NASA STS Recordation Oral History Project
Edited Oral History Transcript

Otto K. Goetz
Interviewed by Jennifer Ross-Nazzal
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Ross-Nazzal: Today is July 20th, 2010. This interview is being conducted with Otto Goetz in Huntsville, Alabama, as part of the STS Recordation Oral History Project. The interviewer is Jennifer Ross-Nazzal. Mr. Goetz, would you begin by briefly describing your career with NASA?

Goetz: I hired into the Marshall Space Flight Center in 1962. At that time I was assigned to the test laboratory and was a lead engineer for the testing of the combustion devices and the turbopumps of the H-1, F-1, and J-2 engines. The F-1 and the J-2 powered the Saturn V [rocket] to the Moon. I worked on those till 1971-2 timeframe, and at that time I was assigned to the evaluation board of the Space Shuttle main engine [SSME]. I participated in the proposal evaluation, and at that time I transferred from the test laboratory to the propulsion laboratory and again was the lead engineer for the combustion devices and the turbomachinery for the Space Shuttle main engine up until the *Challenger* accident [STS 51-L].

After the *Challenger* accident I became the chief engineer of the Space Shuttle main engine. I remained the chief engineer till ’92 [when] I was assigned the program manager for the SSME which I remained till ’[94], and I retired in ’96. I conceived, while I was the chief engineer, of the Block I and the Block II engines. That is to improve the Space Shuttle main engine, the reliability. [From ’94 to ’96] I concentrated on [certifying and] flying the first Block I engine, and then I retired.

ROSS-NAZZAL: It's quite a long and varied career with the main engines. That's what I'd like to focus on today. Would you tell me about the work that you did with the subsynchronous whirl? I understand that you did a lot of investigations into that problem.

GOETZ: At the beginning of the SSME program when we fired up the engine, that is the integrated technology test bed down in Mississippi [NASA Stennis Space Center], we found that high pressure fuel turbopump had a vibration problem, a subsynchronous whirl problem. The rotor vibrates and whirls at a speed lower than the actual rotation of the speed. That vibration was very violent, and we could not proceed for almost a year into the testing of the engine at higher power levels. We had [redline] vibration sensors, accelerometers, on the turbopump and they cut us off. It was something that was not expected. We got consultants from universities, even from England we had a consultant, what to do about the subsynchronous whirl. We struggled for almost a year in order to solve it.

The solution was multifold, but it was primarily a [bearing stiffness, damping and] rotor balancing problem. It was a rotor stack problem. The rotor consisted of multiple parts that got bolted together with a tie bolt that was hydraulically rammed, and then we ran the nut down. We had stiffness problems in the bearing loads [path] to the housing that were too soft, we had to stiffen [them] up.

We also invented, in the process of solving the subsynchronous whirl, the damping seals. We put damping seals around the carriers of the bearings and obtained additional damping through those damping seals. The patent was initiated during that investigation. We had a great program at Caltech in California [California Institute of Technology, Pasadena] where we explored the damping seals in regard to their behavior, in regard to cross-coupling, stiffness, and damping. With those data that we derived in Caltech we implemented damping seals in the turbopump, and finally we solved the problem and it went away. [Parallel we developed bearing models to understand bearing mechanics, heating, etc.]

Later on, since you mention subsynchronous whirl, we also detected—that was much later—subsynchronous whirl in the high pressure oxidizer pump. The same solutions were applied. We implemented damping seals in the oxidizer pump. A little bit different concept, but essentially the same engineering principle.

ROSS-NAZZAL: Were there other task forces that you served on for the main engine? Were there other problems that you were looking to solve that you headed up?

GOETZ: There were quite a few. Following the subsynchronous whirl, we detected cracks in the turbine blades in the high pressure fuel pump. That was the next big challenge that needed to be solved because any turbine blade failure is catastrophic. We had some catastrophic failures with the high pressure fuel pump. I brought statistics with me of those failures, and I can tell you that as soon as 1977 we had turbine blade failures in the high pressure fuel pump.

