NASA MSFC Oral History Interview
Steve Johnson Interviews – Apollo/Saturn Program

Eric Engler
Interviewed by Steve Johnson
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Steve Johnson: I am talking with Eric Engler, who worked with NASA [National Aeronautics and Space Administration] at Marshall Space Flight Center from 1960 through 1986, essentially the Saturn V days through the International Space Station. Eric, would you talk about your education? What prepared you to be a worker in the space program?

Eric Engler: I had a general education in Europe and Germany. I was a student in an engineering school similar to a university here. During the war, I finished about five semesters, and then I was drafted and it interrupted my education. When I came back, of course, I went not back home, my parents were displaced through the ethnic cleansing in Czechoslovakia at the time, and ended up in Berlin [Germany]. I came back to Germany. I could not go directly to Berlin because, at that time, the airlift was on, so you could not get in because of landmines. I came to Berlin in 1949, started night school, and finished my degree in electrical engineering in 1951. From the time I got there to my education and further on, I worked for a large electrical company, which is now no longer existing. They employed me after I finished my degree as a design engineer. I worked there from 1953 to 1956 basically designing hydroelectric generators. In 1953, I went to Frankfurt [Germany] and worked for an electrical company building high tension switches. Really, my education and experience up to that point did not prepare me for [being] a rocket engineer. Through a friend, I became aware that the Army was looking for engineers here. I applied through the Paperclip organization in Frankfurt, through a local lab director, Dr. [Walter] Haeussermann, who got my resume and interested me in coming here. In 1956, I came to Huntsville [Alabama] and worked for the ABMA.

Johnson: The Army Ballistic Missile Agency.

Engler: Yes, ABMA was the Army Ballistic Missile Agency that had been established under General [John Bruce] Medaris. They had split off from another organization that was mostly aircraft, Nike type work.

Johnson: What did you do with ABMA?

Engler: At ABMA, I started work as a design engineer in the Guidance and Control organization, which had a mechanical design group that were doing all the mechanical designs for satellites and guidance and control equipment. I worked there for two years. My first job was the battery component for the Explorer satellite. When that program got terminated because of the Army's decree not to work on the satellite for a time, then we did other work on future satellites that were planned using either the Jupiter-C or the Redstone cluster launcher. In 1958, I transferred over to the Future Design Branch under Herman Keller [Spelling?]. There we did a lot of the preliminary design for future projects, for instance, the use of the Saturn I vehicle, before the Moon Program, and all kinds of other future launch vehicles and application. One interesting thing we did at the time was we had a second program for a lunar base development called Project Horizon. It was not well-known at the time. In fact, it was a secret program, which was later declassified. It was basically preparing an Army base on the Moon. We worked on that for quite a while. In 1960, I transferred over to the Structures and Proportion Division of the same laboratory. That is where I started working on the Saturn V first stage.

Johnson: In 1960, when the [Wernher] von Braun team moved to Marshall [Space Flight Center], which was created that year, you moved with them?

Engler: I moved with them.

Johnson: You worked on the initial design of the Saturn V, is that correct? Tell me about that. What did you do?

Engler: We were given a range of requirements and approximates of the size of the vehicle. Through that preliminary design phase, we looked at different engine arrangements, starting with three F-1 engines, four, and then five, which became the final version of the first stage. We basically did a total preliminary design that lasted about a year. It went through an analysis. We had a special group of about three or four stress engineers and about twelve design engineers. We went through that in pretty good detail of how to put the vehicle structure together, what materials to use, and we worked closely with the materials people and the loads people that provided loads, and so on, including establishing a target weight or estimated weight. The interesting thing was that weight estimate was within five percent of the final design, which is usually a pretty good thing, if you can do it.

Johnson: Is this the weight of the spacecraft itself or the weight of the payload it could carry?

Engler: Just the weight of the stage itself, all the propulsion system, the structure, whatever was needed to lift it apart.

Johnson: How much activity did Dr. von Braun participate in this design phase? Was he vitally interested in what you were doing?

