NASA STS RECORDATION ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is July 21st, 2010. This interview is being conducted with Dr. William Lucas in Huntsville, Alabama as part of the NASA STS [Space Transportation System] Recordation Oral History Project. Interviewer is Rebecca Wright. Thanks again for giving up your morning and coming in for this project. I'd like for you to begin today by sharing with us some background how you got involved with the Shuttle program here at Marshall [Space Flight Center, Huntsville].

LUCAS: I had been with the Marshall team for many years, having come here in 1952 to join the [Wernher] von Braun team. In the latter part of the Apollo program I was the director of the propulsion and vehicle engineering laboratory of the Marshall Space Flight Center, responsible for the propulsion and structural and mechanical design of the hardware. Near the end of the program, when it was evident that we were going to be successful in launching to the Moon, we realized that we had worked very hard during the decade of the '60s but hadn't planned for what happens beyond.

So the Marshall Space Flight Center had a retreat of its top management, and we decided during that weekend that we'd establish an organization that later became called Program Development that would be our new business operation. I was asked to leave my job as director of propulsion and vehicle engineering and head that new organization, and I was given the charter to select about 200 people in the Center to form that organization. Von Braun called me

his vice president of sales. I began that in the early part of 1969 and organized Program Development, a select group of very bright young people who were to lay out the future.

We did develop a long range plan, and the reason for mentioning it here is that one of the first things that we did was become involved in the A and B Phases of the Space Shuttle, conducting those studies. I served in that capacity for a couple of years, and then became Deputy Director of the Marshall Space Flight Center for three years, and then became Director in June of 1974, at which time the Shuttle program was a going thing. So I grew up with the program, and was there from the very beginning.

WRIGHT: Tell us about your involvement in the Phase A, Phase B studies and if you were involved with being a part of any of the Source Evaluation Boards.

LUCAS: Yes, we [were involved in] the Source Evaluation Board. The Source Evaluation Board was done for the Shuttle in Washington [DC, NASA Headquarters] but we did have a group of people up there, and I served on that group evaluating the proposals that came in.

WRIGHT: The history of Marshall had so much in-house talent building and producing elements and components, and the Shuttle program was bringing in more contractors. Can you share with us how Marshall geared itself to working closer or developing those relationships with big companies like Martin [Marietta Corporation] and Rocketdyne?

LUCAS: We were unique in the sense that we grew out of the Army arsenal system, so we did have more of an in-house capability than was usually the case throughout NASA. We had shops

as well as engineering people. But we'd had an experience of ten years working in the Apollo program so we learned how and that was a learning process.

I remember in the early days it wasn't easy to work with the contractors. We'd employ the contractors to do a job, and we were trying to tell them how to do it. I remember one of the first trips we made to one of our contractors on the west coast Dr. von Braun said, "Now look, don't go out there and try to tell these guys. They're smart guys. Just listen, see what they have to say, and we'll critique it later." Well, we did that for a few days. But we did learn over the process of ten years how to work with the contractors, so it was a pretty straightforward thing to do in the '[70s] then with the Shuttle people. Some of the same contractors of course; the propulsion contractor, we'd worked with them for 20 years.

WRIGHT: Certainly the engines were different. What were your experiences working through those meetings—really wasn't a transition, just moving them from a completely different way of the idea of reliability and durability and reusability, those different concepts.

LUCAS: It was a different challenge. It was a building process. I think that was one of the good things. We were in on the ground floor with the development of the rocket engine for the Redstone missile, and so we'd gone through the Redstone and the Jupiter missiles and then the Saturn I and the Saturn IB and the Saturn V [rockets]. We'd gone through those, but this new rocket was different than any of those.

First of all it was to be a different combustion cycle, what was called a phased combustion cycle with a preburner, calculated to be more efficient than the ones that we'd used before. It was a higher chamber pressure, about 3,200 psi chamber pressure, which was a big

step beyond anything before, and that created a lot of problems and a lot of challenges. It was to be reusable as you've mentioned, which also created challenges. All of those things were big challenges for us, and we didn't have a lot of time to develop the program either.

To compound the problem, we competed—I believe we had three proposals for the contract for the engine. We chose Rocketdyne, and of course the other proposers were unhappy and Pratt & Whitney was so unhappy that they contested the choice. Therefore we were excluded from direct contact with the contractor for several months after that, and we were really chafing at the bit because here we were responsible for developing a new engine in a sense and we didn't have much time to do it, and yet we were precluded from working with the people that had to do the job. That added to our concern.

WRIGHT: I imagine that impacted scheduling and cost of moving forward on the project.

LUCAS: We were concerned with cost from the very beginning because in developing the SSME [Space Shuttle Main Engine] the hardware that we had for the total program initially was lesser hardware than we'd had as the test hardware for developing the J-2 engine for example, which was a liquid hydrogen engine as well that we developed for the second and third stages of the Saturn V. We had a lot of hardware for testing [in the Apollo program], and we didn't have that luxury, if you call it a luxury, with the Shuttle program. And that concerned us.

Looking back on it it'd be hard to say we didn't have enough, because it was successful. But it certainly placed a greater strain on us. I think it probably impacted schedule in the sense that sometimes we had to wait for the hardware. It just wasn't available, and developing a rocket

engine you're bound to have a lot of failure problems along the way, that's the way you learn, testing to failure. So it was a challenge.

WRIGHT: The testing culture changed as well from Apollo to Shuttle. You were testing these components differently than what you had been traditionally doing in Apollo, is that correct? Where you had done a component at a time, now you were having to do more components together—is that a correct description? Or maybe I should ask if you could explain better how the testing differed under the Shuttle program than it did for Apollo, and was that a pro or con to moving the program forward?

