# NASA JOHNSON SPACE CENTER ORAL HISTORY PROJECT
# EDITED ORAL HISTORY TRANSCRIPT

HUMBOLDT C. MANDELL, JR.
INTERVIEWED BY REBECCA WRIGHT
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WRIGHT: Today is January 12, 2010. This oral history with Dr. Humboldt Mandell is being conducted for the Johnson Space Center Oral History Project in Austin, Texas. Interviewer is Rebecca Wright, assisted by Sandra Johnson. I want to thank you again for finding time in your schedule to talk with us today. We'd like for you to begin by telling us about your background and what led to your interest to apply with NASA so many years ago.

MANDELL: Well, my entire childhood grew up around airplanes and aviation. I was always interested in flying and flight. When I was 14 years old I soloed my first airplane. When I was 16 years old I got my pilot's license, practically on my 16th birthday I think, which was the earliest you could get it. I spent my whole high school years flying around in little airplanes, so I was always interested in that sort of thing.

When I was going to college I decided I wanted to study aeronautical engineering. In those days there was mandatory military service, so I elected to go into the Air Force ROTC [Reserve Officers' Training Corps] program here at UT [University of Texas, Austin, Texas], with every intention of becoming a military pilot. I hadn't counted on not being able to pass the flight physical because of my eyes. I did go in the Air Force; the year I graduated from college was 1957, and that was the year of Sputnik. So the space program really started the year I graduated from school. I obviously wanted to become a part of that.

My whole Air Force career I kept trying to get into the space business of the Air Force. They had other needs for me, so after my tour was up I got out after three years and went to work for a company in Fort Worth [Texas] that was doing space engineering business, and that was General Dynamics. NASA didn't exist at this time of course. I guess the National Aeronautics and Space Act was actually written in 1958, but there were no Centers yet created, so it was 1959, 1960 before the Centers were really created. There was Langley Research Center [Hampton, Virginia] of course, from the time of the Space Act. Then that Center spun off the Johnson Space Center [Houston, Texas], which opened in latter 1961. Because it was in Texas—I'd always wanted to stay in Texas. I'm sixth generation Texan, and I wanted to raise my family in Texas. Also, because it was going to be the home of the human spaceflight program, I was really excited about getting there. I applied as soon as I heard that they were coming to Houston, though it took me about a year to negotiate the job that I really wanted and the salary that I really wanted.

I joined in December of 1962. Why did I do it? It was just because it's what I'd always wanted to do. It was the ideal career path to do what I'd always wanted to do.

WRIGHT: Tell us about moving to the Houston area and the whole transformation of what was going on at that time.

MANDELL: I'd been working on proposals at General Dynamics, including a proposal for satellite systems and also for the TFX [Tactical Fighter Experimental] airplane program. I got the job [with NASA] in November, and I sent word to NASA that I would be there the first week in December. We had a few delays for one reason or another. As I was driving to Houston with

my family and all of our worldly goods in the back of the car and in the moving van, I heard on the radio that our company had won this big contract that I'd been working on for all this time, so I would have been in on the ground floor of a major contract.

But I had no regrets. We got to Houston in my little 1953 Studebaker, and I started work for NASA the following Monday, which was December 2, 1962. The processing facility was in a bank building [East End State Bank] there on the Gulf Freeway [Interstate Highway 45]. There was no [NASA] Center. NASA had gone in and just really rented every vacant office along the Gulf Freeway. They tried to get them as close together as possible, but they were strung out probably over five miles along the Gulf Freeway. The human resources, or personnel as it was called then, was in the East End State Bank Building. I finally found that building and processed in.

They assigned me to an organization which was located in the Rich Building. The old Rich food plant had gone belly-up and left a building that had a high bay that had been a meat locker, a frozen food locker. It was a big building, and NASA went in and built a second story in that meat locker, and that became my first office at NASA. I'd worked then for three years in an office building that had no windows, because it'd been built during the Second World War and they were afraid of bombs and things, and so it had no windows. One of the things I wanted was windows, and so I get to Houston, and I have this office that's just a complete closed cube, you couldn't even see out of it.

But that didn't last long. We grew fast, we were growing rapidly, and we were renting new buildings. In fact we rented an apartment building as it was being built called the Franklin Apartments. Much of the Engineering Directorate moved into the—I forgot to say that I was assigned to the Engineering Directorate—most of the Engineering Directorate moved into this

apartment house, which had a completely functioning swimming pool, but it had never been occupied. We were the first tenants in this apartment complex. The air conditioning had never been designed as offices. It'd been designed as residences, so it was totally inadequate. We just about burned up the first summer we were in there. They had to come in, and NASA spent a lot of money cutting holes in the wall and putting window air conditioners in to keep us cool in those resources.

I was working in an organization that was ironically planning future missions for NASA, what comes after Apollo, because Apollo was pretty well underway by this time. So we were looking at what comes next. My first job, which actually started in December of 1962, was to design a manned Mars mission. My section chief at that time was a guy by the name of Oscar Olaf Ohlsson, he was an interesting guy. We had a little group, probably eight or ten people. We brought in people from other parts of the directorate and did this marvelous Mars study. In fact I pulled it out the other day and looked at it and it's really—I found a copy on microfiche and had it printed—it was really a pretty good study, considering we were working with slide rules, we had no computers, no hand calculators, we had nothing except pens and pencils and slide rules. Yet, we did a pretty good job on designing those missions.

They were missions that could have been flown. They would have been very risky, but they were no more risky than the Apollo mission was, and the Apollo mission was pretty risky. We worked on that for two or three months and presented it to the director, and it became the plan. We continued to refine it and everything. Everybody just assumed that as soon as we finished the Apollo mission that we would go on to Mars, because we had the big launch vehicles and we had the launch site.

In fact when they built the Interstate 10 Bridge in Louisiana, they built it to our specification of how high the Mars launch vehicle would be when we pulled it under the bridge there from Michoud [Assembly Facility], Louisiana to go to launch it at the Cape [Canaveral, Florida]. As far as I know that's the only residual tangible thing that remains from that work that we did. In fact when you drive Interstate 10 over east of New Orleans [Louisiana] you'll come across a really high bridge, and you wonder, "Why is this bridge so high?" Well, that's why it's so high. That was my first job there.

WRIGHT: Were you pleased with that assignment?

MANDELL: I was. I was very pleased with it. It was exactly what I'd hoped to do when I got there, to work on things like that. With my degree in aeronautical engineering I had been involved in getting my master's program, my master's degree when I was working at General Dynamics in Fort Worth, [Texas] I was working on a master's. My major field of study there was a field called operations research, it was the field of optimization. One of the things that we did is when you optimize something it has to be optimized with respect to something, and that something is cost. So I had to learn something about how to do cost analysis.