Engler: Of course, he was always interested. We had numerous meetings on the upper level. Things were presented to him of what we were doing, what it looked like. The thing that was so interesting is that, at that time, even all the lab directors and von Bruna himself were in those meetings listening to us and exchanging things which should be done and should not be done. Even as a bottom line of the employees, we were always present in the back of the room when that particular subject came up.

Johnson: I have heard a lot about the meeting von Braun had where he expected people to raise their hand if they had an idea or a concern. Did that take place in these meetings?

Engler: Sometimes we had to present detailed things like what you do here, how does that look, why did you do it this way, and so forth. It was a fairly good exchange, I think, which took place. It was so interesting because later on, as NASA progressed, that has kind of fallen somewhat by the wayside. I worked out there until two years ago, part-time, and that has changed. It is not that intense involvement of the upper management into technical details. Von Braun and his lab directors were all very much involved in the technical details, not on a very detail level, but they were aware of all the things that were going on.

Johnson: Certainly the preliminary design that your group was involved with, von Braun was an active participant.

Engler: Right.

Johnson: What were the main technical challenges you faced in designing the Saturn V?

Engler: It was basically the size. Nobody has done something that big together and made it work. All the other vehicles, if you look, the Saturn IB was a cluster of smaller tanks. We were building a huge tank, if you think of that size. I remember one incident we had. Of course, we drew up these things on the drawing board and you said this is 400-inch diameter and on the drawing board, it looks like whatever you can put on there. They put the cross section of that vehicle, before it ever was built, back on one of the buildings, 4701, it is a big assembly building. We walked in there and it took up the whole back wall. You would say, "My god, that is the size that you are really dealing with." You do not fathom it while you are working on it on the drawing board.

Johnson: Did you have to do testing? You came up with the design, but did you test things as you went? How did that work?

Engler: There were certain tests done not by us. There were other groups within the organization that do the actual structural testing. In doing the preliminary design, very little testing was done because of the time involved and the cost. It was not done until the actual design was progressing.

Johnson: Was there a point where you went to a meeting a everybody said this is what it going to be like, this is it, this is the design?

Engler: We proposed that design with certain inputs from different people like the loads people, the materials people, and so on. They had inputs as to what material to select, how to fabricate these big pieces. That was then taken over by the detailed design people and they got into more detail. Of course, there were changes made that deviated from the original preliminary design.

Johnson: As it got more detailed, changes were made.

Engler: Right, you get into details and you say that has to be changed because no material is available or I cannot get it fast enough or to form it, you have to do it this way, things that you cannot always foresee when you go into the varied details.

Johnson: Did you have to come up with any new materials or tools in your design, or was that left to the other groups?

Engler: We usually used what we thought was the best approach for manufacturing, but we had inputs directly from the manufacturing guys and the materials guys as to whether that is feasible. If we put forth a design and then went to the material guys, the manufacturing guys would say, "Can you do that? What would be an alternate way if you cannot do it?" We had what later became a kind of buzz word, concurrent engineering. We had that in the Apollo days, it was just not called that. We used that. Once we got to that point, it was pretty well known that, in general, our approach would work.

Johnson: You started work in 1960 on the preliminary design. Once the president had decided we would do this within the decade, did the pace of work pick up at that point? Was there some pressure put for timing?

Engler: When we started out, that was basically already understood.

Johnson: Was the pace of work fast? Did you feel like you were moving fast?

Engler: It was always fast out there. I will tell you an incident when I first came here. I left Germany and a six day week, you worked Monday through Saturday at noon. That was forty-eight hours. I came here and they had a forty hour week, Monday through Friday. I stayed home on Saturday. That was in the ABMA days. On Monday, my supervisor asked me, "Where were you Saturday?" I said, "I did not know I was working Saturday." "Well, we do overtime." Even then, that pace was always going on. Of course, when Apollo came, it became more pressing to get things done.

Johnson: I have been told that you would work a long day because things had to be finished and you were expected to think about it when you went home. Is that true?

