where you had to bring each one of these pieces, put them together. We had these tolerances that we gave each one of these guys. Wings are put on by bolts, wings on an airplane. Nothing new about that, that's the way you put a wing on an airplane, you attach it to a couple of bolts, interface with the fuselage. Don't know how good that makes you feel. The big truss that runs out to the wing—where it meets the fuselage, you

just have this interface and you just have usually two or three bolts where you bolt that into the structure.

You set up the tolerances that you allow each one of the manufacturers to have to meet those. He has a jig to which he builds the structure, then he takes it off of that jig. That jig has been made to meet the jig that you have in the main assembly plant. You bring that in, it mates. We didn't have any trouble with that.

ROSS-NAZZAL: So no challenges once they started assembling all these parts?

KRAFT: Well, they always go through a couple, but I don't remember exactly what they were. Then you have to start installing all the systems. You know how you build an airplane. All the tubing for the hydraulic system and operating controls, the jacks they call them. Hydraulic jacks that move the plunger, hydraulic thing. I learned all that stuff when I was a test engineer, but a lot of trouble with that.

Biggest trouble was getting the tiles on. Took us a long time to figure out how to do that. Didn't work. They came up with two or three different ideas to do it. They were very unsatisfactory. You couldn't get many of them on at a time; you ended up with these big pallets in the big areas (bottom of the wing, top of the wing), where you'd put maybe 40, 50, 60 tiles in these pallets, a square, sometimes rectangular. Then put the vulcanized silicone adhesive—it's a glue. It's a rubber glue, and if you don't put it on in a vacuum it gets a lot of air in it, then that's bad, so we had to put that pallet up there with the glue on it. It has to be mixed at the time. The formulas and the mixing has to be perfect. Temperature has to be very closely controlled, and then you put it up there and then you draw a vacuum on it. You cover that whole area and pump

the air out of it, and it cures. I don't know how long it takes, somewhere from a couple hours to a couple days. Something like that.

That was a real challenge. We didn't know. That was one of the big problems we ran into because we didn't have the money. As I said to you before, we didn't have the money to build a factory to build the tiles, so we delayed that a couple years before we started the factory. Lockheed built the factory in Palo Alto [California]. Went there maybe 20 times in my life also.

Didn't have the money because we didn't have the budget, so that was one of the things. We said well, we can delay building the tiles. That was a mistake, because that's when we found out the tiles didn't have the strength we thought they would have. We didn't know that until we got a lot more tiles, but that's the reason we were so late in coming up with the technique of putting it on. That was a big schedule driver.

The systems testing in the manufacturing plant up there was also. Used to go up there and argue with Sy [Seymour] Rubenstein [Vice President of Engineering and Chief Engineer for Space Shuttle Development at Rockwell] about that all the time. He found out I knew as much about those things as he did, kind of surprised him.

ROSS-NAZZAL: You were down there in the details. That's amazing to me, how much detailed knowledge you had about this Orbiter.

KRAFT: That's what I tell everybody. They don't believe that, but I got a sponge up here, all that stuff goes in there. It was a challenge to me, and I enjoyed it, so I just liked to do it. I came out of the NACA [National Advisory Committee for Aeronautics]. There were about 25 or 30 of

us that came out of the NACA. That's how we were raised, our job was in the details. We had to design it, build it, test it, then write about it.

That was a hell of a learning process. I had to do the math as well as the computation and the testing. Some days I had hydraulic fluid all over me.

ROSS-NAZZAL: It sounds like you were working fairly long days. Were you working 8 [am] to 5 [pm] or were you working 12-, 16-hour days during Shuttle?

KRAFT: I didn't work myself to death. I don't want anybody to think I did. I worked seven days a week, but at my own pace, and in my own place. I worked in my office usually from 7:30 till 6:00, if I was here, because I was traveling probably at least 25, 30 percent of the time to all these places, then I'd go to the gym. I used to work out for an hour, then I would go home and have dinner. Then I'd read for a couple hours. I was doing my job in different places, so yes I probably was working 12, 14 hours some days.

I played golf on Saturdays and after church on Sunday, but a lot of times I didn't play a lot of golf. Although when I was in Los Angeles, I always played golf with Bob [Robert] Anderson, who was the chairman of the board of Rockwell, and George Jeffs, who was the president, and George [B.] Merrick, who was the president under George at Downey [California], and a couple other guys. Usually if I was going to be out there, and if I was supposed to be there on Friday, I'd stay out Saturday and play golf with them. That was part of the job too. Got to know those guys. Now they wanted to know me, because I'm the guy that's responsible for their fee, so they're scratching my back I suppose is what you would say, but I was unaffected by that.

