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Interview by Virginia Dawson
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My name is Richard Quentmeyer, and I came to Lewis Research Center in 1956 after graduating from the University of Wisconsin. I spent a year here working in Air Breathing area, and then spent three years in the Air Force, and decided to come back after I got out of the Air Force. My first involvement here was at a place called J-Stand up at Plum Brook. And the work we did up there was a rocket test stand. The work we did up there was involved with a nuclear rocket program called NERVA. And we built chambers to simulate the heat flux and the geometry and so forth involved with NERVA engine. So I worked there until 1970 when we decided to move the program to Cleveland. And so in 1970, we finished our testing up at Plum Brook, and then we spent our next couple of years writing reports, digesting the data, etc. Then the nuclear rocket program got canceled for no money. Of course, the space shuttle was here and one of the major problems that the space shuttle had was the failures of the copper liner in the space shuttle main engine. So, what they decided to do is that we should set up some research programs to investigate the characterization of the failure mechanism. So we did that. And that program was earmarked to be at South 40, or the Rocket Engine Test Facilities, as it's officially called.

There are three major programs that I was involved with from 1972 to 1995. I actually spent 33 years with NASA, most of it after I came back from the Air Force in the rocket and test facility. Then I spent another five years in the Rocket Engine Test Facility with a support service contractor. The three major programs that I was involved with down there were the characterization of the materials that are used for high pressure rocket engine liners such as the space shuttle main engine. The other program we did in there which was very successful was to develop ultra thin thermo barrier coatings for rocket engines. And I'll explain a little bit about that later. The third project was the investigation and the characterization and the use of high aspect ratio cooling channels in the rocket engine liners to reduce the wall temperature and to increase the thrust chamber life. As I was saying, the programs that I was involved with the thermal barrier coatings, the materials characterization and the high aspect ratio cooling channels were earmarked for the South 40, or the RETF, rocket engine test facility. And the reason we went into there is the, and I was a research engineer involved, as a research engineer on those projects. And the reason we went into South 40 was the capability of the facility, the A Stand was designed to operate at thrust levels up to 50,000 pounds of thrust. And it had hydrogen, liquid hydrogen capability, gaseous hydrogen capability at high pressure and of course liquid oxygen, and most of our work was done with liquid oxygen and liquid hydrogen. And as a coolant, and gaseous hydrogen as a propellant. So it had very unique capabilities, and that's why we went into that facility. I spent from 1972 until as I said earlier 1995 in that facility doing these three projects.

Now when we embarked on this program, the space shuttle main engine was having problems. The space shuttle main engine liner was the first high pressure rocket engine made out of a copper alloy liner. And the material was called NARloy-Z. It was 96% copper, 3-1/2% silver and .5% zirconium. And as the space shuttle main engines, as they were doing testing down at the Stennis and down at the Marshall Space Flight Center, on the engine, after several cycles, the chamber wall would crack on the inner wall. The engine was originally designed, I believe for 250 cycles. There were periods when they were only getting one cycle and they had cracks in the wall. So, it turned out these cracks were being caused by a phenomenon called thermal ratcheting. And I want to describe that to you a little bit. If we look at the cooling channel, a rectangular cooling channel as it occurred in the throat region of the space shuttle main engine, there would be, I think there were 470 tubes around, cooling tubes, in the cooling jacket. And since the chamber was cooled down to liquid hydrogen temperature which is 410 degrees below zero Fahrenheit, and then when you fired the rocket, it would heat the inner wall up to say 1,000 degrees Fahrenheit. And that cycling through that low temperature and high temperature causes the phenomenon called thermal ratcheting. What would happen, is if this is the inner wall side of the cooling channel, after each thermal cycle, it would start to deform into what we called the dog house. And I coined that term. "Doghouse Failure Mode"– eventually the channel would crack, open up. And so they wanted to characterize what was causing that phenomenon. So we started this program, and to do that, we knew we were going to have to do a lot of tests. And to make a full size chamber, test chamber, such as is shown right here, now this is not the size of the space shuttle main engine. This is a size of another engine I'll speak about later. But in order to do that, we knew we were going to have to use a tremendous amount of liquid hydrogen. So we wanted to devise a piece of hardware that was smaller in scale, yet would give us high heat flux, so that we wouldn't use so much hydrogen, because hydrogen is very expensive.

And so what we developed was this, actually Carl Ackerman, who was my section head at the time, came up with the idea of this piece of hardware here called a plug nozzle. And this doesn't really look like a rocket engine, but it is and it's an inside-out rocket engine. This is a cutaway. This is actually a cylinder, a copper cylinder down here. This is a plug. And the plug, you can see right here, creates a throat right here. The combustion is in here, and this is the injector. The combustion is in here, goes through the throat and then expands on out. So we were able to get a heat flux in the neighborhood of 33 BTUs per inch squared second for those who are familiar with that kind of thermal dynamics. And what we did, is we fired the combustion was with liquid oxygen and gaseous hydrogen. What we cooled, and you can see the cooling channel here, we cooled the cylinder which was our test specimen, actually, with liquid hydrogen. And another unique capability of the RETF facility was that we could burn the hydrogen off up through the scrubber. They had a scrubber that was designed to operate with toxic fuels, like fluorine and RP1 and some of the other rocket fuels. I don't know if they ever used hydrazine[1] down there, but I think it was designed to handle hydrazine.