Engler: (Laughs) Nobody really implied that, but I think it was very vivid and competitive, get this done. One interesting thing was very little paperwork was there but the minimum. Get it done first and worry about the paperwork later on. That was prominent. I do not think it was misused, but it helped speed up the work. In those days, we did not have computers, we did not have computer graphics, everything you would do on the computer, you had to draw it by hand. You had a room full of draftsmen and technicians that were not just drawing what we told them, but they were very skilled people that knew a lot of the specifications for rivets, screws, and so on. You put down where you would need screws, and they would put down specifications, callouts, on the drawings, which helped.

Johnson: Did you have to work long hours?

Engler: Sometimes.

Johnson: Did you ever work overnight shifts, anything like that?

Engler: Yes, if we had a test ongoing, you would have to spend time there while the test was running. Sometimes tests do not work out as planned, something happens, so you stay out there until it gets done.

Johnson: Were these tests being done to check your designs?

Engler: That is the normal way, any design would be tested. In those days and even today, you do not have the tools to predict everything that goes on in a structure when you put the proper loads on it. Testing is something you do everywhere, whether you do aircraft design, missile design. There is nothing unusual that was done here. They maybe did more tests because they wanted to be sure everything works out. Von Braun and the old team were a stickler for tests. They were testing and testing and testing to be sure to minimize the occurrence of unsuspected things.

Johnson: The testing that was done by other people, you were there for either questions or to make changes in the design as warranted.

Engler: We wanted to see what was happening too. That gives you an insight in to the behavior of what you are designing.

Johnson: How about the work environment? Did you enjoy going to work? Did your team enjoy working? Was it a pleasurable experience despite the long hours and extra shifts?

Engler: Because you had a challenge there, I always say that if you compare it to normal industry, which is also interesting, but here we were doing something that nobody had ever done. We were in uncharted territory with everything, whether it was the size of the vehicle, the materials you used, the specifics of the structure, and so forth. You are dealing with things with a cryogenic temperature of the propellants and so on. Everything is new, a challenge. That makes work so interesting. The future thinking of somebody going to the Moon, it is a different world. It is not like designing cars, which I am sure people love that too. I have done other designs which were not as normal.

Johnson: Did you have to control costs or, in this particular case, was money not a problem?

Engler: Money was not as much of a problem as it is today. In the beginning, of course, because of the national importance of the program, money was coming in pretty freely. People that were in Washington [District of Columbia] were very astute and the president had a keen interest in making this program work. It was not like in the old days in the Army, because of certain political restrictions of ABMA being restricted, once we got into the Jupiter Program, we were restricted to 300 miles, so that dropped off a whole vehicle that was basically not needed and not wanted. They had to look for things to apply that existing knowledge and know-how to other vehicles as a question to the Saturn I. The Saturn I was proposed in 1958 to ARPA, Advanced Research Projects Agency, strictly as a carrier of heavy payloads, similar to what the Russians already had. After the Moon Program came along, it became part of the Moon Program, but in the beginning, it was strictly to demonstrate that we could cluster eight engines, that you could build this bigger stage, and so forth. In the Apollo days, that was not the case so much.

Johnson: Were there dead ends in the design field? How did you recover from any dead ends you might have had? Was it a smooth procedure, designing the main stage Saturn V?

Engler: Basically, there were no big hiccups that we experienced in that design. It was just the basic size that we had to cope with. Like I said, we had a lot of interaction with the other disciplines, everything that you came up with had to be built, had to be tested, had to be moved. All of these things had an impact on the initial design.

Johnson: Were there any big surprises?

Engler: There are always surprises when you come up with something. We experienced that in all the programs. When you do something, sometimes it does not work out. I remember on the Shuttle Program, which deviates a little from the Apollo, but on the aft skirt, we had to form a conical structure to support the shuttle. That structure was made out of aluminum and that had to be formed because you could not put it together in bits and pieces because of the water submergence in recovery. We had to make big sheets, machine them out in the proper pattern, and form them. Some of these things had to be worked around. Some of the things that came up were limitation in size, for instance, to want to be forging of sorts. Industry could not supply it initially. They had to gear up to make these big forgings. That sometimes had to be worked around in the design.