As a matter of fact I just got a picture. I was reminded by what I just said. Ed [Edward P.] Smith was the chief engineer of the Orbiter. Damn fine engineer, one of the best if not the best I've ever known as a chief engineer. When the issue over the budget where I think I told you about—[NASA Administrator Robert A.] Frosch going to the President. Anyway I'll repeat it, but I had a picture of him. Somebody sent me a picture of him yesterday on my computer. He was down at the Cape with a bunch of other guys from North American Aviation that were having some kind of reunion down there. They sent me these pictures, so it reminded me of Ed, but you will recall that they gave me these numbers, the total budget they needed, which we were then taking to Headquarters, which they took to the Congress.

Two weeks after we had submitted the numbers, they gave us an update on the numbers, and it was wrong by about 300 million bucks. It really pissed me off, but anyway I gave them a zero on their award fee for that period. It cost him his job, so he's never been very happy with me about that. I was reminded of that yesterday.

ROSS-NAZZAL: Tell us about your recollections of the rollout, the first time you saw *Enterprise* in California.

KRAFT: I've seen a lot of rollouts, so that didn't impress me much.

ROSS-NAZZAL: Not much of an impact.

KRAFT: No, it was a milestone day, there's no question about that. I was there, but it didn't mean anything. That machine was going to be used for ALT [Approach and Landing Tests]; it

was not going to fly. Going to be an approach and landing test vehicle, so it was really a test vehicle. Had a long way to go before we got to a flying machine from that machine. We had some problems with it in the control sense and almost killed Fred [W.] Haise [Jr.] with it. That was the second flight. He was trying to hit a point on the runway; he pulls the stick back too fast, and he'd forgotten that there was a trap in it. What I mean by that, it had different gear ratios between the stick and the control surfaces, depending on where it was, and the speed with which you pull the stick.

We had fixed that, but we hadn't fixed it in that machine, so he almost stalled the airplane and clanged it into the runway there, because he overcontrolled, but that was our fault, not his. He was trying to do the best he could at that point, but he shouldn't have been trying to land at a given point on the runway. He should have just taken what the airplane was going to give him. We hadn't flown that airplane much.

Delta wings are peculiar animals, because when you have an elevon, which is an elevator and an aileron combined, you move them both down this way to get elevons [demonstrates], and then you move them differentially to get ailerons. The only point of that is that on a delta wing, if you want to pitch up you put the elevators up so that it puts a moment around the center of gravity which causes the airplane's nose to rise or pitch up. Only trouble is, on a delta wing it also causes the wing to go down first. When you put these big elevons up, the lift change is in this direction rather than this direction. [Demonstrates]

The lift is still totally up this way, but it's cut off a little bit, because now when you put those elevons up to make it pitch up, it also pushes the airplane down from a lift point of view. He forgot that in the heat of the moment. The delta wing is not peculiar to the Shuttle. There are

a lot of airplanes today that fly that have delta wings. That's one of their characteristics, so the ground effect is modified. Screws up your thinking as a pilot.

ROSS-NAZZAL: What did you think about the inclusion of the delta wing on the Shuttle versus the straight wing that Max [Maxime A.] Faget had wanted?

KRAFT: I didn't have the same hang-up with the wing. Didn't make any difference to me what kind of wing it was as long as it did the job. He did. He was right to a certain extent, because the NASA requirements for the Shuttle were not what the Air Force requirements were. The Air Force wanted a 1,100-mile cross range. That's the reason we had such a big wing and the reason we had a delta wing. To get that much area and still have control capability, that was to get this big cross range. They wanted the cross range because they wanted to go up, go over the target, Moscow [Soviet Union], take a picture, come back and land at the same place that they'd taken off from. The Earth moves under you, and therefore you need 1,100 miles of cross range to do that. That's the reason we had such a big wing.

NASA didn't have that requirement. If we'd had a couple hundred miles of cross range that'd have been plenty for us. To correct any deviations you would get in an orbital trajectory coming in from 5,000 miles back where you fire the retrorockets, so we didn't need that big wing. It may have been easier to do from a thermal protection point of view too, but I'm not sure of that. Probably would have been.

Therefore we didn't need as big a wing. We didn't need that much area. That would have reduced the thermal problems as well as the structural problems. It would have been a more straightforward design problem, straight wings versus delta wings, but I like what Bob

Thompson said. I think I told you that before. Bob told Max, "Stop bitching about it, you'll learn to love it." And he did.

ROSS-NAZZAL: Was the DoD [Department of Defense] ever on the Management Council that you mentioned? Or that was strictly NASA?