There again, that was quite an engineering effort to solve these problems. I don't know whether you're familiar with it or not, but the turbine blades originally were a high strength material that was cast such that the crystals grew in the direction of the centrifugal force. But there were individual grains you could see in the turbine blade. What we did is we went and had a very intense material development program and converted those directionally solidified turbine blades into single-crystal blades. One crystal was a whole turbine blade. That was quite an effort to develop that. We had quite a few materials people and a contractor involved in that. That was one of the things.

The other thing that we needed to do was we needed to coat the turbine blades, because in the start sequence of the Space Shuttle main engine, when the preburner ignited and shot the hot gas into the turbine in order to get it going, the turbine blade was essentially at ambient temperature and the hot gas coming out of the preburner was 2,000 degrees. So within two seconds the blade saw a delta temperature of 2,000 degrees. That is, the core of the blade was still at ambient [temperature] while the surface, the skin, went to 2,000 degrees and that caused cracking because the delta internal to the material caused high stresses. One of the other solutions was to coat the turbine blades. We coated the turbine blades with an insulating material in order to keep the high delta T for a little while away from the core of the turbine blade.

We also had to develop dampers. The turbine blade was originally designed by Rocketdyne with dampers, but the damper was too heavy. When the turbine rotates, the heavy damper locked up, and therefore there was no damping. The damping was by rubbing [between damper and blade], and so we had to design very light dampers in order to effect the damping, the rubbing.

I don't know whether you realize, but the fuel turbopump had a speed of 36,000 rpm [revolutions per minute], which means it has to rotate 600 times a second. The turbine blade itself, I think there were 58 turbine blades on it, but the turbine blade itself was [1.3] ounces. When it rotates at 36,000 rpm, the blade weighs [7] tons because of the centrifugal force. That illustrates how a too stiff damper locks up; you have to make it real light in order for it to effect the scrubbing between the two blades.

ROSS-NAZZAL: That's amazing, all of the work that you did to solve those issues.

GOETZ: There were other problems with the fuel turbopump and with the LOX [liquid oxygen] pump. The thing is that people were afraid the pump wouldn't pump or the turbine wouldn't turbine. And none of that happened. The problems were with bearings, with seals and with dampers in the turbine blades. They were all mechanical [in] nature and materials.

For a long time we struggled. This is not only related to the turbopumps but also to the whole engine. When we started the SSME we did not realize how sensitive some of the materials are to pure hydrogen. We had a hydrogen embrittlement problem for quite a while and they had to change materials or had to plate material. Like, for example, the turbine disks—where the blades are mounted on the outer periphery—they were all gold-plated in order to prevent the hydrogen from diffusing into the material. If the hydrogen diffused in that material, the material becomes brittle and cracks. Then you buy the farm.

ROSS-NAZZAL: Was there ever a point, Mr. Goetz, that you thought you wouldn't be able to solve whatever problem or issue you were facing at that point?

GOETZ: Well, we just addressed one problem at a time, but sometimes we had more than one on our hands. There were multiple problems. During the development program we lost 27 engines. Exploded—and sometimes we found the engine down in the flame bucket after an explosion.

ROSS-NAZZAL: Tell me about the development and design period for the SSME. Then move into the test program that you laid out for the engine if you could.

GOETZ: When the development program was structured the approach was to test every component on its own, develop it, and have a certain maturity before the component goes onto an engine and then test the engine system. So we built COCA [test sites]—this is up in Santa Susana in California, the facility there—in order to be able to test the preburners on its own, the turbopumps on its own—of course you need the preburners to fire the turbopumps—the main injector and the combustion chamber.

I was very much involved. That is a pressure-fed system. The SSME, the combustion chamber pressure is 3,000 psi [pounds per square inch]. The preburner itself runs at approximately 5,000 psi. In order to get that pressure with a pressure-fed system without a turbopump, you have to have a very high supply pressure. We had hydrogen bottles that didn't meet the code. We needed 14,000 psi hydrogen so we had to put the bottles into caves, into the mountain, in order to be safe if something happens. Then we ran the pipe to the test stand and pressurized the run tanks, the liquid hydrogen and the oxygen tank, and then fired the preburner. We successfully developed the oxidizer preburner. That was a congressional milestone where Congress looked upon us every day; we had to report to [NASA] Headquarters [Washington, DC] how far we are on that thing.