Johnson: This is on the Shuttle Program?

Engler: For shuttle and for Saturn too.

Johnson: You were basically doing bigger things than had been done before.

Engler: Yes, and industry did not have it. We did not do the initial or raw materials here.

Johnson: In the design you came up with, did you ever go to the materials people and they would say, "No, we have never done it that large before." Did that happen?

Engler: Yes, we said we would like to have this forging, for instance, and they would say we would have to find out from a supplier like Alcore or whoever does that if they had the capability to do it. Sometimes they went out and purchased facilities to make these bigger things so industry did not have to invest in it. The other thing was you had other demands at the same time from the defense industry for aircraft and you could not get the material on time. They had to shuffle the schedules to make things and get the material on time.

Johnson: Before we leave the Saturn Program, talk about the integration. When you see your basic, macro design broken down into the different parts, eventually that comes together. How gratifying was it to see what your team had come up with, drawn out on a board? What was it like seeing it come together?

Engler: It is fantastic if it works out. When you go and see and test and it holds up for what it is supposed to do, it is very gratifying.

Johnson: In 1960 and 1961 when you were working on the design, when there was finally a test flight and your design essentially flew, what was it like when you saw your design going into space?

Engler: You feel very good when that happens. I will tell you, I have seen most of the flights, not directly, I have seen one Apollo flight, Apollo 9, I have seen the Apollo-

Soyuz with the Saturn IB where they met the Russians in space, and I have seen about three shuttle flights. It still makes you feel good, what is going on up there.

Johnson: You proceeded from working on the Saturn V to working on Saturn Applications. Let us move to the shuttle where you worked on the preliminary design for the External Tank, but you also worked on the Solid Rocket Booster structures. You were on the ground floor, so to speak, on both the Saturn and the Shuttle. Were the challenges different? I gather the timeline was somewhat different, maybe even money expenditures, but how different was it doing what you do?

Johnson: It was not much different. The thing is in most cases when you do new design, there are always challenges, so I did not feel there were any different challenges. The difference on shuttle was the shuttle was not built in Huntsville. The structure for the SRB [Solid Rocket Booster] was not built here, it was built by a contractor at the time we designed it. We had to have the drawings out by a given timeframe, driven by the overall schedule. They said they needed our drawings, these were detailed drawings. Up to that point, that was totally done inhouse, down to the detail.

Johnson: This was the boosters?

Engler: The booster structure other than the Solid Rocket Motor.

Johnson: That was done inhouse at Marshall Space Flight Center?

Engler: It was designed inhouse and my group was in charge of that. We had to deliver the drawing by Christmas of 1974. I remember that because I had planned a trip to the old country to go skiing and take my kids over there for the first time in winter to see the grandparents and so on. My boss said he would let me go if I had all the drawings signed. The drawing package we had to put out was about 1,600 drawings. I had to sign every one of them, amongst others. I was not the only one that signed it, but they had to be signed so they could be given to the individual proposals for building that structure. You can imagine you have tickets bought and everybody was waiting to go on the airplane and you are hoping you get your drawings signed.

Johnson: Did you get them done?

Engler: I got them done.

Johnson: The shuttle being a reusable craft, and you worked on both the boosters and the External Tank, how much tougher did that make the design work? On the Saturn V, you knew it was going to fly one time, you had to make it robust.

Engler: That is the basic thing, it had to be designed not only to be reused, but it also had to be designed to withstand all the environment at reentry and water impact, being in water for several days. That design was a hard one because the loads people had problems defining the loads at impact on the water and the materials people had to deal with the fact that you have a very corrosive environment when you get aluminum in the saltwater. These two things were really challenges. We dealt with stuff like we would propose one design and they said they tried to for a piece and they could not form that piece the way we had it designed because it was all integrated machinery, fairly deep sections. We were not supposed to initiate the bolting because any bolt joints would give rise to corrosion. The material people finally conceded they had to do certain areas where they had to bolt things together. They developed a technique to seal those joints so they would not corrode underneath over a long period of time. If you would do it one time, okay, you would not worry, but on shuttle over thirty years, that was a challenge.