I was self-taught. There were no books or courses at that time. I went and talked to people all over the country, RAND Corporation in California, who was doing similar work, and people at Huntsville, [Alabama], Marshall Space Flight Center was up and going by that time, so I talked to them and came up with a methodology which I documented. I guess I wrote the first cost model books that were written for NASA. My part of these studies was to do what they

called programmatics, which was the cost and schedules and basically how do you go about putting all these pieces together, the logistics and everything. That was my job.

My one regret was that I wasn't the guy that was actually on the drawing board drawing the pictures of the spacecraft, but we had a really good draftsman who did that. His name was Jim [James C.] Jones and ironically he was a guy that I had worked with at General Dynamics. A whole bunch of us from General Dynamics had left there and gone down to the Johnson Space Center. Our Center was started by people from Langley, but we also had a large contingent from Canada, Avro [Aircraft], which had laid off a bunch of people, and people from industry, and then some military assignees. That was basically the four cores of our Center.

We gutted General Dynamics. We took a lot of young guys out of there to start this. Our average age when I got to Johnson Space Center, the average age at the Center was 24.

WRIGHT: That's amazing in itself.

MANDELL: So we were all pretty young guys.

WRIGHT: Did you find that to be very beneficial to what you were trying to do, to have minds of same thinking and from the same background, although you had, as you mentioned, the military and some from NACA [National Advisory Committee for Aeronautics] that had come from Langley, but yet you were able to work with some of the people that you had worked with before? Did that help?

MANDELL: Very much, yes. There were a number of cases where we knew people that we had worked with before, but I think the major advantage was that we are all so young that we didn't have any inhibitions, we didn't know we couldn't do anything, we had none of the built-in fear of failure that now permeates the agency, the conservatism that has crept in. There was just no job that we couldn't do. Most of us had come from pretty successful programs. We had won major competitions, as I mentioned earlier, and we were full of ourselves.

WRIGHT: Was there an adapting period of coming from the corporate industry world into a government where some things are different?

MANDELL: Not so much then, because I had been working for a government contractor. I'd been in the Air Force, which is government, worked for a government contractor, which the government ways of doing business overlay, as you know in your business. They overlay the way that you guys do business, and the same with us. Actually I had more freedom I think when I got to Johnson Space Center. I had the most freedom of all in the Air Force, because you go in with the gold bars on your shoulder, and you're an officer, you can do anything. They would give you any job and just go get it done, so you had complete freedom to do whatever you wanted to do. Then the opposite environment at General Dynamics, and then back to NASA. You again had more freedom than you did in the private sector.

No, I didn't feel any constraints there. It's only been in recent years where the bureaucracy has smothered the creativity, I think, of the young people.

WRIGHT: I find it very interesting that at such an early part of your career you were writing these cost model books. It seems like you always had that link to being the cost analyst person. Tell us about how you developed these first models and then how your career kept on branching off in that area and always hooking you back into that.

MANDELL: There was no body of knowledge, I found that out very quickly. I found a few reports at RAND Corporation as I said. There was a group there that had been started by [Robert S.] McNamara when he was the Secretary of Defense. I don't know if you recall McNamara, but he was one of these whiz kids that came out of the Second World War. He knew that he couldn't hire within the government, the people to do this kind of work. So he spun off these FFRDCs, Federally [Funded] Research and Development [Centers], so they could pay the salaries it took to get these high-powered people. RAND Corporation was one of the first of those; in fact it might have been the first of those. There was a guy by the name of David Novick who had done some work in cost analysis, and I found that. Of course there was no Internet, you had to just scrounge around and find people that had done this in card catalogs.

So I got on an airplane. We had lots of travel money in those days, so I just got on an airplane and went out there and sat down with him. They gave me reports. A lot of it was just logic. Cost analysis, cost estimating, is basically just data, data from past programs. So that was the challenge, was to try to get enough comparable data to construct these mathematical relationships to estimate cost. They were able to give me some data. I was able to scrounge some more data from other programs and put them together. The way you do it is you take a spacecraft, for example, and you break it down into its systems: the structure, propulsion, environmental control system, avionics systems and so forth.

You gather data on that type of system from past programs, and then you try to correlate it with something. It turns out that mass sometimes correlates, capacity like on an electric power system, the number of kilowatts that it generates is something that correlates. You do these mathematical correlations to establish how these things correlate.

We were operating with very small pieces of data. I had studied by this time a lot of probability and statistics in my master's program. It made your hair stand on end, the lack of rigor in these things that we created, but that's all we had, so we went with it.

I, by this time, had hired a couple people to help do the cost analysis. One was named Dick [Edward D.] Lupo and one was name Ivy Schneider, who's now Ivy [F.] Hooks. You may know Ivy Hooks.

WRIGHT: We've met her.

MANDELL: She might have been my first hire actually. Another one named Gil Chisholm who is now retired living down at Yoakum, Texas. He was a math major at UT here in Austin, a very good mathematician. So, I put together this little group. Then once that was put together I was stuck; that became my specialty, which was not all bad, because it puts you at the core of everything. You were always involved. You always had to have the cost analysis done. So every program that was initiated we had a hand in, a very integral part of.

When the Shuttle program came along—I'm skipping a lot of years—throughout the whole decade of the '60s we did studies like ASTP [Apollo-Soyuz Test Project]. The first thing after Apollo was going to be AES, Apollo Extension Systems, so we did a lot of cost analysis on that. We did cost analysis, and always we would do another Mars study, so it was ironic that

about every three or four years we'd do another Mars study. Of course we had this body of knowledge. The second time around in the '60s we had enough money that we actually went out and hired some really high-powered talent. We hired General Dynamics at San Diego, [California] their astronautics division, a guy by the name of Krafft [A.] Ehricke. We had Rockwell [Corporation]. We had McDonnell Douglas, which I think was just McDonnell in those days. Several other contractors including RAND Corporation. We gave a contract to the RAND Corporation at that time, to design these missions.

We had missions called EMPIRE, which is Early Manned Planetary and Interplanetary [Roundtrip Expedition]. They were very rigorously done, much more detailed than the 1960 mission, down to really high-fidelity designs on the spacecraft and the launch vehicles. Again our part of that was the cost analysis. We also had of course contractor cost analysts working with us, but we found out that they weren't even as far along in the state of the art as we were. So the blind leading the blind, we muddled through and came up with cost estimates for all these things.