Then we started to [test] turbopumps with the LOX pump. We had an explosion, facility-caused. At that time we realized that this whole facility, with the extremely high pressures and its facility control system, is much more complicated than the engine itself. Therefore we abandoned the approach of testing every component as a component before it's moved onto an engine system. Essentially we then moved to ISTB (the integrated [system] test bed engine [program]) in Mississippi. We continued to do some testing at COCA, however, only on smaller items, like for example the main combustion chamber and each one of the preburners [which] had an auxiliary spark igniter, which is a little burner. That lent itself to being continued to be tested out there, but we did not test the turbopump or the main combustion chamber anymore.

We had two test stands up there, one primarily related to oxygen and the other one related to hydrogen. Later on we converted one of the test stands into an engine test facility, and we did some testing up there. We allowed Rocketdyne to have their own backyard test facility so they can test up there, and they were responsible for the testing [in California]. NASA, we concentrated on our testing in Mississippi on A-1 and A-2 and later on on B-1 [Stennis test stands].

ROSS-NAZZAL: When you were testing components at COCA were you requiring them to be run for 520 seconds?

GOETZ: Oh no, that is completely impossible with a facility pressure-fed system, because there was not enough [supply] pressure. With 14,000 psi, for example, the pipe that ran from the underground facility to the test stand was about 14 inches diameter, but it had a wall thickness of six inches with a bore of two to three inches because of extremely high pressure. You had to have these tremendous pipes. There is not enough capacity of pressurant in order to make 520 seconds. That’s impossible. We realized that from the beginning that one full run demonstration on a component basis is impossible.

I need to modify that—because when we developed the Block I and Block II turbopumps at Pratt & Whitney down at West Palm Beach [Florida], we wanted to test the turbopumps there too, and we did. But we did it completely different in the approach as compared to the COCA facility. We fired the preburner and let the pump rotate, and then we took the pump discharge to feed the preburner, just like in the engine. That's how we circumvented the problem of having enough pressurant to fire the preburner. We didn't make 520 down at Pratt & Whitney either, but it was a different concept in that the turbopump fed the preburner instead of pressurant from a facility feeding the preburner.

ROSS-NAZZAL: You mentioned the integrated subsystem test program. Can you talk about that?

GOETZ: The ISTB [with a lower expansion ratio nozzle] was primarily a tool to develop the engine start sequence and the engine shutdown sequence. That sequence is rather complicated because the SSME was a feedback-controlled system, thrust and mixture ratio, so the ISTB was used to develop the start sequence and to develop the shutdown and the safe shutdown. However, the whole effort was for a long time handicapped because of the subsynchronous whirl of the fuel pump. We could not get to 100% power level. We were stuck at low power level for quite some time.

ROSS-NAZZAL: And what is low power level?

GOETZ: The specification originally, when we wrote the request for proposal, was that the engine be operated from 50% to 109%. So low power level is 50%, but we never flew at 50%

because we had some vibration problem. As you know even today when the engine flies and the engines are throttled back during max Q [maximum dynamic pressure], they only go to 65; you cannot go to 50 because of vibration problems. And it's not necessary anymore, so it was overspecified at the beginning in my opinion.

ROSS-NAZZAL: Could you describe testing with the main propulsion test article?

GOETZ: I was really not involved closely. I was only involved from an engine standpoint. The testing itself was very structured as I recall. [To start the program] we ignited one engine first and then two engines and then three engines. I cannot recall all the details, but it was a very successful program in that the propulsion system, the feed system to the engines—that was the main purpose of testing—worked quite well. We had some problems. One day I got a call, and we flew down after a test on the article, and [on] one of the engines, the steerhorn was missing. So we had a major mishap on one of the engines, but other than that I think it was a good program in order to test the system between engine inlet and tank outlet.