KRAFT: No, they weren't, thank God. That's all we needed was another oar in the water. They were involved in the requirements, initially. We met with them all the way up to the Chief of Staff. We met with them when they were building the launch facilities out in California. If the Air Force was going to use it, they wanted to launch both from the Cape and Vandenberg [Air Force Base, California], so they were building what they called SLC6, Space Launch Complex 6, out in Vandenberg. Bob had people that were interfaced with the Air Force to build that facility. They built it, and then we never used it. A lot of money wasted there. They built a runway, launch tower, pad, rails to get it out there, and finished it, so we did have some meetings with them. That was with the Chief of Staff of the Air Force.

ROSS-NAZZAL: Let's talk about the ALT flights. You had mentioned a few things already, but how did Johnson prepare for those flights? Obviously they were out at Edwards but there was some control in Mission Control.

KRAFT: No, they didn't have any control over here. They just monitored what was going on from a voice communication point of view and whatever telemetry we had coming down from it was also piped in here, but the operation was really run out of Edwards, just like the X-15 was.

We used their control center, and their people were responsible for conducting the flight. Had a lot of arguments with Dave [David R.] Scott when he was out there. He wanted to be in charge. I said, "No, I'm in charge. You don't like it, get out of here."

ROSS-NAZZAL: What was his reaction to that?

KRAFT: I think he took it to people above me, and they said, "Kraft is in charge."

ROSS-NAZZAL: Were you out there for any of the flights?

KRAFT: Yes, I was out there for all of them. I say that, maybe I wasn't out there for the first one. I was out there with Fred Haise when Fred Haise made that landing, because I was standing there with Prince Charles [Prince of Wales].

ROSS-NAZZAL: Were you really?

KRAFT: Yes. He had been here several days before. He's a pilot, as you probably know. We put him in the trainer. He did what Fred Haise did, overcontrolled. He got a big bang out of that, because he could see it happening like I could. You didn't have to tell me he was having trouble, because I could see that. I've been in that business a long time. I knew that he was having trouble and so did the Prince. He was laughing about it. "Oh, he's having the same trouble that I had," he said.

ROSS-NAZZAL: What did you learn from the tests?

KRAFT: That you could do it. I don't think there was any question we could do it, but it proved that we could do it. From a public affairs point of view, that was important. Prove that we could land it free fall, and that you could do it dead-stick, i.e., no power.

ROSS-NAZZAL: Did you have to make any modifications as a result of the tests?

KRAFT: No. We'd already made those modifications I talked to you about relative to the control system. I don't know why we did it that way in the first place. I'm sure there was some reason, but we had probably run it enough in the trainers to know that that was a pilot trap. We had modified it, so we knew they might have trouble with that. Shouldn't have, but that's one of those things, if you put it there you're apt to get in trouble with it. You shouldn't try to overcome those things with pilot skill.

ROSS-NAZZAL: Let's talk about the first class of Shuttle astronauts that came in in '78. What role did you play in selecting this new group of 35 astronauts?

KRAFT: Too much. We were not only selecting pilots for the Shuttle, we already had some that wanted to and could fly the Shuttle—the ones we had from Apollo, like John [W.] Young who was the first pilot—but we wanted some more good test pilots to fly it. We also wanted some Black astronauts, and we also wanted some of a different sex. We were in the time period where the government was insisting that they be an equal opportunity employer, and so we wanted to

have women and we wanted to have Blacks or any color. NASA also had a Black woman named [Harriet] Jenkins, who served as Assistant Administrator for Equal Opportunity Programs.

I had a gentleman named [George W.S.] Abbey in charge of that. I had put him in charge of Flight Crew Operations, and I put him in charge of the selection group. We put a group together of present astronauts, medical people, and people from the science world; I don't know whether we had any others on there or not. I don't remember that exactly, but I know Joe [Joseph P.] Kerwin was on the selection group, along with John Young and—I don't know who the other astronauts were—and then we had personnel people from Jack [R.] Lister's group on there. We had people from the medical side; Dr. [Charles A.] Berry was on that group. I can't tell you the names of all of them, but there was quite a few people. We always had something like 5,000 or 6,000 people apply, then you go through a process of eliminating certain people out of that group. Well, at first you determined whether they met the requirements, then we took the best of the group and we usually ended up with somewhere around 200, 300.

Then we brought those 200, 300 in in groups of 20 or so, gave them a detailed physical, put them through a number of psychiatric tests, as well as intelligence tests. Put all that together in the hopper, and then you ended up with maybe 100 people. Then the selection board under Abbey chose 35. I was to approve that, and I was to take that to the Administrator, where Mrs. Jenkins was going to sit of course. That's where I came up with the idea of having Astronaut Candidates [AsCans]. I didn't select the astronauts, I selected candidate astronauts, and at the end of two years, we will decide whether they are astronauts. That's what I took to Headquarters.