So that was what we did in the decade of the '60s. In the late '60s and early '70s we had done the Apollo-Soyuz mission. We had done the Skylab mission as the Apollo Extensions became Skylab, so we started to look seriously at lowering the cost of transportation to space. That's always been from a cost standpoint, from a budget standpoint, and by this time NASA was starting to feel budget crunches. In the Apollo program we didn't really have much budget constraint, although some of those guys will argue with you, but we started to feel budget crunches. So the most expensive part of our operation was transportation to orbit, as it still is, so we began to chase this holy grail of lowering the cost of transportation to space.

The reusability came up. Max [Maxime A.] Faget was still very much involved, he was the director of engineering and had been ever since they'd come to Houston. He was driving us toward a reusable Space Shuttle. We had, again, competitions. We brought in several contractors, all the big guys were involved – General Dynamics, McDonnell Douglas and Rockwell. They all brought their individual ideas to the table.

Our job was to do the government estimate, because by this time it was a requirement that we have government estimates for everything before we would submit them to Congress or even to OMB [Office of Management and Budget]. There's a little sidebar issue here that when we would hire good people to do this cost analysis work we were always—in an engineering organization we were given the lowest priority. I'd get a bunch of good people put together and they would get moved over to do some other task in the engineering process. I would lose them, so I'd have to keep hiring people and bringing them in, but we kept a modest capability. By this time [R.] Wayne Young had come into the picture and we put together a team to do the cost estimate for the Space Shuttle. I led that team from start to finish.

We actually brought in other Centers and had exercises in Washington [D.C.] at [NASA] Headquarters. We put together the estimate for the Shuttle, and there was a deputy administrator of NASA named [Richard C.] McCurdy. We went up and spent a whole weekend with Mr. McCurdy going through our estimate. Bill [William E.] Lilly was the comptroller of NASA at that time, and he had a guy working for him by the name of Tom [Thomas] Campbell who was his chief deputy. So they were there scrubbing our estimate and making us explain exactly how we did everything and how we put all the pieces together. We were there all day Saturday and all day Sunday and finally got their blessing on this estimate that we went forward with.

To our credit, the estimates that evolved from that estimate—we went through a number of iterations—but the estimates that evolved from that original estimate turned out to be the ones that they based the contracts on. We finished that contract well within 10 percent of our original estimate, which we were very proud of, because I don't think that's ever been done before or since.

But then success begets sometimes things that get out of control. So when the Shuttle program started, because I'd been involved doing all this cost work, they decided that I should be the program control manager for the Shuttle program. Wayne Young actually came in to do that job at the project office level, but I was taken from the Engineering Directorate. I had no choice in this; I was just assigned from the Engineering Directorate to the Space Shuttle Program Office. Big promotion. You don't often turn down big promotions. I was given a nice corner office in Building 1. All of a sudden you could hire people again, so I put together a staff of people to manage the resources, cost and schedules of this new program. It was a job I would have not ever applied for, because I still considered myself basically an engineer. Why should I go off and do management work? I never wanted to do management work.

But there I was, so I decided to stick with that awhile. Awhile kept getting longer and longer and longer. To make a long story short, I was there for 14 years in that job. It stuck to me once I started doing it. It just stuck to me. I went from doing hands-on doing of the work to the management side of it in 1969 when they set up the Shuttle Program Office.

WRIGHT: During that 14 years a lot happened as far as changes within the program. How did that impact your work? For instance when the Shuttle Program was first announced it had such an aggressive schedule of missions. Possibly up to 50 a year.

MANDELL: That's really funny because one Friday afternoon we got a call from Headquarters. My memory is a little vague on this but I'll reconstruct it as well as I can remember it. We had done basically the development cost, which the predominant part of the cost of a new program was the development cost. So they said we need some operations costs, and we need an operational traffic model. Basically how many flights per year are you going to fly? We had no idea.

We called people at the Cape and said how many can you fly. We did surveys of industry and put together databases on the number of flights that were out there. The AIAA [American Institute of Aeronautics and Astronautics] magazine published a projected traffic in space every year, and they still do that. We talked to corporations about how many satellites did they think they might launch, because in those days we were going to do a lot of unmanned satellite emplacement with the Shuttle. We just researched every avenue that we could to try and find out what was likely to happen in space.

So in this crunch of time we just put all these things together, and it turned out that we needed to do about a launch a week to do these things. We called the people at the Cape and said can you handle that kind of traffic. They said well yeah, based on the design you have, which is basically a completely reusable vehicle. At that time we had reusable boosters and orbiters, great big thing with wings on it that was the booster instead of these solid rockets that we have now.

They said yes, we could turn that around. With a fleet of I think six vehicles we could turn around one a week and fly. It was based on nothing more than that, the best knowledge that we could bring to bear, based on the capability that we thought we could get out of the vehicles. At that time all the checkout capability on the Shuttle was supposed to be on board. The Air

Force was doing this with their airplanes. They had a lot of self-checking electronics on board the airplanes. Basically the concept was it was a three-light system. You'd get in, and you'd turn it on and you'd press the button, and it'd do all its system checks, and if the green light came on you're good to go.

Of course the devil is in the details. When you start looking at what does it really take to make that happen, the state of the art was not only not there, you had this whole body of people at Kennedy Space Center, 10,000 people or more, it might have been as much as 20,000 at one time, who made their living processing vehicles. They were not about to let us design a vehicle that you could just skip all this stuff. So the politics got into it very heavily. We had to process just as we had processed all the Apollo equipment, through all the same operations.

That was never in the plan. The plan was to have this thing just like an airplane, and you don't rebuild an airplane. Southwest [Airlines] doesn't rebuild an airplane when it flies into Austin and before it flies to Los Angeles, but that's basically what they wanted to do. So there was a difference in perceptions and in philosophies.

I don't want to make the Cape guys out as the bad guys, because we were probably way too optimistic about what we could do. Then they were out to preserve their way of life and insisted that we do all this processing, so that's what really got out of hand. That's where we really missed things.

We were looking at 60 flights a year, something like that, as this first traffic model. We were not given very much time to do this by NASA Headquarters. I still remember we got all the people in my office one Saturday afternoon, and we got to the blackboard and just started putting these things on the board and adding them up. It looks like well, all these assumptions, it could come out one a week.

In our defense, as you know, after the [Space Shuttle] *Challenger* [STS 51-L] accident we were forbidden from flying anything, just commercial satellites. It came down to we could just fly military and NASA satellites. So some of the traffic that we had envisioned—well, most of it just didn't show up. Most of it just wasn't there, but some that was there we weren't able to launch because we didn't have the mandate to do it. There were a lot of factors. I way oversimplified it, but there were a lot of other things involved in it as well, but that's the essence of why we missed that so badly.