LUCAS: That was true [in] a sense, but I think the big step we'd already made. Marshall, our culture was to test component by component and build it together. For example, when we started developing the S-IB stage [of Saturn IV], the first flight test was a live first stage but with a dummy upper stage. Then after we were satisfied with that we put the second live stage on it; we did one stage at a time. We were required by circumstances in the Saturn V program to go to the all-up concept, have a stack and all of them are live for the first time. That part of it we had already encountered.

In the Shuttle we don't have that opportunity, because we needed everything to get off the ground. We probably [did] less [engine] component testing. We had less components to test before we put the system together. We did testing in Rocketdyne of course initially and then we did testing here in Huntsville with our test stands. Ultimately, we did the real workmen testing down in Mississippi in the [NASA] Stennis [Space] Center, which began as the Mississippi Test Facility of Marshall Space Flight Center.

WRIGHT: Any testing episodes stand out in your mind more than others? Sometimes people have shared with us that a test that maybe would have been routine didn't go so routine, and that they remember that one. I just was curious if there were some episodes with the engines that made you have more concern than others.

LUCAS: Well, [in] testing a rocket engine you always have concern. As I said one time, never turn your back on a rocket engine. You have these failures—that's the reason you do the testing, to have those. So I was never very comfortable with any of the tests. I believe it's the 29th anniversary of the first launch of the Shuttle just a few weeks ago, and I kidded J. R. [John R.] Thompson. I said, "I got a lot of calls about problems, mostly at night, and J. R. would call and say that well we had a little problem on the test stand today. We had a fire and we destroyed the test article, but we saved the flame trench." We had a lot of those in the early stage of it, but that's a part of rocket testing. So you're never comfortable, but you're not devastated. You know it's going to happen [occasionally].

WRIGHT: I guess at that point in your career you had seen a lot of testings of a lot of engines so there weren't too many surprises.

LUCAS: I'd been through more than 20 years of it at that time, so you get prepared for that. We did have some problems that really shook us a little. In a program such as that we had investigative committees appointed already before we were doing the tests. So if you had a major problem on a test stand that did a lot of damage, we would immediately put into action

that investigative committee and they'd be there the next morning looking at what happened. We didn't have to wring our hands and say, "Who will investigate this?" We knew already who was going to investigate. That's what we did, and when we'd have a situation like that we'd involve primarily our people, but we also had people from JSC [NASA Johnson Space Center, Houston, Texas] and from KSC [NASA Kennedy Space Center, Florida] and from Headquarters involved in that. I don't have any at the moment that stands out in particular.

The engine strained us in many respects. Not only did we have a different combustion cycle, which was new, but due to the high pressure and so forth we had different materials. We had some very, what we call superalloys, highly alloyed steels, that were difficult to work with. They were difficult to weld, they were difficult to machine, and we were introducing numerical milling at that time on many of those parts. We had some labor pains there too.

Ultimately we developed some casting techniques that saved welds. With welds you build up more thickness, and every ounce you add to it costs you payload because the engine, since it's recoverable, has to go all the way to orbit and come back. So a pound saved on an engine gives you an added pound of payload. That was a big problem too. That's one of the problems of not being able to test as much as you'd like, and that is you have to be a little bit more conservative in your design, and that adds weight to the system.

WRIGHT: A lot of balancing.

LUCAS: A lot of balancing.

WRIGHT: You were mentioning about all the investigative teams. I know that you had a lot of meetings with people, reviews. Can you share with us your management style and your philosophy of thinking of the monthly reviews and the weekly notes? All those pieces that you put in together to offer an opportunity to exchange information and have issues be addressed.

LUCAS: Yes, actually I considered that one of my main functions. I didn't have to solve any engineering problems. I had to make sure some other people did, I had to motivate some other people to do that. I learned by long experience that most of your problems occur from the failure of one element to communicate with another. You start with competent people, and in a program such as the space program where you have highly motivated people to begin with, the problem comes when they fail to consider a different discipline, something else that has to interface with it. One of my main concerns was to be sure that all the right people considered the problem.

We did have a great amount of joint meetings, not only within Marshall but within the other Centers, because the Shuttle had more complicated interfaces than we had dealt with before. In the Saturn program we had an interface at the IU [Interface Unit] with the JSC components, but with the Shuttle it was far more complicated than that. We had the tank, that was Marshall, that had to go through the orbiter, which was JSC, and come to the engine, which was Marshall again. Some of the valves and things like that, the highly expensive things that would normally be on the tank, we put in the orbiter because it was coming back, to save it. That influenced the relationships. We have a computer mounted right on the engine, but it had to talk to the people up in the flight deck of the orbiter, so that was a problem that had to [be worked] out between Centers.

Within the Marshall Space Flight Center, we had very frequent reviews of each element of our program, where people would stand up and tell what the story was. The project people would lead that, but we would have our engineering component—the science and engineering people would be there and they would challenge things or make suggestions. That was a great and very important part of our growing together.

For a long time in Marshall we had what we called automatic responsibility. We had a small project office, but we had a larger number of people from science and engineering who were responsible for the program as well. So a specialist didn't have to, wasn't expected to wait till somebody asked, "Well, do you agree with that?" If he was a specialist and he didn't challenge something in his field that was wrong, he was to blame. He wasn't doing his job if he didn't challenge something that was wrong. We found that worked very well, and it does when you have a team that's motivated because everybody feels accountable for his responsibility.

We brought that to focus in the meetings, and I would always attend these meetings. I mainly asked questions, questions to find out whether the right people were working the problem, and whether I thought they understood the problem, and also probably to challenge logic on occasion. I sometimes use a little story that I learned back when I was in graduate school that became associated with me which was called the East Tennessee method of weighing hogs. Everybody learned what that was so I only had to mention that to challenge logic.