ROSS-NAZZAL: Why did you decide on that category or that distinction at that point?

KRAFT: That's what I thought the government wanted to do. That was my responsibility as a government agent to do that. It was. The government really told me—I don't know who I would say that was, but I guess my bosses, who were Alan [M.] Lovelace and Bob Frosch, and their adviser, among others, was Jenkins. They told me, "Look, we want women, and we want some Black people here, and that's what the government wants. We want to be an equal opportunity employer." Frankly, I had no trouble whatsoever with that.

ROSS-NAZZAL: Were they happy with your list?

KRAFT: Damn happy. I'm happy with the people we got, too. All three of the Black men were fine people in my mind. I thought they were well qualified. I wouldn't have done it if I didn't think they were well qualified, but I thought all the women and the Black men that we picked were well qualified for the job. It turned out they were. After we got them here they were as good as anybody we'd ever had here.

Now they—like the scientist astronauts we'd previously chosen—some of them couldn't fly, so we taught them to fly. The category we put them in, they did not have to be pilots, but they had to fly. They had to travel in T-38s. They had to be trained in emergency procedures in flying in T-38s. Abbey was the head of Flight Crew, and he chose the crews that were going to fly, and I approved them. I turned some of them around.

ROSS-NAZZAL: Tell us about that decision to fly the first American woman Sally [K.] Ride, and then Guy [Guion S.] Bluford.

KRAFT: That was my decision.

ROSS-NAZZAL: Would you tell us about that decision?

KRAFT: Well, he, with a number of astronauts, chose the first woman to fly. They brought that to me, and I said no. Not because I had anything particularly against her, but from what I knew personally their reasons for choosing that particular one were, in my mind, not quite valid, because I thought that there were particularly two others that I had observed personally that were equally qualified. The one they brought me, I really didn't know as much as I knew about those two.

Then he and two other astronauts lobbied me after that, but they went away, and put these other two women into the process so to speak, and came back and gave me the same one over again. On the basis of what Mr. Abbey said and what the two astronauts that were being used—[Robert L.] Crippen and somebody else—they lobbied the heck out of me for Sally Ride, so I said, "Well you guys know more about her than I do, and you've evaluated the situation. I trust your judgment." That's how I chose her.

ROSS-NAZZAL: What did they like about Sally? What were they telling you?

KRAFT: They thought her performance, particularly in the control of the arm [Remote Manipulator System], which she was going to be responsible for, was outstanding. They thought

she was the best. For me to override that would have been difficult. As far as I was concerned, I'm sure she was qualified to be an astronaut.

ROSS-NAZZAL: In her interview she did mention to us after she was picked she had a meeting with you in your office, and she thought that your message was very reassuring to her. Can you tell us about that conversation?

KRAFT: I don't remember. I'm sure I assured her that I had every confidence she could do the job. And I did, but there again, as you know, I'm very dependent on the people that I have around me and work for me, or I wouldn't have them there. I had a high regard for George Abbey's opinion. She did a fine job in space. She did an exemplary job in space. It was probably perfect.

ROSS-NAZZAL: How did Johnson prepare for these six women that were coming into JSC? Were there any changes that you had to make on site to any facilities or buildings or even social attitudes that you recall?

KRAFT: Well, yes. We had to figure out how women can urinate and defecate in space, because they're built differently. I don't think we ever satisfactorily solved that, because we used a condom at first to hold the man's penis when he urinates in the spacecraft, then later we came up with a cup that the man could urinate in, because he has a nozzle. We had trouble with that, because at zero gravity the urine was going everywhere. You've seen these things in a fighter airplane. It's a cone that the man urinates in. That's what we used at first, but it didn't work

very well, because at zero gravity drops of urine would hit this thing and bounce off, going everywhere, so we had to design a grid that you put in there.

Now that wouldn't work for the woman, so we had to put something around the vagina that sealed so that she could urinate into a receptacle like that. I don't think that was ever very satisfactory. You have to ask the women about that, but I don't think it worked very well. Now in the Shuttle you have a toilet, so it's a little simpler there, but there again you have to be very careful about feces and urine floating around at zero gravity. It's still a problem. That's where we came up with this centrifugal device. Fluid and solids go into this thing, and it hits this centrifugal wheel. It's thrown up against the side and then that's where it's collected and disposed of, put into a tank. It's still not a very satisfactory thing at zero gravity. They suck air into this thing, try to keep a vacuum. That's been a tough process.

The feces is in the intestine, comes out as a spring. Think about that. It's all coiled up in your body. At one G it's not a problem, but at zero gravity it's in a coil. It's a spring, and it wants to stay attached to the anus, so it just got tougher with women, that's all. Embarrassing I'm sure. I can talk about it, because I'm used to talking about it, but always it's been a problem. It still is today. You always have trouble with the toilet. Get criticized like the devil for it. Spent $10 million and you don't know how to build a toilet. Well, we don't.