I think every program that I was involved in—and I'm still involved a little bit in some programs—there is concern about what is called the propulsion system, that is the feed lines, the pressurization system, the control system and what have you. A test program like that is very much in order. I think in my experience I would not develop a vehicle without a propulsion system test program.

ROSS-NAZZAL: Did you do any work with the National Research Council and their study on the SSME?

GOETZ: No, not really. I made at one time a presentation to the National Academy of Sciences, but only one time. It was following the *Challenger* accident. We had to implement quite a bit of correction, even on the SSME, after the *Challenger* accident even though the SSME was not involved in the accident at all.

After the *Challenger* accident Dr. Richard [P.] Feynman, the Nobel physics man, came to Marshall. He was interested in the other elements other than the solid rocket motor that failed during the *Challenger*. We had a session with Richard Feynman, and we explained to him the turbine blade problem, cracking. He was very much interested in that, but eventually the session evolved into a discussion of reliability of the Space Shuttle main engine. In the course of the discussion, the Marshall management had one number of reliability. I recall very vividly that it was said that the reliability of the engine is one failure in 10,000 missions, and Feynman leaned back in his chair and said, "You mean to tell me that you can fly every day [for] three years and never have a failure? I don't believe that." So he challenged the whole thing.

He also then asked us—and I was [in] engineering at that time, I was not management. He took a piece of paper and made little pieces out of it, and he asked the management to leave the room, and he said, "Write down what you think the reliability is." Based on the 27 failures that we had on the engine I had kept my own statistics, and I wrote down one in 300. If you read the Feynman appendix to the Rogers Commission Report [on the *Challenger* accident], in Appendix F he mentioned the one in 300. From then on we had our task cut out.

I then was transferred and became the chief engineer, and we initiated redesigns. I think we had over 30, some of them very minor. We initiated failure mode and effects analysis, the critical items list—we restructured our criteria as to when is it safe to fly and what factors apply.

For example, the FAA [Federal Aviation Administration] has a criteria, a factor of two. That factor of two was, before *Challenger*, on the SSME a little bit loosely applied. It means that if you have, for example, a turbopump of a specific design, and you want to fly the pump five times, you have to have a pump on the test stand with exactly the same design that made ten equivalent flight durations. That's what the factor of two means. Post-*Challenger* we applied that very rigorously, while before *Challenger* we tolerated some deviations from that criteria.

ROSS-NAZZAL: This was the Phase II engine?

GOETZ: The Phase II engine followed the *Challenger* accident. This is all of the history of the development. [Demonstrates] At first we only flew 100% power level, for the first five flights of the Space Shuttle. Then we went into Phase I, which allowed the flight to be at 104, and we flew up to the *Challenger* accident with this 104. We initiated the Phase II after *Challenger* and tried to go to 109% and never succeeded. We could not make the engine go to 109 safely.

We made 38 changes after the *Challenger* accident, and then we made some turbopump improvements, and then we followed with the Block I and Block II engine. That is what is flying today. We implemented quite a few changes in order to offload the high pressure system within the engine. The chamber pressure originally was 3,000 psi. With the Block I, Block II we went to a combustion chamber with a larger throat, and that reduced that pressure by about 10% to 2,700. Of course we made other improvements like the alternate turbopumps from Pratt & Whitney—the LOX pump and the fuel pump—the two-duct hot gas manifold, single-coil heat exchanger, and the large throat main combustion chamber.

That was quite a development effort in order to do this. At the beginning of the Shuttle Program most people were mostly afraid of the Space Shuttle main engine because of the extreme power density that the engine has and the high pressures. Everybody expected that if there is a failure of the Shuttle it may be caused by the engine. Thank goodness the engine never failed on a flight. We had one premature cutoff on one of the engines during a flight, and that was due to a sensor failure. It was no big deal, but we made orbit because the trajectories are designed that from a certain point on you can cut off one engine and from the next point on you can cut off two and you still make orbit with one engine. Before that we always had the thing go to Africa or go to Spain. Have you ever attended a Shuttle flight?