The way you [weighed bags in] the Sequatchie Valley [according to my source, was to place] a rail across the fence, and then you'd tie the hog to [one] end [of the rail and] a sack [to the other end] that you'd place rocks in [the sack] until you balanced the hog, and then you'd guess at the weight of the rocks and that was the weight of the hog. So when people gave me a story that didn't seem to have much logic, that's all I had to mention. Everybody understood

what that was. We learned a lot in those question and answer sessions. Everybody was free to speak up and raise a point. It produced, I think, a good product.

The weekly notes that you mentioned is something that was started back with von Braun, and I continued that through my whole 12 years. Our Center was divided into laboratories. [These] were major components, [as many as] 1,500 people [in some cases. The laboratories were] propulsion and vehicle engineering, astrionics, and aerodynamics and so forth. Each laboratory [was allotted] a sheet [which] they'd send every Monday—I think by 11:00 or noon. People at [any] level could raise a problem and make an observation or ask a question or suggest that something wasn't being done. [The comments weren't edited but were restricted to one page per laboratory per week.] So [in that way] John Doe [at a low level] in the organization could communicate with the [center] director directly.

Then it was my job to read those, tried to do it on Monday night, and annotate [them]. [For example] if [someone] said the project office wasn't paying any attention to him, I'd write a little note to the project office. The annotated notes then were copied and sent back to the people that were involved. They were expected to answer those, and someone on the staff would follow up to make sure that that happened. It was a good technique, and I think it substantially added to our effectiveness in communicating and involving all the people that needed to be involved in the program.

WRIGHT: For you in particular, being a Center Director—with your history of being part of Jupiter and Explorer and Apollo—did you have an inclination to want to be more hands-on on this?

LUCAS: Yes, I have to plead guilty, but I worked hard to avoid that. They call that crossing the great divide, crossing from doing to having done. There is an inclination to do that, but I worked hard not to do that. I worked hard to be sufficiently familiar with all the hardware that I could judge when progress was being made or not being made, and when problems were not being resolved. But I worked hard also not saying, "Well, here's the way to do it." I tried to do that by asking questions, and oftentimes I knew the answer to the question but I wanted some other people to recognize the question, and the smart guys to go off and solve the problem.

That was particularly hard when it got in my discipline. That was difficult. My discipline, which was materials engineering, was involved in virtually all the hardware. Everything's made of materials. I did become involved not so much in the Shuttle Program but in the Apollo Program in fracture mechanics, which was a comparatively new concept in design, because of my background, I guess because it was interesting, and because it needed to be solved.

WRIGHT: It certainly was very important, fracture mechanics in the Shuttle Program. As a Center Director, where do you find that you had the most challenge between these three extremely complicated components that you were working together? You had the engines, you had the [solid rocket] boosters [SRB] and you had the tank. All three were a pretty big project all by themselves, very complicated work with a lot of details.

LUCAS: Of course, [and] the SRB, the stage itself, we did in house. So that was really a fourth component. I think without question the SSME, the Space Shuttle Main Engine, was probably the greatest challenge in the whole stack. We were further out on the edge of technology in that

case than the others. I think that was a great challenge. However that was Marshall's forte, we were strongest there. We figured we knew about as much about it as anybody on propulsion. So we were prepared, I'd say, for that challenge.

The tank, we'd been through that before. One of the problems with the tank—there were many—was just its size, handling [the] comparatively fragile [hardware]. That was a problem, but we'd been through that. We understood the importance of fracture mechanics. We understood welding. We understood non-destructive testing of welding. It was a challenge, particularly the insulation on it, and because of its size. But we'd been there, we knew that problem.

The solid rocket motor [SRM], we didn't understand it as well as we did the other things. We were not experts in that. Matter of fact, I don't think there was any real expertise in NASA on that so we had to depend more on the contractor in that regard. It was a challenge in the sense that we may not have understood some aspects of it as well as the contractor, but the contractor didn't understand handling big hardware so that was a real problem for him. He'd done smaller hardware but he'd never built a motor of this size. Some of the problems we had early on were just in handling. He had dropped some hardware, which was just a no-no. You don't do that.

We had to supply some help there that was a little unusual. In every case, in every component Marshall always had a local office there, and the size of that office depended upon the severity of the problem at any one given time. We also worked with tiger teams. [When] we had a special problem, we'd call together a group and send them out to the contractor for an extended period.

In the case of the solid rocket motor, I remember they were having problems handling [large hardware components]—they just didn't understand this too well. I had occasion to meet

a retiree from The Boeing Company [who] had been through the Saturn V program. We were at an occasion down at [NASA] Michoud [Assembly Facility, New Orleans, Louisiana] when they were recognizing a little memorial to the S-IC stage that Boeing was responsible for. I asked this man how he was doing. Well, he's okay, but he's kind of bored. He said, "What I need is a project to push."

So I said, "They're having problems handling big hardware out at Thiokol [Chemical Company]. How would you like to go out there and help us solve that problem?"

"Oh, I'd like that."

I said, "Well, I'll see whether they want to hire you or we will." So I came back to Huntsville and called the manager out at Thiokol and said, "I've got a person that can really help you solve that problem. He just wants to work, he's not concerned about position or anything of that matter. Would you like to employ him as a consultant to yourself or do you want to me to employ him and send him out there?" He of course chose wisely and employed him himself, so he went out there and helped a great deal. That was a time that we did make a unique contribution to the SRM. I still say that the SSME was the greatest technical challenge. There were challenges to all the others—none of it was easy, but it was a challenge all the way.

WRIGHT: You mentioned that the forte of Marshall was the engine. Did the reusability factor create a bigger challenge for these engines?

LUCAS: Yes. We had tried some rocket engines back during the Apollo program. We had taken an engine and submerged it in the Tennessee River, and then pulled it up to see how it was affected, how much teardown it would require before firing it again. Fortunately the SSMEs

were never submerged. But then at that particular time we were thinking that the first stage might be liquid as well. That [would] require different materials and seals and that type of thing, that was a new situation.