Those costs, they grew substantially. We thought we could turn a vehicle around for a few million dollars. It's a few billion dollars it turns out to turn around, but again the concept is different. We were using a fully reusable vehicle, but they went to the external tank that's expendable, that costs as much as an airliner, and the solid rocket boosters are very expensive. Of course they say they reuse them, but really all they reuse is the cases, and they have to be remanufactured before they can be reused.

All of our reusability really went away on everything but the orbiter itself. Even with the orbiter, we had envisioned that the thermal protection system, the tiles would last basically forever, like the Apollo heat shields. We didn't realize how fragile it was and all the maintenance that's going to be involved with that.

Estimating is predicting the future. Nobody can really predict the future, so there were many things that happened that were not the conditions we had assumed when we did those original estimates. We were right on on the development cost; we really missed the operations cost.

WRIGHT: I think somewhere while I was reading some of the stuff that you put together that you made the comment that cost actually drove the configuration.

MANDELL: Oh yeah. The Office of Management and Budget gave us a peak annual funding constraint of I think it was $1.1 billion a year that we had to subscribe to. The two-stage fully reusable vehicle, you had a peak like this [referring to hand-drawn illustration]. They said you can't have that money, so we had to design something that fit within this budget.

This was the big reusable spacecraft, reusable booster up here. The only way we could do it is to have an orbiter, and then these solid rocket boosters which were cheap to develop, and the external tank, which was cheap to develop. It's expensive to buy, but who knows? If we'd built this thing, I don't know if it would have lowered the operational cost or not. It might not have, because then we would have had to turn it around every time, with all the same problems, but anyway that was what I meant by that, it was a budget-constrained program.

There was a stretch of time there one summer where we looked at 40 different Shuttle configurations in a month. We were doing cost estimates for all of them. Contractors were doing cost estimates for all of them, and it was a cut and try thing. We'd do a configuration, and it'd bump over the cost constraint, so we'd take things out and try again, and change the configuration a little bit. It evolved from the two-stage fully reusable with the two airplanes, gradually to what we had at the end of the time, was what we have now, is the solid rockets, the tank, and then the Orbiter on top. Every one of these things was to bring down this peak a little bit. This is the only one that fit under the peak.

WRIGHT: You touched on it a few minutes ago about the culture of having the pressures from, for instance the Cape, of you've had this processing already from the Apollo tradition and there was the pressure. How did that impact what you had to do as well?

MANDELL: It didn't really impact us as much. The thing that hurt us on the Cape was the operational cost. The Cape's culture didn't really affect the development cost much. We began to realize probably in the early '70s, like '71, that that was going to be a problem for us, that we had not budgeted to keep 10,000 people on the payroll at KSC [Kennedy Space Center]. So that was probably going to blow our operations cost, we started to realize that, but there was nothing we could do about it at that time.

They had a very strong voice at the table. Kurt [H.] Debus was still the Center Director at KSC and he had been one of Wernher von Braun's key guys at Peenemunde [German rocket research center during World War II]. Von Braun had a huge influence over what we did. Politically at the table there was Bob [Robert R.] Gilruth, our Center Director, Wernher von Braun, the Marshall Center Director, and Kurt Debus, the KSC Center Director, who basically made those decisions working for George [E.] Mueller, who was the Associate Administrator for Manned Space Flight at that time.

They just decided that was what it was going to be. We quickly revised our estimates to catch up, but since it came after the peak of the development program it didn't matter much to us, because it was out here when all that extra cost happened. The Congress, the OMB, nobody really cared at that time about what the operations costs were. They were just interested in keeping underneath that budget ceiling. That was the primary constraint on us.

WRIGHT: This time period was prior to the actual development of the Orbiter and its components?

MANDELL: During this time period here, which was probably ’71 when we were going through all these different configurations, that was the Phase B preliminary design portion of the program. I think that we awarded the contract to Rockwell in 1972 to build the Orbiter. Rocketdyne had already received the award to build the main engine, but that award got hung up by protest from Pratt & Whitney for a year.

We estimated the engine had to start at least a year before the rest of everything, because it was a longer development time. We started the engine and got a protest, and it hung it up for a year. So here we are marching through time. We had started our buildup of personnel at all these other places, including Rockwell in California. They just had to march in time until we could get this engine under development and know what we were working with.

The thermal protection system hung us up for a while too, but the engine protest hung us up for a year. That added a year to our development time that we hadn’t really counted on, but fortunately we had budgeted enough reserves in the development cost that that didn’t blow our estimate. But it did take away all our reserves, at least a lot of them.

WRIGHT: Once the contracts were let, were you constantly reevaluating cost?

MANDELL: Oh yes. In fact that was really what my job was. We were what they called the Level 2 office. We were managing really four different projects, the Orbiter, the engine, the external tank, and the operations program. We had four projects working for us. Bob [Robert

F.] Thompson was the program manager, Aaron Cohen was the Orbiter project manager, J. R. Thompson was the external tank program manager. We had three projects at Marshall, one at JSC. The Orbiter at JSC, the external tank, the engine and the solid rocket boosters were at Marshall. Then we had the fifth project was the Cape, the launch and landing project as it's called. We were responsible for all those. They were pretty independent; they were off doing their own thing. They didn't much like Level 2 meddling in what they were doing, but I finally developed a rapport with most of those project managers. We could work with them very well after a while.

We managed the cost part of it. The way that that was managed was with what they called the Change [Control] Board, CCB, which was chaired by Bob Thompson and met every week at least one day and sometimes more often. What they did is every time the contractors would hit a snag and say oops, we can't go there, we've got to make some changes, then they'd have to come in and present it to the Change Board. Then all the projects had to buy off on it basically. Bob Thompson says in his memoirs that "I never approved a change that wasn't mandatory." Well, that's a matter of opinion. I love Bob Thompson. He's still very much alive and still a very good friend. I think he did a magnificent job of holding that herd of cats together during that development period.

He also authorized an awful lot of changes. At one time we were running 3,000 changes in the system at any given time. It was a lot of changes. Of course we couldn't keep up with that with our little staff. No way we could estimate the cost of all these changes. The bigger ones we would try to do that, but on the little ones we couldn't even keep up. The contractors would bring us in a number, and the program manager would look at me and say, "Have you looked at this number? I'd say, "No Bob, we haven't." He'd say, "Well you go look at this and tell me if

this is a good number. We'll be in session until 4:00 this afternoon. Come back and tell me before we adjourn."

So you'd have a couple hours to look at this stuff. All that you did is you just called the contractor and said, "How did you do this estimate?" He'd tell you. So who are you to argue? He goes out to his guys in his shop and asks how many man-hours will it take to do this job. Of course they're going to protect themselves. They're going to say we can probably do it in ten hours, but they're going to multiply that by two. Then the boss multiplies it by two again. So they come in way overinflated, but you're at their mercy.