ROSS-NAZZAL: Yes.

GOETZ: There is a call when it's safe to go to transatlantic abort, and then there's a call abort to orbit. This all is engine-related.

ROSS-NAZZAL: You mentioned that the development effort for the Block I and the Block II engines was huge. Can you tell me about that effort? Can you give some examples of how the Block I and Block II was developed and then tested?

GOETZ: Originally we thought that we could do the whole thing together. Due to some fiscal constraints we did it a little bit in sequence, and that's why there is a Block I and there is a Block II. The major effort—well, all of it was a major effort—was to replace the turbopumps, because the turbopumps had to be removed after every flight from the vehicle. In order to do that the engine had to be removed from the Shuttle. That was very costly, and we wanted to get higher reliability; we wanted to get longer time between overhaul. That's why we conceived the Block I, Block II.

The turbopumps were developed down by Pratt & Whitney, designed and partially tested at the facility that I mentioned earlier. The main development was on an engine system at Mississippi, both LOX pumps and fuel pumps. The original SSME had a hot gas manifold we call it, where the two preburner and then the two pumps were mounted. Then from the turbine discharge, the hot gas goes into the main injector. It's mixed with liquid oxygen and burned. That's how you produce thrust.

The design of the hot gas manifold was such that the feedback from it into the turbine, especially on the fuel side, was such that there was a mal-distribution of pressure going into the turbine, and there was a mal-distribution of temperature. Both of them affected, for example, the turbine blade life. The prime objective for redesign was in order to correct the distribution of the temperature and the pressure going into the hot gas manifold that affected the turbine. Of course originally when we designed the SSME in the early '70s, we didn't have the computer programs, and we didn't have all the sophisticated analysis techniques that we have today.

In the redesign for Block I and Block II we really made use of these sophisticated tools, the models, calculated pressure distributions, flow distributions, and temperature distributions and let some of those models guide us in the redesign of the flow system from [preburner to] turbine [and] into the main injector. That was very successful. The use of these modern tools was a key factor in the successful development. We did not have many problems on the test stand when we tried to test the redesigns for the first time. Too bad we didn't have these tools at the beginning. It really helps. Those tools are being used today also on the J-2X and the other engine development that are being considered.

ROSS-NAZZAL: Did these tools shorten the design, development, and testing program for the Block I and Block II engines?

GOETZ: I don't know whether these tools shortened the design phase. I am tempted to say yes, but you still have to design. These tools were very effective to do it right the first time, and you didn't have to go around and around and redesign here and redesign there. So the tools were, in my judgment, very effective in shortening the development program in that it cut out a lot of trial and error. The SSME at the very beginning relied mostly on testing to prove is the design correct or not, and in quite a few instances it was not. While in the Block I and Block II, thanks to the modern tools, those iterations were not necessary.

It was quite helpful to have these tools. Of course I need to say that some of these tools you cannot just take what the computer spits out at face value. Some of the tools had to be verified, and at Marshall we had a hot gas test facility where we essentially calibrated the tools. Not necessarily at the same condition as the SSME, but the tools were calibrated, and you gained confidence that yes indeed, what the computer tells you is correct. So we insisted on some calibration effort of those tools. It was not just taking them at face value, because you could be misled by computer outputs, but I have to say that these tools helped a lot in Block I and Block II.

ROSS-NAZZAL: Would you tell me about the flight acceptance of the various engines as they evolved?

GOETZ: Each flight engine went through a flight acceptance test down in Mississippi. We had a prescribed program of a series of tests that the engine had to go through in order to be able to be flown. For example, one of the test programs was a stair step test where you go from 65% power level in increments to 104 in order to show that there is no vibratory or any other problem hidden in the engine. Some people think that from a vibration standpoint the worst case is the highest power level. That's not necessarily the case. You can have vibration problems or coupling at low power levels while the high power levels are okay, and that's why the engine had to go through these steps, [to] demonstrate that there is no hidden vibration problems.