We didn't have much of a track record, any guidance much to help us in that regard. Matter of fact, that was true of the solids as well, because nobody had ever flown one again. As we said, they always buried their problems at sea. We didn't get to evaluate the seals and O-rings and things of that nature [in precursor rockets and] that eventually gave us problems on the solid rocket motor. The reusability always placed a different strain on us.

WRIGHT: You had to balance of the cost of products for the durability against the efficiency. You had mentioned earlier about Marshall being part of bringing in new materials to use—some of the alloys, the welds. Can you share your recollections of some of the contributions that Marshall made to the products? Maybe some of the new state of the art [technology] that you brought forward to use on the Shuttle? Or even some of the processes, the automation of doing some of the welding and the foam applications—some of those ways that you did things that were new?

LUCAS: Well, I wouldn't want to claim that we invented everything, but by virtue of our culture to become involved in doing it and having a comprehensive capability across the board, we were in a position to make substantial contributions to the [development of certain alloys]. I think that Marshall made a very significant contribution over the years to the development of high strength aluminum alloys. For example, I remember when we built the Redstone missile we were using what's called a 52S aluminum, which was essentially pure aluminum. When we [advanced] a

little later in the Saturn I program, we wanted to use a higher strength aluminum, and a higher strength aluminum existed, the 2014, which was used in airplanes.

So we said, "Well, what about welding that?"

We went to Alcoa [Inc.], and they said, "If you want to weld it, you use 52S."

But we needed that strength, and the 2014 was used in airplanes. They riveted it together, but we developed techniques—along with the contractors—for welding 2014. There were other alloys that were developed along the way that Marshall made a contribution to. Not alone, but with the vendors and with the contractors, enforcing the development of these alloys. Particularly castings. The alloy that we ultimately used in the external tank—after my time they used the lithium-aluminum alloy, which was an alloy that was influenced greatly by the Marshall Space Flight Center.

Welding was something that we developed early on too, and eventually even after we were not doing the [manufacturing] work in house we set up a shop for experimental work, experimental welding and other techniques. That did contribute. That was available for the contractors to use if they needed to. They certainly had the results of what came out of that.

WRIGHT: I've heard people refer to it as the simple component of the Shuttle, but the tank is very complex in itself.

LUCAS: It is.

WRIGHT: The foam, even at the beginning you had some issues. Can you share with us some of the challenges that you had originally with the foam and choosing the right foam and the application processes from that?

LUCAS: That was a trial and error sort of thing. It sounds very simple, but when you apply it to something that large it's not so simple. We did have problems with spraying it on uniformly, particularly around protuberances where entries were made in the tank and this sort of thing. It was hard to get to get it to stick to the tank.

You look back, and you wonder whether we would do it again that way or not. We insulated the hydrogen tanks on the Apollo by putting insulation inside, but that creates a lot of problems as well and it was heavier. This was supposed to be much lighter, but we probably didn't account properly for the fact that something always falls off of a rocket. [There's] a tremendous shaking and vibration that goes on, and I don't think I ever saw a rocket launch that something didn't fall off.

Back in the old days when ice was the insulator, it would shed off, but that wasn't any problem. The problem was here's another system problem. The foam, it wouldn't hurt if a few pieces fell off just from the tank. That would lose a little hydrogen, but so what? We could account for that. The problem is the very fragile insulation on the Shuttle [orbiter]. Instead of being above the rocket as we always had, here it was down where if it was vulnerable to being hit by something coming off the tank. That's the problem that if we were doing it again we'd probably solve differently.

That insulation is still a problem for that matter. One of the things that I thought, in my mind, would be a way of doing it is to incorporate in the exterior of that foam some mesh, like

cheesecloth or something like that. But that complicates the manufacturing process and also adds weight. Here again, weight is very important on the tank.

WRIGHT: It seemed like when there was weight removed from the entire configuration, it always went to the tank to find where to lose the weight. What were your thoughts when you first heard about the ideas for the new lightweight tank and the super lightweight tank, and then saving 7,000 pounds from the paint, just not painting the tank itself?

LUCAS: Well, the paint wasn't a new concept, we'd been through that before. Actually the first weight saving on the tank was while I was still Deputy Director I believe. When we heard that our project manager was agreeing to that we almost wanted to shoot him because that was early in the program and we just were worried about that. You're always nervous when you have to cut down weight, particularly when you have a limited test program. It's impossible to test entirely the tank on the ground—it's impractical I should say, especially when you're taking into account fracture mechanics. If you have a small flaw in the weld it can propagate [when the tank is] pressurized but [if] you haven't really tested it under flight conditions over the whole tank [there] was a concern [that after repeated testing, the undetected flaw might propagate catastrophically].

The paint was a given. That's a way to save weight. We'd been through that back 15 years before, right after Explorer I and launching [other] satellites. The paint weighed more than the payload so we took [the paint] off. I remember one funny experience. I was in charge of materials engineering at that time, and we developed this lightweight paint with a pigmentation that was white from the standpoint of visibility and tracking but it was much lighter weight than

the average paint. I got a call one day from the shop saying, "Shall we put the lightweight paint on this particular vehicle?" I said, "Absolutely we have to have it." I didn't realize at the time he already had the other paint on so he paints the lightweight paint over that. Then we had to take it all off. So lightweight paint wasn't a new one on us, we'd been through that.

WRIGHT: You have all the people at Marshall you're working with, and as you mentioned JSC and Headquarters, and you're also working with the Air Force. Can you talk about the relationship with the Air Force and how the Air Force requirements impacted some of the work that you were doing here on the Shuttle?