This was the fallacy of the culture of the way that NASA has done business from the outset. You're just at the mercy of the contractor once you get them on board. Fortunately we had contractors with some integrity. I was pleased with the integrity of the contract management we had around the program. They helped us hold the line on cost, otherwise it could have really gotten out of hand. Our job was really just oversight, mediator, look at the big stuff, sign off on the big stuff, be the adviser to the program manager on matters of budget and cost.

WRIGHT: How did your tools change over the years? I go back to when you were talking about your first Mars study with the slide rules.

MANDELL: Well, see, this era here is the '70s. We still didn't have computers. They had big vacuum tube computers to crank out the trajectories and things like that that required a lot of precision. I told you I hired a guy by the name of Dick Lupo out of Georgia Tech [Georgia Institute of Technology, Atlanta]. Brilliant, brilliant man. He developed software for us; took these things that we had been cranking by hand and turned them into software. The old punch

card things that we'd do a box of punch cards and then take them over to Building 12 where they had the mainframe computer, it was a UNIVAC computer. You'd hand your cards in to the window, the guy would put them in the card reader. You'd go back an hour later and you'd have an error and you'd have to debug it. It was a long process.

We developed a lot of—mid '60s we started. I think that's when I hired Dick Lupo and he started developing. It was just taking the equations that we'd already developed by hand and putting them in the computer so you could run them very quickly and very accurately. Other than that we were always data-starved, because again your accuracy, your integrity of your estimate is always predicated on having analogous data. There were not too many human spacecraft around. We had the Apollo program, we had the Apollo-Soyuz and we had Skylab and Gemini and Mercury, and that was it. We had three points of data, so we did a lot of these estimates based on three points of data.

WRIGHT: I guess that's the good news. You didn't have to incorporate a whole lot, but it was very limited.

MANDELL: Yes, it didn't change a lot. The accuracy of the methodology didn't change a lot. For example, in developing the original Shuttle estimate, we knew it was going to be a big airplane, so we did go out and gather a lot of big airplane data. We went out to Boeing and got the development cost of the Boeing 707 airplane, which was one of the first jet airplanes, and used that for the body structure. That helped our accuracy some, but the cost analysis, cost estimating, is a function of how good of data analogies you have, and if you don't have very many you don't get much better.

WRIGHT: We've talked a lot on the business side of it, but I wanted to ask you on the personal side about your thoughts of when you saw the STS-1 take off and land safely and the work that you had done, what that meant to you on a personal basis.

MANDELL: I developed a friendship with Bob [Robert L.] Crippen. He's a University of Texas alum. Through the alumni activities we had I had developed a personal relationship with him, he was a good friend. I talked to him enough to know that they were very confident. John [W.] Young and he were very confident that the machine was going to work. They had been spending their lives looking at a lot more details than I'd ever looked at, so I was pretty confident that it would work, because everything that we had done—there was the Apollo [1] fire—but everything we had done up to that time had worked, except for that one exception.

We just didn't dwell on the fact that it might not work. In retrospect I look back and I think you're talking about heroes, John Young and Bob Crippen when they crawled in that thing for the first time. That was a pretty risky deal, because all the things that have happened since then. All the dings and the tiles and all that killed [Space Shuttle] *Columbia* [STS-107] and all the stuff that killed *Challenger*. All those failure parts were there at that time.

WRIGHT: It's a good mark, to know that the work that you went through was such a success for all. At some point I believe in the mid '80s you moved from Shuttle into [Space] Station.

MANDELL: Yes. I had a good friend again from here at UT who was named Clarke Covington. Clarke had been named program manager of the Space Station Freedom program. So he called

me one day and asked me if I would be interested in being his program control chief. Again it was a promotion for me, so I said well, let me think about it. I went and talked to my bosses. They said yes, we've peaked out, because this program was 14 years old. So they said sure, go ahead and do it.

So I accepted the job and went over to the Nova Building and moved out of my nice corner office in Building 1 and over to not-so-nice quarters in the Nova Building. I guess I started working full-time in '82 on the Space Station. So that was where we really started getting into politics. Gradually NASA programs have gone from pure engineering to almost pure politics. At least five Center Directors insisted that they be given a role. Their congressmen insisted that they be given a role in doing the Space Station. In fact one of the Center Directors didn't even want to participate but his senator, who was Barbara Mikulski from Maryland—this was the Goddard Space Flight Center [Greenbelt, Maryland]—he didn't even really want to play. He was happy doing what he was doing, but he got told how the cow ate the cabbage, so he decided he would take a work package.

Well, work packages are the antithesis of good management. To do a big job like this you really need to have strong central management. What they were going to do is they were going to give the Johnson Space Center a role for integration. Marshall was going to have the role for their usual launch vehicle things, but then they were going to have responsibility for one of the modules. That created a lot of strife, because there were a lot of power struggles going on as to which module would be the one that was the dominant module, and who would in fact be the program manager. Marshall was pushing really hard with their congressional delegation to have the lead role on Space Station.

But somehow we came out of it intact, that JSC was going to have the lead role, but all this politics swirling around, we started doing the design studies and let contracts, and it just went nowhere because of all this squabbling, all this bickering. So after a year or so NASA Headquarters realized that this was the greatest fiasco that had ever been created. They just threw up their hands. They brought in a new guy, and they said we're going to do away with this project office in Houston. We're going to change management. So basically we got fired. Nobody ever really gets fired in NASA, but we got fired. Clarke Covington got pushed off to the staff. They brought in Neil [B.] Hutchinson, who was a flight controller, and John Aaron to head this new program office.

So I was without a job. I was relieved actually, because it had really turned into such a political mishmash. So, I just shopped around, and I found Mark [K.] Craig, who had been authorized to start a Mars program again, the Lunar and Mars Exploration Program Office. I said, "Aha! I'm going back to my Mars roots." I jumped ship and went and asked Mark for a job. Well, actually he came looking for me and offered me a job, so I said yeah, that's what I want to do.

So it's back to Mars and another promotion. I became the deputy program manager after Mark left for Washington. Doug [Douglas R.] Cooke took over and then I became Doug's deputy. When Doug left, I became the program manager. That was the ideal job that, if 30 years ago before that I had sat down and said what's my perfect job, that would have been the perfect job.

WRIGHT: Took it 30 years to get there, but you got there. So talk to us about those first days and the 90-day study that was going on, and Aaron Cohen was leading the effort, but yet you were so much a part of what that was all about.

MANDELL: Well, I've got all the documentation for the 90-day study, but basically it was you got 90 days to do this, now come back and give us the right answers.

WRIGHT: But what I found very amazing is it wasn't just you, it was 90 days with a very large contingent of interagency work within 90 days, and coming up with the report, how that worked together.