Then you may have heard about the fleet leader concept. I mentioned that earlier with the factor of two. Any flight engine had to have a test engine demonstrated by a factor of two, the duration and the power levels that the flight engine was supposed to see. Originally if we had a failure on something we asked ourselves, "What's the effect on the flight engine?" Usually the failure was addressed, and then we applied a factor. Depending on the failure it was either a factor of two or even a factor of four sometimes, depending on the failure analysis, [our knowledge] and what we found [in the hardware] in regard to the failure.

For example Feynman, when we discussed with him the blade cracking, we got into an argument. "What is a failure? Is the failure when the blade flies off? Or is the failure when the crack starts?" It was his opinion that the failure is when the crack starts. We took that to heart and examined quite a few turbopumps, and then after the *Challenger* accident structured the limit of the fuel pump exposure to that criteria.

Later on we modified it somewhat because the crack can grow and not grow to a catastrophic failure, which is fracture mechanics. Of course, in order to make a case with fracture mechanics you have to have very solid material properties, crack growth rates, and understand the environment exactly before you can say, "I let a crack grow in flight." That was quite an engineering effort in order to arrive [at the conclusion], "Can we or can we not tolerate crack growth?" On some of the locations in the SSME we tolerated crack growth, and some we did not.

ROSS-NAZZAL: What areas did you allow for crack growth, and what areas didn't you allow?

GOETZ: For example on the main injector, there is an [interpropellant] plate that separates the hot gases from the liquid oxygen. There are cracks, and those cracks grow. You have to have a very good analysis, understanding the material what have you, but the cracks grow till they reach a neutral fiber where the stress field transitions from tension to compression. Where you have compression, essentially the crack does not grow. Where you have tension, the crack grows. You have to [have an] exact good understanding as to where the neutral fiber is. If you cut apart a few of those items and demonstrate that yes indeed, the crack has stopped by inspection, by cross section of the material and by analysis, you can tolerate a crack up to that point. While in other cases where there is no neutral fiber, a crack cannot be tolerated, period.

ROSS-NAZZAL: How did the initial engine perform on the first flight, on STS-1?

GOETZ: Perfect, on STS-1.

ROSS-NAZZAL: Did you make any changes as a result?

GOETZ: Well, that's a long time ago now, in '81 in April, but I do not recall any major problem on STS-1. If it would have been a major problem I would remember it. It flew at 100%, not at 104, as I indicated earlier.

ROSS-NAZZAL: Same with the return to flight and the Phase II engine performed perfectly?

GOETZ: Yes. But as I said, during the whole flight program we had one premature cutoff. [STS] 51-F was the flight I think.

ROSS-NAZZAL: I believe you're right, because it was an abort to orbit.

GOETZ: It was rather interesting, that flight, because a temp [temperature] sensor failed and on the second engine another temp sensor failed. We inhibited the cutoff and flew with two engines, and it turned out that was a benign failure of the sensors. If you predict, from a reliability standpoint, that two sensors fail in the same flight on two different engines—it was very extremely remote, yet it happened.

ROSS-NAZZAL: Did Mission Control call you at that point? Or were you in the Launch Control Center to advise?

GOETZ: Yes.

ROSS-NAZZAL: I imagine things were a little tense at that point.

GOETZ: Oh yes. Everybody was sitting on [pins and needles; it] was quite exciting.

Going back to the transitioning from Phase II to Block I. The discharge volutes of the turbopumps and the inlet on the turbopumps, the manifolds on the main combustion chamber, the outlet and the inlet for the coolant for the main combustion chamber—they were all originally built by welding together forged segments. You had little pieces of forged segments that fit together but that had to be welded. These welds caused a lot of problems. They had to be X-rayed, dye-penetrant inspected, and what have you. Cost a lot of money, was very very expensive and time-consuming. In the Block I and II we specified to get rid of these welds, and we developed with a contractor a fine-grain casting of these manifolds.