The other thing was you were always trying to collect it, because the urine tells you more about what's going on. Particularly the urine, but you also wanted to collect the feces so you could get a total calorie balance and metabolic data. So collecting it was on top of the list. In Skylab, you collected all the urine and froze it. They had to freeze it because urine after so many hours—you might as well throw it away if you don't freeze it, because the chemistry changes, and then we collect the feces and freeze it, bring that back for analysis. We knew every calorie

and the metabolic value of everything that went into the body and everything that came out. That was a hell of a project.

ROSS-NAZZAL: One heck of an experiment.

KRAFT: I'll tell you, we knew everything about the food they ate too. We knew what they used as a spray on the fruit.

ROSS-NAZZAL: That's amazing.

KRAFT: That's the reason spaceflight costs so much, isn't it?

ROSS-NAZZAL: Do you think including women and minorities in the astronaut corps changed JSC or the astronaut corps in any way?

KRAFT: It's bound to have, but from a performance point of view, I don't think so, no. No, I've never seen anything that would say that anybody that flew wasn't as good as anybody else, particularly in the types of jobs that they have to do. They're well trained. The training people, they're the best in the world. The evidence is what they can do when they get up there. Have you ever been out to the swimming pool [Sonny Carter Training Facility Neutral Buoyancy Laboratory] and watched them do the training?

ROSS-NAZZAL: Oh yes.

KRAFT: It's fantastic. They're throwing that away, that's craziness. The training that you have to go through to do the jobs, whether what sex you are or what color you are doesn't matter. They're all very very capable people, very competent, smart, and very well motivated.

ROSS-NAZZAL: What involvement did you have in the designation of the payload specialist categories?

KRAFT: Very little. I really didn't. At the level I was at when I was the Director I had nothing to do with that.

ROSS-NAZZAL: You were more technical and institutional.

KRAFT: Yes. Now when I became the Deputy Director—I have to be careful how I say this. I had little to do with the selection of the crews that were going to fly. That was all left to Deke [Donald K.] Slayton and Bob Gilruth. I frankly didn't know how they did it.

The first thing I did when I became the deputy was go into Dr. Gilruth's office and say, "I don't like it. I want that to be a more democratic process, and I want people who are going to interface with those crews to know before they are selected who they are, and have a voice in saying they don't want them. I'd like to hear it." He said do it, so after I became deputy director we had a board of people representing the various organizations that were going to interface with the crews. Deke had to present the names of the people that were going to fly.

ROSS-NAZZAL: Is that a similar process you carried through for the first four Shuttle flights?

KRAFT: Yes, indeed it was.

ROSS-NAZZAL: Interesting. Had not known that.

KRAFT: Now I don't know that they still do that. Just done while I was there. I always said, and I said in my book, I thought it was wrong to have an astronaut in charge of the astronauts. Now some of them are okay, some of them would be okay. I guess some of them would have performed a good job, but I thought it was in error to have an astronaut. That's the reason as soon as I had the opportunity I put George Abbey in charge of it. I got rid of Slayton; I put him in another job.

ROSS-NAZZAL: What effect did that have on your relationship with Deke?

KRAFT: He was one of my closest friends. That didn't mean I liked everything he did, particularly his relationship with the Public Affairs Department. God, we would make agreements between what the astronauts were going to do and how they were going to interface with the crew and what their time would be devoted to Public Affairs, and that would be the call of the head of the Public Affairs Department. Invariably he would ignore that. I'd have to call him on the phone and say, "Look, this is the agreement, I want it done." Same is true with the doctors. Many times I had to call Deke and say, "Dr. Berry is the head doctor in this group, you're not."

ROSS-NAZZAL: It's interesting that you say that. I've seen some of the memos between him and Dr. Berry. They're humorous, especially in relation to Skylab.

KRAFT: Yes. I also called Dr. Berry up and said, "Stop running the organization. I'm in charge, you're not." You don't see any memos on that.

ROSS-NAZZAL: I don't think I've come across any of those.

KRAFT: I did it. I used to give him a hard time because he was always wanting to be out in front of the press. I didn't like that. We're still the closest of friends, we still have dinner together every once in a while every two, three months.

ROSS-NAZZAL: That's great. I just had a couple more questions for you. I was thinking about operations when I was putting together this list of topics. I was wondering how, if at all, Space Shuttle operations changed from the early human spaceflight programs. In your opinion has it changed from the plan, train, fly? Has it evolved?