MANDELL: Right, and actually it worked very well, because these were hand-selected people. We knew each other. We had grown up together in NASA. They were at other Centers, but we either knew of them or knew them personally. We traveled a lot; we had a Gulfstream airplane that we traveled a lot in. For a while in Marshall during the Skylab program we had a contract airplane, which was an old Lockheed Electra, that flew to Marshall every week and back. In fact it might have been more often than that. Anybody could just go out there without travel orders. You'd just get on the airplane, go to Marshall and spend a day, and then come back that evening. So we'd gotten to know these people over the years just because we'd worked with them a lot. They could do the same thing, they could come over and work with us.

Aaron Cohen was a good boss. He could be really stern and demanding when he wanted to, but he was a people person. He was a mean son of a bitch when he had to be. He could crack

the whip on you. Everybody was terrified of this little short Jewish man. If you ever got called in to his office—

WRIGHT: He seems so gentle, right?

MANDELL: Yes, that's right, but just his authority and who he was, having been the successful Orbiter Project Office Manager, made everybody happy with him as a boss. We met at a lot of different places. We met in Washington, we met in Houston, we met at Langley. At one point in time they had a building set aside for us at Langley that we did some work in. I've forgotten all the nitty-gritty details, but it was I think a very successful study. We had trajectory guys working, we had engineering guys working, we had business people working. I think for 90 days it was one of the more successful things I was involved with with NASA. It could have been done. It could have been. It was an executable project.

WRIGHT: Part of what your results were was the cost.

MANDELL: Yes. Again I had the cost team for a while, but I had other duties as the deputy program manager. I had other duties to deal with. I guess I got drafted back to do my old cost stuff, but we had a lot of good cost people in NASA by that time. We had a bunch at Marshall. Marshall put emphasis on cost analysis a lot more than JSC did. Bob Gilruth and Max Faget treated the cost analysis people as stepchildren, but at Marshall it was given full engineering status and they hired good people and kept them involved.

So we had some really good folks working from Marshall. From Langley we had some good people. JPL had some good people that we leaned on every once in a while.

WRIGHT: What your study came up with were acceptable plans, but was just the cost so much out of range?

MANDELL: What happened was this. We had put together costs that I had cautioned everybody when this thing started, that we were going to be slapped with a cost ceiling again. I got lectured to by a guy by the name of Frank Martin who was at Headquarters saying, "This is the President's program, we will receive whatever resources we need, don't worry about cost constraints." Well, I knew that wasn't right, but we proceeded that way. Aaron Cohen, bless his heart, we took him in cost estimates. Instead of saying go back to the drawing board and bring me in lower costs he'd say—because we'd been under such pressure up to this point in time, because NASA had been, ever since that first Shuttle R&D [research and development] cost came in, everything after that we'd blown every cost estimate that we'd put in there, so we were under a lot of criticism from OMB, from Congress, from NASA Headquarters, and all the way down from the President, that NASA couldn't be trusted on their costs. So Cohen says we're not going to go in with a lowball cost, we're going to go in and tell them what we really think it's going to cost.

I said, "Look, Aaron, it's a mistake, because it's going to kill it when it hits the Congress." "Oh, I don't think so. I think they really want to hear the truth." I argued with Aaron for a while but once Aaron got the bit in his teeth there was no use to argue with him. I don't know if you know him very well, but he starts to build this anger inside. After you worked

for him for a while you could see it coming up. So you knew okay that's as far as I can go, I got to back off.

WRIGHT: You knew your limit.

MANDELL: Yes, so I backed off, so we went ahead and here's the basic mistake we made on the 90-day study. Here's the NASA budget rocking along like this [refers to hand-drawn illustration]. In here is all these different codes at NASA Headquarters. Code M, which was the Office of Space Flight, which was the biggest. Code E, Code S, which was the Science Directorate, and so on. All this added up to this NASA budget that rocks along like this.

Well, instead of taking this and some of this and some of this and applying it to the 90-day study estimates, this we called MERTS, because those were the codes, M, E, R, T, S. Instead of taking some of the MERTS stuff and applying it, which we could have easily done, they said no, that's sacrosanct; you got to add everything on top of it. I said that's a mistake. Well, no, that's the way it's going to be.

So no, we started coming up with all these different alternatives. They would have these really high peaks. They'd say this is A, this is B, this is C. You could extend it out for a while. So they'd go forward and present these humongous costs. The word we got back was that when they took it over to OMB that it was a nonstarter. They said uh-uh, it's just too much money, you can't. There's no way we can give you that much money. It just killed it right there. That was DOA [dead on arrival] as they said when it hit the OMB.

So that ended it. Here I was, my ideal job. The thing that really got us though was not even this, now that I think back on it. This was a big part of it, but as I think back on it, it was a

presidential election year. We had a Democratic Congress, and we had a Republican President, George H. W. Bush, who was trying to get reelected. The head of our committee in the Senate was Senator Barbara Mikulski from Maryland. She was totally attuned to this S thing here, the science people, because that's the people that she had to protect. So she didn't like some of the propaganda that was going around as if you put this money in here you're going to have to take money out of here.

Well, it wasn't true because we had preserved all this money. The truth of the matter is that every time this goes up this goes up also, it always has. She had that built-in bias, but the main thing that she objected to is this was a George H. W. Bush program, and she did not want to give him any talking points for reelection. Now I don't know if that's well known or not, but I do know that we got a call from Kevin [P.] Kelly, who was Barbara Mikulski's chief of staff at that time, and Kevin basically told the Administrator to shut us down.

So I got a call. I guess he called Aaron Cohen, who was the Center Director. I got a call from Aaron, who said you are hereby shut down, so that was it. End of ideal job, end of Mars program. We had recruited really really good people. That's what I spent most of my time doing as the program manager, was bringing in people. Mike [Michael D.] Griffin was our program director at Headquarters and later our associate administrator at Headquarters. Mike and I were totally in accord on how this program should be managed, in fact I've written a document. That's what I wanted to present at this conference in Galveston [Texas]. All these years as I was doing this job I was doing research on the more successful [programs], because I was always interested in how do you really lower costs.

Turns out that the only way to really make substantial improvements is to change the culture of the organization. We had made major strides, and as I was hiring new people I was

making sure, much as Admiral [Hyman G.] Rickover had done when he started the Polaris program. He personally interviewed every person that went into that. I had benchmarked him, and Doug Cooke and Mark Craig and I were doing the same thing, making sure that everybody that came in was attuned to doing things in a different management culture.