LUCAS: We worked with the Air Force on what was called the tug I think at that time. As far as I can see our relations with the Air Force were pretty good, because the Air Force lacked the in-house capability that was available at NASA. I thought they evaluated us rather favorably in that regard, and that made our working with them, at least at the level that I was, much easier.

The Air Force requirements drove the configuration of the Shuttle at the outset, and that was a handicap that we dealt with until today. That's the only way we got the Shuttle approved, by [considering] the Air Force requirements. At some level in the DoD [Department of Defense] it was decided that the Shuttle would be used for certain Air Force payloads—it drove the size of the Shuttle. We had to make it larger than NASA would have made it.

Also the requirement for cross-range on the basis that they may need to come back sooner than we would. Those were the requirements that drove the configuration of the Shuttle, and we paid for it on every flight, and [cross-range capability] wasn't [needed]. From my

perspective we found working with the Air Force to be pretty good as far as the Shuttle is concerned.

At the same time we were doing the Shuttle we were doing some other programs. There were the High-Energy Astronomy Observatory, the HEAO we called it, and we competed for and won the responsibility of developing the Hubble Space Telescope. Our contractor for developing that optics was an Air Force contractor, and [the plant] was highly sensitive and classified. They restricted the amount of people that we could put into the plant. We couldn't penetrate that contractor like we were accustomed to doing, and therefore we did have some problems.

Also we developed the Spacelab with the European Space Agency. [Thomas] Jack Lee was eventually the Deputy Director and then Director. But at that particular time he was the Level II manager of the Spacelab, which flew in the cargo bay of the Shuttle. We launched the Apollo-Soyuz in 1975 so we were spread pretty thin.

In addition to that Marshall was [reducing personnel]. After the [Apollo] program we had to reduce our complement very severely. That continued on through the middle of the '70s. To reduce your complement in the government you can't always determine who goes. The system of personnel management specifies how you get rid of people, and sometimes if you could select you'd be better off maybe. But you couldn't do that.

WRIGHT: You certainly had a lot of hats on during that time period.

LUCAS: We did. It was a challenge.

WRIGHT: It's complicated to put your aspects together, but then of course you have to integrate them with the work that was being done at JSC and KSC. Would you share with us about the challenges and your processes of pulling everything together across the agency to ensure that the Shuttle was tested and ready to fly as a unit?

LUCAS: That was an absolute necessity. As I mentioned in another question, the interfaces between Marshall and JSC were much more complicated in the Shuttle than had been in Apollo. It required a closer-knit working relationship than we had experienced before, and it was important before. With KSC, they had to interface with all of us, because they had to launch the hardware and they had to be acquainted very thoroughly with all the hardware. We maintained an office at both JSC and KSC to help in the communication between the two.

There were very frequent contacts between the project people, on a daily basis I would say. Of course JSC was the Level II for the Shuttle, and we had that relationship. We had very many meetings, frequent meetings, and a lot of travel back and forth for technical meetings. I didn't attend all of those, couldn't have, but some of them I did to get a flavor of how things were going. Then we had the management council meeting on a monthly basis involving the three Centers and Headquarters.

There were problems I'm sure in working relationships, but I think overall they were pretty good. I think [we were] rather successful in working together on some very difficult problems. I think there was enough competitiveness to keep a tension that was positive and helpful. There was a lot of pressure at every level but I don't think in any case there was any pressure on any Center greater than that Center applied on itself, because we were dealing with

people that were committed, that had pride in what they were doing, and that pride if nothing else drove them to do the best job possible.

WRIGHT: All the different Centers were working toward common schedule. Once the preparations for STS-1 began at the Cape [Canaveral, Florida], did Marshall receive a lot of last-minute changes or requests from the Cape on any of your components that needed to be changed in order to get the configuration ready for launch?

LUCAS: I don't believe that there were a lot. There were some I'm sure, but they'd been welded together pretty well beforehand. It was probably easier with KSC than with JSC, because initially KSC was a part of Marshall. In the early days we had a launching and handling group that we called it, and when we got ready for launch they would take the hardware and go down there and launch it and then come back. Some of the people that did that from Marshall were key people at KSC and were accustomed to working together. So KSC did make, I'm sure, important contributions to the design in the sense that we had to make it compatible with what they could do with the launch equipment. I don't recall anything that I considered out of the ordinary. I'm sure JSC experienced some of the same kind of things that we did because KSC has to launch the hardware.

WRIGHT: Could you give us your thoughts about STS-1 and watching the launch and knowing that it safely landed at Edwards [Air Force Base, California]?

LUCAS: No, I can't really. It's an experience you have to have. I've thought about that a lot of times. We were frantic in our preparation for it, and we had a delay or two. Finally when it launched it's a feeling I can't even describe, and I haven't found anybody who can. It seems that the anxieties of weeks and months just flowed away, just a sense of relief that I can't describe. It's just a very exhilarating feeling.

I remember when we launched STS-1 and we flew back that day to Huntsville in NASA-3 [aircraft]. All along the way the radio stations, when they acknowledged NASA-3, they knew who that was and they would congratulate us. Just I think expressive of how the country reacted to that launch, but particularly those of us whose lifeblood almost had been into it, it was a very exhilarating experience. We talked about that not too long ago—as I mentioned we had this little party of key people here at Marshall. I said at that time that it was a feeling that I couldn't describe in words, and challenged anybody else to but nobody did. When you think about what we'd been through that period of time, and suddenly it blossoms in success, it's wonderful.

WRIGHT: I was thinking about the 400 tanks that were originally slated to be made for the program. When you first started on the program it was supposed to have been able to be more robust than it turned out to be. How did you adjust to that? I know it affected schedules and it affected your cost, but was there an actual process of knowing that the flights per year were going to be less than what was originally scheduled and so therefore Marshall had loss of personnel or loss of funding? Or did you continue on your road to working toward that schedule even though it wasn't going to be attainable?