KRAFT: Not while I was there, to my knowledge. I think the relationship between the flight director and the flight controllers, between the medical people and the astronauts, I think those relationships were very clearly known and spelled out about who was going to be in charge. I know since then that that's not the case, because I've had a number of emails asking me how it

was, what I thought, and what I thought they should do. There's almost an insurrection on occasion between the flight crews and the flight directors. I don't know how that happened.

ROSS-NAZZAL: The only other question I had for you is about our second Orbiter, which was *Challenger*. How closely were you following its assembly and its design?

KRAFT: I was still doing all the same things I did all the time. I was out there approving the processes that were gone through by Rockwell and NASA to accept the machine, to test the machine, and to put it through the Cape. I was in charge of that. Yardley tried to change that a couple of times. When we sent that first Orbiter to the Cape, it was a total change in environment there. Going from Downey, where Rockwell was totally in charge of the machine, to the Cape, where now the Cape was in charge of the machine in terms of the processes that are gone through, etc. Except it wasn't that way in that we had yet to accept the machine as being verified to fly. We sent it to the Cape with a great deal of work still to be done to finish it in order to improve the time period it might take to do that transition from being in Downey under test to the Cape under test. There was a mixture there of testing versus assembly, versus verifying the machine as being built to print or whatever you want to call it.

We had this flat-out argument that said they wanted to turn that over to KSC. I told Mr. Yardley, "You do it over my dead body. I'm in charge of it; it's my contract. You want to relieve me of my duties, you may do so, but I am not going to turn my responsibility over to KSC, because I don't like the way they do business." I still don't like the way they do business. They know that. I always thought they were going to have a contract out on me when I went to

KSC. I never liked the way they did things, and they knew it, but they wanted to be in charge. I said, "Not until you relieve me of my duties, and it becomes their contract."

He said, "Well, I want to assign your contract to them." I said no. I sent Kenny [Kenneth S.] Kleinknecht to the Cape to be my guy in charge, and he was. Rockwell was happy with that relationship. I had fire in my eyes with that situation.

As far as the technical work down there, and what was going on, I put Kenny Kleinknecht in charge, and I guarantee there is nobody that was better in the world than Kenny Kleinknecht. He was like a slave driver, but he knew how to get along with the Rockwell people. There again, I was there every week. I got a briefing every week during the time that Orbiter was sent down there. "Tell me and George Jeffs what you're doing."

ROSS-NAZZAL: How did your job change once *Columbia* had finally flown STS-1? What sort of changes did you experience in your job as Center Director with the Shuttle Program itself?

KRAFT: Unfortunately that's when Mr. [James M.] Beggs came in. He and I were on a different page. He asked me to resign, and I did. He had me over a barrel. In order to not change my retirement, I was advised by Jack Lister to retire and be rehired as an annuitant, because then I would be under the old administration of the retirement rules. It would have cost me I don't know how many thousand dollars per year, if I had not done that. He advised me to do it, so when I did that as an annuitant I did not have any civil service protection, which I would have had otherwise.

Beggs and I, we never got along with each other.

ROSS-NAZZAL: Like oil and water, is that the phrase?

KRAFT: Exactly. What prompted me to bring that up is that he immediately wanted to change the relationships at the Cape. He wanted—and so did the Cape—to do what I did 20 years later, change the contractual arrangement that they had down there, because Rockwell was still the primary contractor for preparing the Orbiter. The Cape and Beggs wanted to put out an RFP [Request for Proposal] and select a contractor to do that, in other words put it out for bids. I thought it was extremely poor timing to do that. I thought it would be dangerous to do that. That in the midst of all this early flying of the Shuttle when we were all learning how to do this thing, that it would be better to not impose that on the system.

Now that was only part of it. I disagreed with that. I remember being in his office around a table similar to this one day. Walt Williams was up there then as an adviser to Beggs. He had been brought in by Low per my suggestion, because I wanted Walt back in NASA. I thought he was a good man. He's a tough guy but I liked him, because he was brilliant. Anyway he was in this meeting. We were having this hot argument, as I always had whenever I was in the presence of Beggs. You know me, I always tell it like it is. He didn't like it. After I'd said I didn't think that contractual changing was a good idea, he said, "Kraft, when are you going to be ready?"

I said, "Mr. Beggs, I'll tell you when I'm ready." I didn't raise my voice to him, but he did to me.

He looked at Walt and said, "What do you think of that?"

He says, "I think you better listen to Chris." Now he didn't; he went ahead with that contractual arrangement. I was opposed to it. It cost him dearly. It cost him a lot of money to

do that because what they found, as soon as they got the new contractor, they chose another contractor, and they immediately had to go hire all the people from Rockwell under a separate contract to be the guys that did the approval of the work, so it cost some big amount of money a year to do that, but that was only part of it.