The way we were going to do this is basically, we were going to have a very very small program office, 15 or 20 people. We were going to delegate a lot of this to a competitive private sector environment where we would have very well defined pieces of work, and then we would go to people like—for rovers for example, we'd go to Ford Motor Company or General Motors instead of going to aerospace contractors. We would get the foreign governments to take major pieces, like the Italians were wanting to do the communications infrastructure for us at the planet Mars, because that's their thing. Ever since [Guglielmo] Marconi [inventor of radiotelegraph system] they had been the communications people. The French were willing to do the nuclear reactors. The French have a major nuclear industry. We had talked to all these people. We had talked to their representatives. Some of it is not even for publication probably at that time. I don't think anybody will mind me talking about it now, but we had a lot of backroom discussions on can you do this, can your country do this. We were starting to get all the pieces in place to do these basic work packages.

The idea was to disconnect everything, that unlike [International] Space Station, where everything was connected, every piece of the Space Station is connected to every other piece through the system, we wanted to have everything disconnected. We had come up with a mission where we would commission somebody to develop the habitation modules. We would deploy these things. Instead of making a heroic Apollo kind of a mission we would deploy basically a little village on Mars before you ever commit people. You would put it together

robotically. The concept was that when the people got there all they had to do is go from their landing spacecraft over to this little village and go in and turn on the lights, and the refrigerator is already stocked with cold beer or whatever, and they could relax and get a good night's sleep.

So that was the concept. It would have worked, it would have been very low-risk. Not only that, we could have done it, we continued to refine, even after they shut our program down. I still stayed involved, and we started cutting the cost down by doing these different management approaches to where we were convinced that we could take a third of the NASA budget for a decade and have a really good safe Mars mission. I still believe that by the way. I still believe that, because NASA's budget, what is it now, $18 billion a year, something like that. For $5 billion or $6 billion a year for 10 years we could do a very good safe Mars landing program.

That's where it sits. After I lost this job, Aaron Cohen was still the Center Director. I went in to see him and I said to Aaron, "What do you want me to do?" He said, "Well, what do you want to do?" By this time I had 35 years in or something like that. I don't want to retire. I was still young, still having a good time, so I just shot from the hip. By this time I'd just had two grandchildren here in Austin, so I said, "Well how about an IPA [Intergovernmental Personnel Act] assignment in Austin?" He said, "You set it up and I'll authorize it."

I called these guys here, Byron [D.] Tapley and these people, and I said, "Can you provide me with an office? They said, "Sure, we'll do that." Called the governor's office and said we'd be willing to supply a person to work with him on an IPA assignment. They said sure, come on. Ann Richards said send him on up here. It's free labor for them. It doesn't cost them anything. So, I came up here. It was part of my Senior Executive Service requirements to do this sort of thing anyway.

I came up here and it was supposed to be for 14 weeks. Well, 14 weeks, you can't get much done, so they asked me to be reextended. By this time this was about the time Aaron Cohen went out and Carolyn [L.] Huntoon came in to replace him, so I talked to Carolyn and she said, "Well I think I'm just going to assign you up there. I think we need a permanent presence in Austin, and I think you're doing a fine job, so I'm just going to assign you up there." I said okay, fine, so I built a house here, brought my family up here. I'd been here for about a year and George [W. S.] Abbey became the Center Director. He had Duane Ross call me up and he said, "Mr. Abbey says that we're getting some more Mars money, and he wants you to come back."

So I went home and I talked to my late wife, and I told her what the deal was. She said, "I'm not moving back." We still had boxes in the garage that we hadn't unloaded yet. She said, "I'm not going back." So, I went down and I just got an apartment in Houston and worked with Doug Cooke and all the guys on Mars missions for a couple more years. Then what happened was my wife passed away. That caused me to reassess my life. By this time I had a good rapport set up with these guys here in this building and our office had moved from the university out to here. It was close to my house. I said this might just be a good time to hang it up, so I did.

WRIGHT: I'm glad it's worked out well for you.

MANDELL: I'm having a really good time. I get to work as much or as little as I want to. If I want to take three weeks off to go to Egypt, as I did not long ago, you don't have to ask anybody, you just go. I don't get paid anything by the Center for Space Research. I'll show you my office. It's a nice office, and all the logistics and secretarial help that I need and computer support, so it's almost a perfect situation for a retired guy.

I still write papers. I still go to symposiums, but the thing I like most is that occasionally I get to teach classes down at the university. I'm always working with seniors designing spacecraft. Every semester it seems like I have a class that I'm monitoring. The Space Grant Consortium is in this building as well, and they have a thing that's called a design challenge. The design challenge is from El Paso [Texas] to Beaumont [Texas]; UTEP [University of Texas] El Paso all the way to Lamar University in Beaumont. We have something like 20 different universities that are involved in this, so we put out these projects for these kids to work on. They can select them. I nearly always have at least one team, last year I had five teams, so I get to work with these kids and mentor them on how to design spacecraft and what to do and what not to do, how to do cost analysis. Then I teach cost analysis occasionally, so it's perfect retirement.

WRIGHT: I read somewhere that you think that engineers need to also be estimators. So are you able to help them learn that?

MANDELL: Yes, in fact that's the major point that I make with these kids that I teach, is that the temptation is going to be for you guys to just stick to designing, which is basically all done with computers now, and there's not a lot of judgment involved, just cookie-cutter stuff. It's going to be tempting for you to try to hand all this off to a business major or something to do your costing for you, but bear in mind that your future is going to be tied up in how accurately you can estimate these cost numbers. If you go in the private sector you better hit that cost number pretty close or you're not going to have a job. So you better get involved in this stuff.

It's had an influence. I've had kids come out here and spend time with me on how do you do this. I've gotten the access to the NAFCOM [NASA/Air Force Cost Model] that's run

out of Huntsville, out of Marshall Space Flight Center. I have it on my computer terminal. I'm the only authorized person to use it, but I can help them do things using the NASA cost model, so I still do stuff like that.

WRIGHT: That's great. You're using all your lessons learned to share with next generations coming up.

MANDELL: Yes, so I have varying levels of ambition. Sometimes I'll say it's time for me to write another paper, and I'll do some research and slap together a paper and go present it somewhere. I'm busy. I am busy.

WRIGHT: Sounds like it.

MANDELL: I put in only four hours a day usually here, but I'll be down at the university, I'll be at the LBJ [Lyndon Baines Johnson] School [of Public Affairs], I'm involved with the continuing education program here in Austin [University of Texas at Austin Osher Lifelong Learning Institute]. It's called UT FORUM. That's mainly for retired persons like myself, but we have professors. Living in a university town like this there's so many things going on, there's always something going on. We get experts in just any kind of field that you want to come and talk to us about the latest and greatest developments in that field. They love doing it, and we love learning things, staying up to speed on things.

WRIGHT: Keeps our minds moving in the right direction, doesn't it, learning something new.