For example, we went from more than 500 welds on one of the turbopumps to zero welds in Block I and Block II by eliminating the technique of putting together, almost like a puzzle, these single pieces and welding them together to volutes and to manifolds. This development of the fine-grain casting is, in my judgment, a major achievement in not only reducing manufacturing time, saving cost, and what have you, but also in increasing the reliability of the engine. Because we never knew exactly, did we or did we not get everything by X-raying these welds, and are there left over cracks or not? With fine-grain casting all those concerns were essentially eliminated, and in my judgment that was one of the major achievements.

In addition to that, for example, I mentioned earlier that at the beginning when we had the turbine blade cracking problem that we went to coating the blades. The Block I and Block II turbine blades don't have any coating. We went to a different material, and that material does not need any coating. There's all kinds of disciplines involved in improving the engine, stress dynamics, thermodynamics, materials. There's a lot of inputs and a lot of coordination required between the various disciplines in order to achieve something like that.

ROSS-NAZZAL: Do you have any idea of how much these improvements changed maintenance time or overhauling of engines? Does anyone keep those type of figures?

GOETZ: Our goal was that we fly ten times without removing the turbopumps. I really don't know now exactly what the criteria is today, how many times they can fly. The latest I had an input was that they were flying six times. I don't know if you are familiar with the Cape [Canaveral, Florida], but when they have to remove the engine on the orbiter in the OPF [Orbiter Processing Facility], it's quite a thing to remove engines and then remove turbopumps, put them in the engine facility, and inspect the turbopumps. Quite time-consuming, costs money. The latest I have was a factor of six.

ROSS-NAZZAL: How long would it take to process an engine once you took it out of the OPF and the orbiter itself until you put it back into the orbiter?

GOETZ: I have been down there quite a few times, but that's hard to answer. It depends how many engines they have to work on. If there are no problems and you just inspect and put everything back together the way it was, I would think that it could be done in four weeks, but I'm not sure. That's a guess.

ROSS-NAZZAL: How long might a Space Shuttle main engine last? Did it vary depending upon the original engine, Phase II, Block I, Block II?

GOETZ: Right now I think the engine can make ten flights, and then you have to—not refurbish everything, like the main combustion chamber. At the beginning of the program the temperature distribution out of the main injector was not ideal. We had what is called blanching on the main combustion chamber. I don't know if you are familiar with it or not, but there's a copper liner where on one side you have hot gas of 3,000 degrees and on the other side you have liquid hydrogen flowing through channels at -420 degrees. The separation between the two, the 3,000 and the -400, is about [20] mils.

If that web in the main combustion chamber would break through or fail then you lose the hydrogen going into the main injector, going into the preburner, and you essentially lose the engine. First there's a performance degradation, and then because [of] the leaking hydrogen. It had to be that thin because of the heat transfer. You cannot put a big barrier between the hydrogen coolant and the 3,000 degrees hot gas in order for it to cool and not melt the copper alloy. You had to make it as thin as possible, what the structure would allow.

At the beginning we had some blanching. Then we had to take sandpaper and prepolish and be careful not to get it too thin. That was one of the limitations that we had to take out. This is not the case anymore with the Block I and Block II. The temperature distribution is such that there's no problem anymore.

ROSS-NAZZAL: Would you tell me what your role was in terms of mission support over the years?

GOETZ: Post-*Challenger*, when I was chief engineer, I was down at the Cape during the launches sitting in the firing room with Rocketdyne people and making decisions. In some cases it was rather stressful because [if] there was an anomaly, "What do we do?" And then can you lift off or should you try a hold? In order to cancel a flight you had to answer a lot of questions. It turned out that only once did we have to cancel a flight.

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

GOETZ: There were other problems whereby flights were canceled that were not related to SSME. For example, hydrogen in the aft compartment. The hazardous gas was too much, and things like that.

The hydrogen in the low pressure fuel pump—while the propellants are loaded, that pump is full of hydrogen. We had the pump insulated but it was apparently not completely adequate. Because of the very low temperature, like the -400 degrees, the surface was accumulating [liquid N_2 (nitrogen)] from out of the aft compartment atmosphere. The [LN_2 (liquid nitrogen)] was dripping on a sensor that was critical for liftoff, and the sensor went out of whack so it was inadequate. Later on we improved the insulation, but that was one of the incidents where we did not lift off because that was a flight-critical sensor, and it was completely off range. But only because the dripping of the extremely cold fell onto the sensor.