When we were having these CCB meetings he, the Administrator, would come into those meetings and start criticizing us telling us we should do this, that, and the other. I wouldn't put up with that. I started going to the meetings for that very reason, because he was telling my guys what to do. They didn't quite know how to deal with the Administrator telling them what to do. We used to get in this argument just like kids. He'd say, "Yes, you did," and I'd say, "No, we didn't," that kind of a spat, ridiculous.

When we flew the second flight we had an in-flight failure of the fuel cell. The mission rules had been written that said if you have a failure of a fuel cell, thou shalt come down. At the time, we didn't have that much in-flight experience with the Shuttle. That's what we had discussed. Mission rules are done in the cold light of day so that when you have these problems you don't have to start arguing about them. Here's what it says. We had three fuel cells, if you have a single failure you should come down at the next available primary landing site, not immediately, which you could have said. We could land anywhere in the world with the Orbiter.

That required us to cut the flight short. It was a five-day flight, I think, on the second flight. That happened on the second day, so we prepared to come in on the third day. Well, Mr. Beggs heard that, called us all together, and said, "That's not what I want to do. It's going to make NASA look bad, going to look like the Shuttle is a weak vehicle. We should not come in. I don't want to do that."

I said, "Mr. Beggs, that's what we're going to do." Now that event was a significant event in the history of NASA because it's my opinion that's when everybody else went underground in the management chain. They stopped being as forthright as they were. We, the local management, including Rockwell, said, "Look, we've been exposing our decisions to all this business for the last year and a half or so, we're not going to do that anymore. We're getting tired of being beat about the head and shoulders for making what we know are good technical decisions. We are not going to tell that Administrator what we're doing again. We're going to make the decisions among ourselves." That was a very bad thing, very bad, because I think that's what happened on the *Challenger* and *Columbia* accidents. I think the attitude within NASA changed because of Beggs. I think that people stopped saying it like it was, as a result of that. It's too bad, but I think that's true.

Now eventually he called me on the phone and says, "We're not going to hire this year. I'd like for you to leave."

I said, "I don't want to leave."

He said, "Well, that's what we've decided." Now it was just Hans Mark's doing as it was his, but irrespective of that, they said, "You're gone."

I said, "Yes, sir," that was just before the fourth flight. I could have gone to the end of the year, till January 1st, but I said, "I don't want to. Under the circumstances I'm out of here," so I resigned after the fourth flight as a result of that.

It was a bad day for me. It took me at least two days to get over it. What I did was go make money.

ROSS-NAZZAL: Who did you go to work for?

KRAFT: I got a retainer from Rockwell, which I had to get Begg's approval to do by the way. They paid me handsomely, paid me a lot. I suddenly was on the board of a lot of companies in downtown Houston where they paid me handsomely.

ROSS-NAZZAL: Were you still working on Shuttle for Rockwell?

KRAFT: No, I walked out that door. The next day, I don't believe I ever felt so light in my life, because I said, "Well, it's not my responsibility anymore." It wasn't too long after that that we had the *Challenger* accident. I guarantee you, I guarantee you that if Chris Kraft had been there that wouldn't have happened. Guarantee you that. The decision they made that morning was indefensible. Indefensible. People on that flight were close friends of mine, particularly Judy [Judith A.] Resnik. She was like a daughter to me. Very disheartening, but that's life, isn't it? It wasn't my responsibility at that point.

ROSS-NAZZAL: But still it must have broken your heart.

KRAFT: It did. I watched it happen. They had the pictures of that thing an hour later, it was pretty obvious what happened. You see that flame coming out of that seal in the solid rocket onto the tank. There was no escape system that could have gotten them out of that. That's what all these pieces of paper say today. Everybody wants them to build a capsule. We tried that, but if we'd have done that we would never have flown. Think about that. What you got to do is

build another spacecraft, because you got to design that thing to survive under all flight conditions.

Just putting a whole cabin as something that you could separate away from the Orbiter structurally would have been almost impossible. Not impossible, but almost impossible, then getting it to not break apart anyway. It would break apart when you got it out of there. The Air Force did that on the B-58. Never used it. Took it off the airplane, because it was just too dangerous to use.

Even today you got all these fancy ejection seats. You know what the survival rate is on those? Fifty percent. Still today. If you eject from a fighter airplane or any other airplane, B-2, B-1, it's about 50 percent. We had ejection seats on the Gemini. God, that was the worst thing we ever did. I knew those damn things would kill somebody if we used them. Thank God we never had to use them.

There again spaceflight is dangerous. Spaceflight is hard to do. Spaceflight is risky, so if you don't approach it that way, from a management point of view, you're going to get in trouble. You can't do it as if it were some inanimate object; it can't be done. Got to look at it as there are human beings in this thing and every decision you make involves their life. If you don't make your decision process that way, I couldn't live with myself if we ever did that. That was what was so horrible about the *Challenger* accident, and almost as bad for *Columbia*.