Johnson: Knowing there are parts from the initial solid rocket boosters that flew on STS-1 and then flew thirty years later, how does that make you feel about the design work? You did your job, did you not?

Engler: It was not only that, but also the fact that we designed to a load set that was in the very beginning of the program. That load has changed several times, become more severe. They had to work around, but the basic structure, every time I saw a shuttle fly, I said, "There goes one we did and it still works."

Johnson: You worked on the External Tank. When people look at the tank now the Shuttle Program is over, the foam on the outside led to a lot of problems, in the design work, the work you did, was that just the way it had to be?

Engler: The foam part is something we did not have much to do with. It was mostly a materials thing. It does not contribute anything to the substance of the structure itself. The thing could fly without the foam. The foam was there for protecting the cryogenic fluids from boiling off too quickly on the stand and secondly to protect from ice formation. On the Saturn V and Saturn I, we did not have the super cold liquid hydrogen. On Saturn I specifically, remember the launch pictures, you see all that ice falling off, people did not worry about it impacting anything and doing damage. Here, the orbiter was put in a position where any little piece of ice would fall off, hit the orbiter, and then do a lot of damage. That was the difference. We in mechanical design had very little to do with the foam itself. That was all materials.

Johnson: As a designer, the way the orbiter was attached to the External Tank or the Solid Rocket Boosters, did it feel like this was the way we ought to do it?

Engler: No. We felt they should have done it with the Saturn V two stager like Skylab with the shuttle on top. The reason is actually three-fold. Number one, the Saturn V two stager would have been more than adequate to put that orbiter in space, in low Earth orbit. Number two, it was a liquid propulsion system where you could shut off the engine if something happened and get away from the vehicle, get the crew away from it. Shuttle with the Solid Rocket Booster, once you light off the solid, you cannot get away from it. If something happens in the first two minutes, you are stuck with the vehicle, you cannot escape. The whole agency looked at numerous ways to see whether you could separate the shuttle orbiter from the rest of the stack. They have not found a way to do that because you cannot get away from it, that solid keeps burning. The liquid thing, you can shut the engines off and you have gain some time to get away from the vehicle. These are two things. The placement, as I said, put it on top, you would not worry about anything falling off because it could not hit that orbiter in front.

Johnson: Did you recommend going with the Saturn V-type design?

Engler: I think it was proposed, but what happened was they did the same thing they did with shuttle now. They shut down Apollo, said, "Stop. This is it, that is all we fly." Did you know Apollo had two vehicles that were ready to fly plus one Skylab that was ready to fly and they did not use it? There was one vehicle down at the Cape [Canaveral, Florida] and the other Saturn V is down at JSC [Johnson Space Center]. The backup Skylab is at the Smithsonian. These were three vehicles that were ready to fly. They also had five Saturn IBs that could have flown to the Skylab.

Johnson: When you think about what you could have done as opposed to the Shuttle Program, which at least one NASA veteran has told me was needlessly complicated, as a designer, did you feel like we missed it on the shuttle?

Engler: Yes. I feel strongly about that. The shuttle design, everybody did a fantastic job with the task given, but the initial decision was made on under [Richard] Nixon. We worked for quite a long time, I was involved in that quite a bit, on a reusable shuttle where you reuse both stages. When Nixon came put and said, "I will give you eight billion dollars to do the program," which was a lot of money in the 1970s, they came up with this solid rocket approach, External Tank, and orbiter. It was partially reusable.

The Solid Rocket Boosters were partially reusable, you throw away the tank. From that point, that was a given, you did not have a choice anymore. Up to that point, we worked on a fully reusable system. Then the decision came down and someone worked out the concept of the shuttle as it was built and that was it. It was not just a cost design, it was also a political decision made by all kinds of different people.

Johnson: As a designer, knowing you were working on a design you obviously did not think was appropriate, was it tough? You were trying to make it the best it could be, but was it tough knowing that this was not the way we ought to do it, at least in your mind and your team's mind?