LUCAS: We did what I think was expected of us, but I think that we recognized that we were not going to have the launch schedule that was used in the sale process. The selling part of the Shuttle was cost per flight, cost per pound of payload. If you look at the formula, the more flights you have, the more effective your cost. [Initially, there was talk] about $100 per pound [of payload] and stuff like that. Realistically one knew that wasn't practical. We just worked to the shorter range schedule; I don't think we expected [a 400-tank] flight in reality.

WRIGHT: Do you recall if you changed any of your testing procedures for any of the components once the STS-1 launched? Was there something that you did differently or changed to be more aggressive on any of your testing based on the fact of that successful launch?

LUCAS: No, I don't think we changed anything on the basis of one launch. For example, the Shuttle main engine was designed to be throttled from about 65 percent thrust up to 109. We'd flown a lot of Shuttles before we got up to 109 thrust. As I recall we did 100 and then 102 and 104, and I think we jumped up to 109. But you wouldn't change much on one flight I don't believe.

WRIGHT: That's interesting that you kept moving.

LUCAS: That was more consistent with what Marshall liked to do on everything, but we weren't able to. It's a more conservative approach. As I said before, a conservative approach in testing may ultimately work in favor of saving weight and more effective vehicle because you learn

when it's going to fail, you know how far you are from failure if you do enough testing. That's why I say one test doesn't make a program.

WRIGHT: You also had mentioned the management council. Did they as a group make decisions that impacted you directly? Or were the decisions made collectively with the groups that you met with?

LUCAS: I think by and large the decisions were consensus types of decisions. I'm sure that was not true in every case. Sometimes there were budget things over which [Headquarters] didn't have control and they had to say, "This is the way it is fellows, we've got to figure out how to do it like this." They were deeply involved. Probably, from my standpoint, maybe more deeply involved than they should have been. On the other hand I recognize the pressures on them. They had to interface with Congress and Congress asked questions that they probably didn't understand the answers to but they ask them anyway, and the people at Headquarters had to be prepared to answer those questions. They had a heavy responsibility too, so I account for that.

It's, I guess, human nature that you resist a little bit of pressure from above, particularly when you think you know more about it than they do. On the other hand that's what makes programs work. You've got to have pressure at every level—reasonable pressure, I don't mean unreasonable—reasonable pressure at every level. It's a matter of accountability. Everybody's accountable to somebody, and you got to recognize that if you want the program to happen.

WRIGHT: I think one of those individuals was John [F.] Yardley. Did you have a lot of day-to-day interface with him?

LUCAS: Yes, we did. John was an exceptionally well-qualified, dedicated engineering person. He had the same problem as all of us. [Like most of us, he] started on the technical side of programs. He involved himself I believe productively in the day-to-day operation. Many of his contacts were directly with the project office. He didn't come through me to ask a question. He went directly to the project office. He was more like the project manager. He really wasn't responsible for the institution. We had an institution boss. He could be influential with personnel, something of that nature, but he didn't control our personnel. So he went directly to the project and he would not hesitate to come to me if things were not going according to what he thought they ought to be. He was a very hands-on, involved person.

WRIGHT: The way that the organization was established, did it put you or put the Center Director in somewhat of an awkward position because you were over the people who were doing the work for the program, yet you were indirectly involved with those decisions that were coming out of that Level I, Level II direction?

LUCAS: I guess one might say that. I have the impression that it's the case now. Looking from the outside, I think that's the case now. I don't believe it was the case back with the Shuttle Program. I think there was a pretty good understanding. For example, a Center Director with other responsibilities couldn't become involved in every detail on the engine or the tank or anything else. You might as well be in the project office. So I didn't object to direct contact because my people kept me informed and if I didn't trust them I guess I might be concerned, but I wasn't.

WRIGHT: And from your list, you had so many other major projects at the same time.

LUCAS: That's right. And that was partly my fault because I mentioned I started in the Shuttle Program as the director of program development, and I was instrumental in making the decision to diversify Marshall because I knew approaching the end of the Apollo Program that there's not that many launch vehicles to develop. If you're going to exist as a Center or business you got to diversify.

So we made the deliberate decision to diversify and competed for some of the science programs, which was very good, because in our experience the scientist who thought about Hubble for example, he didn't know how to make it happen. He knew what he wanted to do, and he knew the science involved, but how do you get from that idea to hardware? NASA, which was expert in that, made a big contribution in that regard, and it turned out to fill our Center. I believe we may not have existed as a Center without that diversification.

WRIGHT: Came very good with timing and planning to bring it there when you did. If you don't mind, I was going to ask Jennifer if you have some thoughts?

ROSS-NAZZAL: Yes, I was curious—we have talked with Chris [Christopher C.] Kraft about his Shuttle experiences and Shuttle days as Center Director at JSC. He talked about the management council and mentioned that a lot of the technical decisions were made at that level. Can you give an example or two perhaps of some of the technical decisions that were made at that level?

LUCAS: I guess that depends on how you define technical. I would say that schedules and that things certainly were, allocation of resources were, configurations were made at that level. But I think they were more a consensus decision. I don't think that everybody presented their story and then some major figure said, "Yeah this is the way it's going to be." I think we just evolved into consensus. I have an image right now of Max [Maxime A.] Faget. I remember when we were talking about the configuration of the orbiter, he had a model he'd built, and he stood up on a chair and showed how it would enter and so forth. That level was discussed there. That decision was primarily a JSC decision, but it did impact the rest of the program too. In that sense the major systems technical decisions were made at that management council meeting, but not the detail ones like what should be the composition of the insulation on the Shuttle or something like that.

ROSS-NAZZAL: Would the management council meet always at Headquarters?

LUCAS: They rotated between Headquarters and [each] of the [three] Centers.