We're flying the thing today. We still have the debris coming off that tank. They know how to fix that, and they can fix it, but they don't want to spend the money on it. If I was there, I guarantee you we would have fixed it. To hell with the schedule, to hell with the cost, we would have fixed it. The fix they made on the solid rocket—Max Faget had a piece of paper in front of me, neither one of us was working for NASA at the time, showed me how you do it in 15

minutes. That's how it should have been done. Well, NASA has got to go redesign the thing, and it works fine, but costs two years and a zillion dollars. He said put a piece of metal around the joint. Put a bellyband around it. We did that and flew the Atlas in 1961.

WRIGHT: Can you share with us what kind of work you're doing with Orbital [Sciences Corp.]?

KRAFT: Today? Well, nothing. I've tried the little bit of influence I had, which is almost nothing, to get the Congress to turn this 2010 budget around. They could. They could say, "No, we don't want to do this; we want to continue the Constellation Program or some variation thereof." They could still do that, just depends on how much strength the people that would do it have, and how much they'd be willing to overcome what the White House wants to do. I don't say that's Mr. [Barack] Obama, because I don't think he knows that much about it. There's some people that do. It's just the wrong thing to do. What I'm doing at the moment is consulting for no pay, by the way, for Orbital Sciences, which wants to consider bidding on a crew launch vehicle.

Let me go back and say what I would do is I would extend the Shuttle. I probably wouldn't fly it after I had the capability to get up there otherwise. I would save a couple of flights of the Shuttle to possibly repair the Space Station, because I don't think you can depend on the Space Station lasting another 10 years without some significant maintenance, repair, and replacement. Now they got a lot of spare parts up there. Big pieces to do that, but invariably it ain't going to be the right one.

If you go to your closet and say, "I haven't got the right lightbulb," it's that simple. You can't think of all the things you might need. And you probably can't put some big things up

there that you'd like to have up there, like replacing a whole joint in one of those solar panels. They do have some what they call CMGs [Control Moment Gyros] up there, and they can use those. If they can do the EVA [Extravehicular Activity] to put it in and get it out of there, but irrespective of that, that's what I would do. I'd save a couple of flights for the Shuttle to do that. I would use the Russians to carry people up there if I had to. I would continue with the Ares launch vehicle and the Orion spacecraft, some version thereof, because I think that's the safest and cheapest at this point and less risky way to go, because the Ares I is man-rated. That means that the principles of design, certification, and piece part selection has been properly done to meet the best you can do. Costwise that's expensive but it's the right way to go today.

I would continue the commercial stuff. I think that's a good idea, but they ain't ready, number one. Number two, they can't do it. They don't have the rockets to do it. There is no rocket that they're using or can be bought that will do the job. It can't carry the mass. Most of them say, "Oh yes we can carry the mass," but the trouble is they can't get it to the Space Station. It takes about 20 percent more payload capacity to go to the Space Station than it does just to launch something into low Earth orbit.

I was asked by Orbital. "We'd like to get into this business, come tell us what you think about what we're doing and give us any ideas about what you think we might do to respond now if this is the way the government is going to go." That's what I'm doing.

ROSS-NAZZAL: I think that we might have picked your brain enough today about Shuttle, unless there's something else you want to talk about. At some point you might want to come back and talk about your Kraft Report and the efforts to privatize Shuttle.

KRAFT: You mean the one that I wrote on the Shuttle? Be happy to do that.

ROSS-NAZZAL: I think that could be interesting.

WRIGHT: Be a good topic. By then you might have more to tell us about what life brings in the next round.

KRAFT: Yes. I want wings on it. It's hard to get. I don't like water landings and parachutes. They're too suspect. Gilruth said, "At least this plane is going to land in a dignified manner." That's what I like too, so I'm trying to influence that, but it may be too complicated. The biggest problem is, how do you abort off the pad? Tough to do.

WRIGHT: You have plans to go to the last Shuttle launch?

KRAFT: No, I might bring them bad luck. I've never seen a launch.

WRIGHT: That's what I thought you had told me.

ROSS-NAZZAL: Really. You've never seen a launch?

KRAFT: Never seen a manned launch, never. Always from the [Mission] Control Center. I don't want to go now.

WRIGHT: Maybe you can just go back to the Control Center.

KRAFT: Well, I'll do that. I might do that, but I haven't been back since they launched the *Challenger*. I was too sick. That was a terrible feeling.

WRIGHT: We look forward to you coming back. See what it brings us next.

KRAFT: Good.

[End of interview]