Engler: I think at the time the real dangers were not understood fully by everybody. Even in the beginning, they were looking at a different heat shield design for the orbiter. Then the tile business came up and it was mostly because of the likeness of the weight problem and the complexity of the other thermal protection systems that were feasible at the time that they selected that. I am not blaming anybody, but I think some of the real problems were overlooked or not recognized. I did not know them either. The thing was so fragile. I have seen tiles in the beginning where somebody took the tile without the hard coating and started writing on a blackboard with it. It is that soft a material that is in the tiles. Then it is coated with a very thin ceramic coating, and that makes it a little more resilient, but the basic tile is very fragile. You can nick it with your fingernail if you push hard enough. Then the problem of protecting ice from forming on the tank became a major problem. Again, we were doing the preliminary design that was also turned over to a design and we worked on the Source Evaluation Board. Boeing, General Dynamics, Rockwell, and McDonnell Douglas were bidding on the tank. Of course, Martin Marietta was the fifth one and they got the tank design.

Johnson: After the space shuttle, you worked on numerous things, you worked structures on the Hubble Space Telescope. I want to ask you about coming up with new materials which applied to your work on Hubble, coming up with ways to build structures. Would you talk about that?

Engler: When the composites came along, that was in about.

Johnson: Would you give a very brief explanation of composites?

Engler: It was using a fiber material.

Johnson: As opposed to using aluminum or steel.

Engler: It is a replacement for that. It is a material that consists of fiber like fiberglass, graphite, boron, then there are aluminum silicate fibers that are very strong. Of course, fiber by itself has very low resistance to any load, so you bundle fibers. It has been done before, the Romans had their weapons of bundled fiber, basically sticks that were put together that makes it a very resilient structure. The idea is to imbed those fibers in a matrix of either epoxy or any other plastic, or, later on, they looked at whether they could put them in aluminum. Basically, at the time, we talked about graphite fiber and an epoxy base. You laminated the fibers, soaked them, and it becomes a solid.

Johnson: Talk about the kinds of composites you were investigating for use with space applications.

Engler: For space application, the first one was using boron epoxy. Boron is a metal material, it is very strong, and that was used on the space shuttle for certain, specific parts in the engine compartment in the truss structure of the space shuttle orbiter. We did some work there in preparation for the all-up reusable shuttle. They gave us quite a bit of money to do a structure demonstration of various parts made out of these composites because they were good for application for shuttle or for the all reusable shuttle. When the reusable shuttle program ended and this program began, we switched over some of that material into other applications. One application that came along was the Hubble Space Telescope. You are talking about an element that goes into orbit, so if you can save pounds, you can do more with the same amount of payload available. The other requirement on the Space Telescope was the telescope truss, which has a primary mirror and holds the secondary mirror in place, is very sensitive to change in dimension.

Johnson: Because of the heat and cold it would be exposed to?

Engler: It would be exposed to cold and you would have shrinkage and you want to keep that to a minimum, especially if you go through an Earth shadow every ninety minutes. They gave us a very strict requirement as far as temperature and temperature length changes between the primary and the secondary mirror. We used that composite material to do what they call a thermalized structure, a structure that moves through temperature changes with a minimum of length changes. For that, we used the graphite epoxy and proposed a truss design for the telescope itself. The money we had left over was given to Boeing to build a truss that was similar to the size, actually a little bigger than the size, that Hubble Telescope became later on. That truss design was done by Boeing under Marshall's supervision. That is the one that flew, not the same one, but this design went into the Space Telescope, in the Hubble. The focal plane structure, which is also a structure that has the experiment, again, it holds the experiments, cameras, and so on, at the proper space at the focal point of the telescope. You are again talking about thermal excursion to hold it to a minimum. That is where we used graphite epoxy too. Those were the two big things.

Johnson: Saturn V design for the main stage, some of the structures on the Solid Rocket Boosters, the External Tank, new materials for the Hubble Space Telescope, as a designer, as somebody involved with the program for this period, when you look back, what was the toughest thing you did?

Engler: That is a hard question.