ROSS-NAZZAL: You had mentioned you couldn't have your hands so deeply involved in all of these projects because you were running the Center and working on diversifying the Center itself. How closely were you working with project managers like J. R. Thompson or Mr. [Robert E.] Lindstrom who was head of the Shuttle Projects Office? What was your relationship with those people?

LUCAS: Very intimate, everyday business. I don't think very many days went by that I wasn't in contact with them. Certainly no weeks. We had formal meetings at least once a month. We've been through the note situation, and I had a staff luncheon every day that involved the key people so we spent about 30 minutes gobbling down something and also talking about the program. It was a very close relationship, and I was informed in almost real time about any major problem that developed.

ROSS-NAZZAL: Did they ever come to you and say, "This is a big problem and we've got this opinion and this opinion but I'm not sure which opinion is best?" Did you ever weigh in on any of those decisions?

LUCAS: I can't imagine any one of them ever coming to me like that. No, they would not have surrendered their prerogatives that easily. But I don't think they would make a decision of great consequence to the Center or to the program without having informed me. I could always veto it if I chose to, but that usually wasn't the case. That would have been true only if it impacted some other thing that wasn't known to them.

I believe our communication was such that they kept me pretty well informed, and I let them do their job. I think where things break down is when you don't trust the people working for you to keep you properly informed. Then you inject yourself into every little thing that they do, but I had known both of those people you mentioned for a long time. Bob Lindstrom and I worked together back on the Explorer I. J. R. had worked in propulsion and vehicle engineering laboratory when I was director there so I had high confidence in him. He's a dedicated individual that drove himself harder than anybody could have driven him. A lot of it depends

upon trust. Where you get in trouble is where you try to make every decision yourself I think—I'm not that smart.

ROSS-NAZZAL: It's funny that you say that because Chris Kraft mentioned that. He said he's not a smart person; he always surrounded himself with smart people.

LUCAS: Yes, I think that's exactly the way he should, and I think he did. I said just a few days ago to somebody about a different problem altogether, I judge a manager by whom he gets to work for him. You got to select the right people and let them work.

ROSS-NAZZAL: You had mentioned a few minutes ago that Yardley would come to you if things weren't working quite right. Can you give an example, anything that you recall? Maybe the main engines for instance since they were a pacing item for the project itself.

LUCAS: I think particularly if we had a major engine problem he would involve himself in that and discuss it with me right away. I remember one fire we had down at Mississippi that happened one night and he was calling me the next morning about it. Fortunately I'd already put in place an investigating committee. I don't recall any special thing that I would mention other than just keeping informed, I don't think anything significant at this time.

ROSS-NAZZAL: Thank you very much.

WRIGHT: The years that you spent putting the Shuttle Program together and the successes were so many, and then of course the [Space Shuttle] *Challenger* [STS 51-L] incident occurred. Would you share with us the processes and the meetings that you put in place after *Challenger* to help find the answer and determine the problems so that they could be addressed and fixed and that the Shuttle could fly again?

LUCAS: The problem was associated with the O-ring on the solid rocket motor, and I'm not sure that the exact cause was ever known. I do know that we had discovered a long time before that we needed to redesign that joint, and that had already been started at a low level. The main thing was to redesign that joint because we'd had some burns of O-rings before that time, been well discussed at every management council meeting. Everybody was aware of it, and the judgment had been made that it was not as bad as it turned out to be.

Part of that is due to the fact I mentioned earlier that there was no track record of solids before, because you never had the chance to look at one after it was fired; it was buried at sea. The ones that we'd seen had been a concern to us to the extent that we already were talking about a redesign, but it was more critical than it appeared.

WRIGHT: I know you weren't here at the time of [Space Shuttle] *Columbia* [STS-107 accident]. But some of the issues that have come up from the foam—were those issues that were discussed in the original times of the discussions of processing the foam and applying the foam? You had mentioned something always falls off of rockets when they were launching.

LUCAS: To my knowledge it had not been considered a significant problem at the time I was involved with it. It's another one of those things that you look back in arrears and you say [we] should have done [something about] that. But we always get smarter tomorrow, and I don't think it was ever—it never bothered me much because I was accustomed to things falling off of a rocket. I never saw one [without] ice [or something] falling off. I guess the thing that we overlooked is the velocity of impact when [the orbiter hits something that] comes off the [tank]. It's like if you toss a feather up and hit your windshield or you throw a rock through it. It's a different situation.

That's one of those things that you get smarter [about]. I think we decided on the configuration of the Shuttle probably too quickly, because this configuration that we decided on was not studied thoroughly enough in my opinion. I think we went from Phase B into Phase C probably a little too soon. But that's hindsight. At that time we were just glad to get approval to go ahead, and we did go ahead.

If the Shuttle were sitting up here on top of the stack that would never have happened, because stuff would fall off below it and that's the way it was always done before. On the Apollo the capsule wasn't bothered by any ice falling off. If it'd been down here on the side it might have been, although it was a more rugged vehicle than the foam on the orbiter.

WRIGHT: We've discussed how each one of these components was extremely complex. Of all that you were able to accomplish during that program, is there one aspect that you feel is the most significant contribution that you were able to direct or to guide to make sure that that got done? One of the things that you're proudest of during the Shuttle program?

LUCAS: That was the payoff, STS-1. And it doesn't make any difference how good the engine was—if the tank exploded, it was all lost. If I were down in the laboratory I'd say, "Well, I designed this or I selected this or that or the other," I could point to one thing. But as Center Director what I point to is that successful launch. That was it; that was it. There's nothing that happened anywhere along the way like the launch of STS-1. That's the payoff. So regardless of how smart or dumb I might have been at any one point, it's all determined by what happens on launch day. I think we had a fine group of people, and whatever I might have done in motivating people to get the job done wouldn't have amounted to anything unless we had a successful launch. Maybe it might have been more fun to work down in the lab somewhere, but that wasn't my assignment.