MANDELL: Yes it does.

WRIGHT: As you look back on those years that you spent with NASA is there a time that you feel like it was the most challenging part of your career?

MANDELL: Well, there were several times that we had real challenges. I guess when we changed management on the Space Station Program, every time there was a change in management, it created a lot of stress, because you have new personalities to deal with. As far as the job itself goes, there was always stress, but it was manageable stress. People were always fair, you were always dealing with intelligent people that you could reason with. That's what I like about this place here too, because they're all rational intelligent people. I think by far the worst part of my career was the Barbara Mikulski phone call that shut down our program, because we had just let a contract to McDonnell Douglas, a support contract, which was small, it was $40 million. As contracts go at NASA, that's not too big. They'd already hired a bunch of people. I knew that those people were going to be let go, and they they all had families and they were going to be out on the street.

That was the hardest part of my career, is calling up the contractors and saying they've shut us down, they've taken our money back. We have enough money left to pay your termination liability and that's it. It was a human tragedy. That was the toughest part of my career, because I was not concerned for myself because number one, I had enough years to retire, number two, I knew that there'd be interesting things to do. When I went out to California and

sat down with the contractors and had to look in their faces and tell them these things, that was tough.

WRIGHT: What do you feel to be the most rewarding aspect of those years?

MANDELL: There was never a day that I didn't want to go to work in all those years. There were days I didn't feel like going to work, but there was never a day that I didn't want to be there. That in itself is a reward. The most rewarding thing about NASA was the people. No question. The associations with the exceptional talent that we put together. If you stop to think about it, you probably know this, but when we were hiring and building up our Center, we could only hire engineers. We couldn't hire business majors or anything without going through a civil service register, so we had to take engineers and turn them into business people and that kind of work. A guy that graduates from engineering school, he's probably come out—at least the engineering school here in Texas—there's nobody in that engineering school that wasn't in the top 10 percent of his class in high school. Then those people, of the entering ones to the graduating ones, about three fourths of the people are screened out between the entry and the graduation, in a lot of these engineering programs. So there's another tough screen. Then NASA comes along, and at the time we were hiring we always had more applicants than we had people, so you'd have this other screen of taking the best out of that best of best of best. You take that and you put it over the entire population of people, 3,000 people that we had there, civil servants, and we had some really really good people, some genius kind of people. It was just fun to work with. That was my greatest reward, was to be able to work with folks like that. You didn't have to explain things to them.

WRIGHT: They helped, right, instead of having to hinder.

MANDELL: Exactly.

WRIGHT: Well, as our time is about to close for now, is there something else that you wanted to add where we are?

MANDELL: Well, as I think back on my years at NASA, NASA was a good employer. It was always rewarding to work there. We had as much freedom as we were willing to take. We were not exceptionally well paid, but we had enough money to send our kids to college, to live in nice houses, buy a new car every once in a while. We had enough resources to live the good life. We had opportunities to travel internationally. NASA sent me to Europe a number of times on various things and I wound up taking my family on some of these, at my expense of course.

Living in Clear Lake was a perfect place for us because it was suburban, in the country, where we were living. It was a good place to raise kids, it had a really good school system. Never had any problems with any of our girls as far as things that happened at school. There were no gangs at that time. There was just no problems in kids growing up. Living in good communities with good neighbors. I can't think of a thing negative about working at NASA. I can name a few individuals, but for the most part, it was almost idyllic, looking back on it. The high-stress times were when I knew that I was in the right and that decisions had been made that constrained me to do things that I knew were stupid. I've enumerated a couple of those. That was the toughest times, except for that final thing with the Mars program.

WRIGHT: Still got hope we're going to Mars?

MANDELL: Well, that's a good question. Even after I came up here to Austin I was running a project to develop a drill. When I got called back to Houston by George Abbey, I went over and talked to a bunch of people at the Center. I talked to a lot of the scientists. I said what's the next thing that you want us to do at Mars so you can learn more about Mars. I got various answers, but the consistent answer was we need a drill to drill below the surface and see what's down there, because all we've seen now is the surface.

I said well, we're here in Houston. We got drilling people that drill stuff all over the world, so I put out a call and got responses from two people. I got responses from Baker Hughes [Incorporated] and from British Petroleum [BP] willing to help us. Well, I didn't have any money. British Petroleum said that they wanted money, so that ruled them out. I sat down with the CEO [Chief Executive Officer] of Baker Hughes. He said, "This is just so exciting to me. I just really love this project. I'll give you whatever resources you need."

So he assigned two full-time engineers to me. These guys knew everything there was to know about drilling, so we actually over the next five years, developed a drill that'll work on Mars, and tested it in the Arctic. It's ready to go. It's there in Houston.

WRIGHT: It's packed. It just needs a ship to get there.

MANDELL: Yes. I don't know if you know about Technology Readiness Levels, but it's about Technology Readiness Level 6 or maybe 7. You have to be around 8 or 9 to fly, so we got some

more testing we'd have to do and more qualification for space. We've not qualified it in space yet, but basically the technology is there. They developed the cutter heads for the drill. Baker Hughes did all this on their own money. We scrounged money from some—I better not say who we scrounged it from, because they're still there.

WRIGHT: They may be looking for that money.

MANDELL: Yes. That gave us money for our shop. We basically built the drill in our own shop except Baker Hughes supplied the drill bits that they made in a little private shop out in Nevada someplace. Maybe it was Utah. We got it put together and it worked, in fact I'll take you back by my office. I'll show you some of the cores that it drilled in sandstone, but it drills in basalt, it'll drill in anything, permafrost. It operates on 40 watts of power. That was the thing that blew the mind of the Baker Hughes people. They're used to putting 1,000 horsepower into a drill stem. We were talking about 40 watts. They said 40 watts, what can you do with 40 watts, but they did it. Doesn't drill very fast, but it drills about an inch a minute.

WRIGHT: I'm sure the people on Mars when they use it will be glad it's only 40 watts.

MANDELL: Well, it won't be people. This is to be an unmanned mission to go and actually drill a water well. We'd go to someplace where the gamma ray spectrometer tells us that there's water. We could drill as much as a kilometer deep with this drill. As it sits right today it could drill about 20 meters, but with automation of the adding of drill stem and all we could go to a kilometer.

I think someday that may actually fly, but I don't know, because they got wise to our funding. The machinist that was working on it for us got put off on another project. The guys, the engineers that were working with us that were taking it to the Arctic for testing, got pulled off on Constellation work, so it's there. The people are still there. We could put it back together if we had to.

WRIGHT: I bet you can. We look forward to hearing about that. Well, we'll stop for now and see where we want to go next.

MANDELL: Okay.

[End of interview]