Anyway, so we were able to burn the cooling hydrogen off the stack. And we would cycle this over and over and over, to simulate that "doghouse failure mode." So the first materials we looked at were just plain copper. And the reason the space shuttle main engine and high pressure engines of today use a copper alloy liner is because of its very high thermal connectivity. You could transfer that high heat flux load that I described into the copper. And the heat is picked up by the liquid hydrogen to keep the outer wall cool and the inner wall cool so it doesn't burn up.

So, we embarked on that and Carl Ackerman, as I said who was my section head at the time, he devised this piece of hardware. We were able to use like $1/7^{th}$ of the amount of hydrogen that we would have had to use in a chamber of this size. The center body was just to provide the throat section in here. We coated this with zirconium oxide to protect this. This was water coolant; that's just dumped down into the scrubber. And when the coating would flake off, we would just take it back to the shop, have it sandblasted, stripped off with the coating off and put a new coating on. We had a whole bunch of these plugs, and we just could change them in and out. But our test specimen was this outer cylinder. Now the materials we investigated were copper, we did NARloy-Z which the space shuttle main engine was made out of. We used a material called half hard Amzirc. It was copper that had zirconium dispersed into it. And we checked that, and then the people from the materials division said that in order to avoid thermal ratcheting, or to suppress it, you want materials that are somewhat ductile. So we actually built an outer cylinder out of pure silver. And we ran that, but it did not last long. It just was too soft. And we actually melted it. But we did make a cylinder out of pure silver. The things we found out, we had all the…a lot of the facilities involved or departments involved here at Lewis, and I'm saying Lewis, because that's where I worked, its now Glenn, of course. We had metallurgy involved. I worked with a fellow named John Kazarov who was a metallurgist. He was in our division, but we used the Met Lab a lot. We also used the people in the structures division. Gary Hulfert is world famous for his work in low cycle thermal fatigue, and Mike McGaw. And we used the people in the thermal barrier coatings department which I will explain later. And, of course, you can't do anything without taking a lot of data in the RAC building. I believe research and analysis facility recorded all our data. We had computer programs written to reduce the data and put it in the engineering units and put it out. We had curves plotted and we got performance information and then with all the data we had, then we could write our research reports.

So, the first thing we embarked on as I said was the characterization of the material failure. Now, we had every one of our cylinders cut up at the throat section, so we could see what was happening to the metallurgy of the material. For instance, the NARloy-Z which the space shuttle main engine liner is made out of, it's a very, very good material because it is in yield (?) condition. It has an ultimate yield of 50,000 psi

[1] Hydrazine: "A colorless fuming corrosive strongly reducing liquid base, used especially in fuels for rocket and jet engines." (Webster's Dictionary).

which is very good for…because copper has a very low yield of about 8,000 psi at 1000 degrees Fahrenheit temperature. So NARloy-Z was a very good material, but what would happen is that as we had this thermal ratcheting going on, the material around that would start to harden and become brittle, and what we would see eventually as we got our doghouse shape, it would eventually snap from being brittle, and we would study the metallurgy. That's why we had to have the Met Lab involved. And we studied the metallurgy and what was going on, and what we could do to improve the materials in that.

So, that was the initial work we did. I was the first. And I got the best paper award at the AIAA conference in 1978 down in Orlando, Florida. I presented a paper on this work with the various materials that we had characterized, and it was quite…I got the best paper award, and I was very happy with the results. And that sort of put us in a new arena at Lewis here in this particular field. So we spent several years writing the reports and so forth on that work. And then the next thing we did was we went into thermal barrier coatings. And in a rocket engine...thermal barrier coatings, and in this case I'm talking about zirconia or aluminum oxide, they have very, very low conductivity. I just described the copper liner has a very high conductivity. Well, the thermal barrier coating acts to prevent the heat from going into the liner and reduces the heat flux as the wall temperature goes up. For instance, this particular coating here would operate in the neighborhood of 3000 degrees Fahrenheit, whereas the copper wall would be operated in the neighborhood of 1000 Fahrenheit.

So we embarked on a program, space shuttle main engine because of its uncoated configuration, the throat section of the space shuttle main engine reached temperatures in the neighborhood of 1000 degrees, 900 to 1000 degrees Fahrenheit, and the heat flux was a hundred BTUs per inch squared second. I told you we were able to generate 33 out of this, so only a third. Now space shuttle main engine has a 10-inch throat. It's big and it's a rather massive engine. It has 400 and it had at the time 470 tubes in it. So, we looked at…in order to use the thermal barrier coating on that, I'll give you a little example. The gas turbine industries used thermal barrier coatings for many years on the turbine blades. Now, they use the turbine blades are made of super alloys, high-strength, nickel chromium steels. And they were also subject to getting too hot. So they put on what was called a bond coat, which was generally made out of the material, mostly what was used was nicroline.[2]

Anyway, in the space shuttle main engine, it required a very thin coating, if you wanted to protect that wall. We're talking about a half a thousandths. In the gas turbine industry they use coatings 20 thousandths, and in the diesel engine industry now uses thermal barrier coatings.