ROSS-NAZZAL: Looking back over your years with the main engine, what do you think was your most significant accomplishment for the program?

GOETZ: I am tempted to say there were a lot of accomplishments, significant ones. From an emotional standpoint, the most significant affecting me was the first flight after the *Challenger* accident [STS-26], even though it was no problems. We all were very very excited and very apprehensive because of all, like I said earlier, the 38 modifications that we had made. We had quite a few meetings down at Kennedy [Space Center, Florida], [especially with Frederick H. "Rick" Hauck, the commander] and then the flight readiness review where we had to go through all we did and how safe it is. I think from a personal emotional standpoint the reflight after *Challenger* was to me more exciting than STS-1. STS-1 was exciting too, but I felt the reflight after *Challenger*.

ROSS-NAZZAL: Did you work with the return to flight crew at all?

GOETZ: Oh yes. I knew quite a few astronauts, yes. The astronaut corps always had one guy assigned to the SSME. He participated in all the meetings either here at Marshall or out at Rocketdyne. People like Dick Richards—Richard [N.] Richards—John [E.] Blaha and Brewster [H.] Shaw. Those were all people that I had to interface with. A lot of others, like [Daniel C.] Brandenstein. Yes, they were very much involved.

One of the things, we put a briefing together with movies and charts of all the [major] incidents that we had on the engine. You see in the movie how an engine explodes. Bob [Robert

L.] Crippen insisted that we show and make this briefing to the younger astronauts. I think we scared some of them.

ROSS-NAZZAL: Was this before [return to flight]?

GOETZ: That was after *Challenger*, yes. But he insisted that we do that, just to make them aware how catastrophic a failure can be.

ROSS-NAZZAL: What do you think was the biggest challenge working on the SSME? I know you have lots, but is there one in particular?

GOETZ: It was a great challenge. It was a great [personal and] professional challenge to work on the SSME. My background a little bit. I came here to the country—I worked in Switzerland before I came, and I worked on pumps and turbines for big power plants. So from an engineering standpoint I had quite a background on pumps and turbines, but I had to learn a lot about the other systems on the engine, for example the control system. I was pretty much a greenhorn on the electrical systems, and I had to learn a lot. There were quite a few challenges.

Going back to my background, in Switzerland after I graduated from the university and hired into that company, I had an introduction by the chief of the company. He told me, among other things, that it is the policy of the company to design everything for a lifetime of 25 years. From a fatigue standpoint, design everything for 25 years.

When I transferred over to NASA after I came here, and I attended a meeting on the F-1 engine. I was a greenhorn a little bit on rocket engines at that time; I knew about pumps and turbines. There was a problem with a discharge duct on the turbine. It was a live problem. I asked the question, "What is the design life of this engine?" At that time the program manager turned around and looked at me like "you dummy," and he said, "It's 150 seconds." Based on 25 years I couldn't believe it. That's how much I had to learn. It's quite a transition from stationary power plants to a rocket engine, which is also a power plant.

ROSS-NAZZAL: What brought you to the United States?

GOETZ: Oh, that's a long story. I wanted to go back to Switzerland and make more money with US experience, but I never went back. We had some interfaces with US companies when I worked in Switzerland. For example, we designed the turbines for the Grand Coulee on the Columbia River, the big dam there [in Washington state]. That's 25-year life.

ROSS-NAZZAL: That's pretty good reliability.

GOETZ: Quite a difference.

ROSS-NAZZAL: Yes. Is there anything we haven't discussed that you were hoping we might talk about today about the main engines? I think we've hit pretty much all of the questions that I had prepared.

GOETZ: I think that we touched almost on everything.

ROSS-NAZZAL: All right. Well, thank you very much for your time today.

[End of interview]