Johnson: Did each thing you did have its own challenges and rewards?

Engler: Each had its own challenges. Also, what you do is you learn as you go. Remember that I did not really know what a rocket was when I came to Huntsville. I was not in the rocket business. At my age, I was not at Peenemünde [Germany], I was too young for that, unfortunately, in a way. I came here and I had to learn all the way through it. Every time something came along, we tried to understand it, had help from other people to understand the behavior and to try to apply it to the task on hand. In my opinion, my experience as a designer would not have been as interesting if I would have worked for General Electric and so on. There are challenges there too, but this was something where everything you did was new. Nobody had flown a telescope, nobody had flown the Saturn V.

Johnson: You said you learned from your experience, is that something that the space program has lost with designers who have worked on a multitude of programs and faced a variety of challenges, which they have learned from? It was valuable to you. Is it something the agency may have lost?

Engler: Since I left NASA, I have worked for different companies to do different things, all space related, the last from 2002 to 2010, I worked back in my old design group as a mechanical consultant, if you will. We worked through a number of things. I met the younger people and I have to say that there are very good people out there and what they like is exposure to challenge, to do new things. The program is not as vivid anymore. You have monetary restrictions and so on. I worked with one guy specifically, I left the aerospace field and went up to New England to work for a small company doing a new design on casting of metals because you did not have the challenge here anymore. If you are an engineer and do not do things, if you do paper things, if you say this could be done but you do not do it, you lose that relationship to the hardware and what if it does not work. If you see your results and they work, and sometimes they do not work, so you have to change something you overlooked or did not have enough background or analysis support because of the tools available, then you lose your touch.

Johnson: It is one thing to put it on paper or put it on a computer screen, it is another thing to see it built.

Engler: The computer screens and papers are very patient. The hardware is not forgiving. If you do something wrong, you get burned.

Johnson: You have already mentioned the names of several contractors you worked with, but was the contractor experience a good one for you as far as the people you dealt with and the results you got from these various contractors?

Engler: I was always on the government side and these contractors you worked with, they claimed the contractors are more knowledgeable. I was reluctant when I retired from NASA to see how I would make out in private industry. I specifically looked for jobs that would keep me engaged in engineering, not in management. I told people I did not want to manage people, I did not want to manage programs, I wanted to be an engineer. You give me the job and I will do it. If you do not like it, that is my problem. I have enjoyed it. I worked five years for United Technologies here in town, it was called space flight systems. It was mostly preliminary design work. They were trying to get new programs and bid on a lot of different things, shuttle follow-on, new launch systems, they are coming up with SLS [Space Launch System]. We did that from 1986.

Then I worked for a small company doing a flight experiment design that went on shuttle, went to the Mir space station, was put on the outside for a year, brought back, and was evaluated. It collected data for material exposure in space at certain conditions. I worked that and then went back out to Marshall to work after USBI [United Space Boosters Incorporated, group in United Technologies], that was between USBI and that small company. I worked two years for replacement weight and I did some educational work with the design group. I put together some tutorial materials of how to do things in design, which was nice, but was rehashing old stuff. After the experiment in 2002, they asked me to come back out there as a consultant. It happened right before *Columbia*. I was involved in the *Challenger* evaluation and fact-finding and became involved in the *Columbia* accident investigation. I then worked on a program that was the precursor to the Space Launch System. I worked on that in a mostly contracted job and then worked on the upper stage to Constellation for the design of the upper stage in the same group.

Johnson: All the different work you have done in any one of these programs is almost a career. In Saturn V design, shuttle design, Hubble design, did you know you were in the midst of making history? Did that occur to you?

Engler: You just live with it. The only thing I can say, my career, as far as I am concerned, was very exciting, a lot more exciting than if I had stayed with regular industry. I know that I have done designs, and every design is a challenge, whether it is a spacecraft, an experiment, I had to learn to work with an experiment of a one by one by one foot cube coming from the Saturn V and from Hubble. It was another experience and I learned things there that I did not know before. I am looking at my career more as a learning process. It is wonderful.