I'm just glad to be able to be a part of the program, it's a wonderful program. Not only did it accomplish [its mission], but I take a great deal of pride in the fact that the space program should not be evaluated on the [success of the] launch entirely, but it should be evaluated on its contribution to society. I can't think of any single program in our country that has done more, made more overall contribution to society, than the space program. It's been the driver of technology for the last half of the century, it has been an important instrument of international relations, it has built the reputation of our nation among all the nations, and it has generated spin-offs that have made untold contributions to society. To consider that we, for less than 1 percent of the national budget, could have gotten that return on the investment to me is nothing short of miraculous. Looking back on things that I have done, I like to think that I've been a part of something that has benefited not only a small group of people but has benefited all of society.

WRIGHT: Thank you. That was a nice synopsis.

LUCAS: Well, that's the way I feel.

WRIGHT: We talked about the [Shuttle] Program, but again while you were here the Hubble was underneath your umbrella and Spacelab, and of course you finished the ASTP [Apollo-Soyuz Test Project]. It was interesting that so much that you just discussed branched out into those programs as well. It was not just the Shuttle Program, it was these other pieces.

LUCAS: Chandra [X-ray Observatory] also, I don't think I've mentioned. The HEAO, the High-Energy Astronomy Observatory, was a package of three different launches of high energy telescopes. Then that fed into the Chandra X-ray telescope, which has made a tremendous contribution to our understanding of our environment. Marty [Martin C.] Weisskopf is the scientist on that program. I first met him in the Skylab Program, he was part of the telescope and science program. He was working for one of the contractors, but I hired him to be the chief scientist for the X-ray telescope that we were competing for. I was criticized at the time because they said he was too young. Years later, I said, "Marty, I thought you were going to be too old before we launched this thing." Many years. But he's done a tremendous job, still is working. We happen to have seats next to him and his wife at the symphony concerts so we laugh about that a lot of times. That's part of our diversification [that] came about.

This long range plan that we developed—I mentioned early on as introductory—included virtually everything that NASA has done so far. We haven't gotten some of it. Some of it was a permanent site on the Moon and manned landing on Mars, that's still some way away. I was trying to encourage Jim [James M.] Ellis a little bit as we came in, because we've gone through

these valleys between every program. I've been doing this since 1952. It seems maybe it's a little worse this time. I don't say that to him, but I am concerned that we may not have the support—I'm pretty sure we don't have the support in the national administration that has resulted in all the progress that we've had up to this date. Even in the decade of the '70s when we were developing the Shuttle Program we didn't have near the support that we did during the Apollo Program. That support of the national administration is very important.

Having a President—who of course has to be concerned with the day-to-day problems of our society—but if he's not concerned about the future, we're in trouble. I frankly am concerned today about the direction—or lack of direction, lack of focus in the space program. I just think to back off of the space program is like backing off the high ground. We just don't do that as a great nation.

WRIGHT: I appreciate you offering that. Is there anything else that you had that you wanted to ask?

ROSS-NAZZAL: Did you talk at all about budgets around the Shuttle Program? As you closed out talking about that I was just curious.

LUCAS: We started off by saying that the Shuttle was underfunded from the very beginning, and that impacted the hardware that we could have. It particularly hit I think Marshall, because our culture was more of test and verify. We were probably more conservative than some, and that may have derived somewhat from the German influence, doing a great amount of testing program.

What sometimes appears to be a saving of money becomes the most costly way of doing it. To drag a program out, to starve it, is the most costly way of doing it in the long run. You want to save cost, you get the program done, and get the people off the program doing something else. I think that if the Shuttle had been properly funded we could have done it, in total cost, probably for less. I said earlier too that it's hard to argue now that we didn't have enough testing program, because it worked, didn't it? We've launched 130 odd of them. But on the other hand, who knows? If we'd had enough testing program, we might have been able to save more weight, give more performance, save cost of operation than we have.

In the Apollo Program we had a fixed deadline, so we had a fixed schedule. Performance of course was fixed. The variable was cost. Whatever cost we needed we got. In the Shuttle Program of course performance was fixed, and cost was somewhat fixed. The variable was the schedule. And that's the way, in my opinion, you really in the long run build cost. I'm not saying this to be critical of any individual at this juncture. I know within NASA we got all we could get.

The problem was that we didn't have some people in Congress who were as dedicated to the space program as they were during Apollo. Tiger [Olin E.] Teague was your representative [from Texas]—he was a stalwart. [President] Lyndon [B.] Johnson, they made sure we got money. We had some people in Huntsville. But that doesn't seem to prevail today. I say that without knowing all the problems that the national administration has—I know they have a lot of problems, but when you can't spend 1 percent on the future, that's shortsighted.

ROSS-NAZZAL: Were you ever afraid that the program might be canceled when you were working on the Shuttle?

LUCAS: I was afraid not only that, but that the Marshall Space Flight Center might be closed. I believe had we not had the diversification that we would have been. We had come down, we were on the declining manpower schedule through at least the mid '70s. When you're trying to build up a new, highly challenging program and reduce manpower at the same time that's bad. It was not a comfortable situation in that regard.

ROSS-NAZZAL: Do you credit any one individual for ensuring that the program would continue on?

LUCAS: No. I wouldn't credit any individual, I credit a lot of individuals. I credit a lot of individuals for doing that. The three Centers, none of them tucked their tails and ran away. We did the best we could do. We maintained a stiff upper lip as they say and got it done. I don't know that I would say any one. There might have been somewhere along the way, but there are a lot of individuals.

WRIGHT: Well, we thank you for taking your time this morning.

LUCAS: You're welcome.

[End of interview]