Okay, so we, under contract and using this test hardware here, we built outer cylinders of copper and we coated them with zirconium oxide. And we used nicrol, nickel chromium as a bond, what's called a bond coat between the outer, what's called a

[2] Nicroline: A nickel-chromium alloy used as a plating to protect surfaces.

substrate, the outer cylinder, and then the bond coat and then the thermal barrier coating. So we worked on that under contract and at South 40, again doing the same thing, the cyclic, running the, continuously running the hydrogen, cycling the combustion part on and off just to evaluate the life of the coating, and that work went on until about 1990 in the South 40, or RETF facility. And then we took time out to write our research reports in that.

Then the next thing that came along and I'm going to go over here is this particular cylinder here was used also for low cycle thermal fatigue work, but it was also used in the coatings program. Ned Hannum and Harold Price did work in the South 40 area using this particular configuration here. Now the thing that we did, we went into looking at high aspect ratio channels. And what I mean is instead of the channels being sort of square like this, the channels will be very tall and narrow, and which created, these are called ribs here. And then we would have many, many, many ribs. And it would increase the heat transfer, lower the wall temperature in the throat by a considerable amount. So again we used this particular piece of hardware here. And we had chambers made up with as many as 400 channels in this little 2.6" diameter cylinder. The space shuttle main engine had a 10 inch throat and it had 472 tubes, but we were able to put as many as 400 in this. But the ultimate configuration we did had a ten-thousandths-thick wall and a ten-thousandths-thick cooling passage. It lowered the wall temperature significantly. The normal operating temperature was a 1000 degrees Fahrenheit. We were able to lower it down to anywhere between 400 and 600 degrees Fahrenheit, dramatically increasing the life. So we did a lot of tests with this little configuration here, and then we wanted to validate that work. And the way we validated it, we used…this particular chamber here is a chamber that was designed by Rocketdyne in the early '70s called the Advanced Space Engine, and it was an engine that was going to be used to put satellites up in the high earth orbit. And that... although that was never built, we used their inner contour, and as I said, we used the ASE, but it was the advanced space engine was the research work that was done at that time. They had a 400-to-1 nozzle, expansion ratio nozzle on that, and those engines were tested out of Santa Susana. But what we wanted to do is to validate our work on the high aspect ratio cooling channels. And so what we did is we used the ASE contour, and built up this rather robust chamber. This particular chamber here has 100 channels up in the combustion region, 200 channels in the throat region, and then it goes back to 100 channels in the nozzle region. So this was done. We built this up, did all the analysis work in the early 90s on this. This was finally tested in 1994 I believe. And we demonstrated their big reduction in the wall temperature. And the life increased, this particular engine, you can't see the inside, but this particular engine experienced no thermal ratcheting, and it was tested for hundreds of cycles, because the wall temperature was reduced so much. And we tested this at like 2000 psi chamber pressure. The space shuttle main engine was 3000. But we were able to get very high heat flux in the region of 65 to 70 BTUs per inch squared second. About two-thirds of the space shuttle main engine. What we demonstrated was that with the use of high aspect ratio cooling channels, you could greatly increase the chamber life. And today, all modern rocket thrust chambers, what is called the thrust chamber assembly, and that's this part down here before the nozzle. The nozzle is a separate piece, all of them are using a copper-based alloy now with high aspect ratio cooling channels in their designs.

The results of the work from the high aspect ratio cooling channels is now being used throughout industry, Rocketdyne, Aerojet, Pratt-Whitney, all are still involved in the rocket engine business. TRW is involved too. Everybody is now using high pressure rocket chambers with copper alloy liners and they all now incorporate high aspect ratio cooling channels to prolong the life. It is a very, very remarkable and dramatic improvement in life using that concept.

So after we finished that work...I've got to stop here. One of the other projects I was involved with in the South 40, or again, the Rocket Engine Test Facility was the B Stand. Now, I was not involved as a research engineer in the B Stand. The B Stand was designed and built to test rocket engines at very high area ratios. And the reason you need, upper-stage rocket engines need, the very high area ratio in order to get specific impulse that's a measure of performance, to get the best performance out of it. So we were doing work, I should say the group that was involved with that was doing work with nozzles. They wanted to get research data on nozzles that had an expansion area ratio. By that I mean, the area of the throat of the rocket engine to the end of the nozzle. And, nozzles, or engines that operate in a vacuum, which would you need if you are deep space or high earth orbit, require very high area ratios in order to get the maximum performance out of the engine. So, where we were going to run a rocket engine, where you had exhaust gases that were 5000 degrees in temperature, and so the B Stand was built. And what you do in a rocket engine that has very high area ratio, it has to operate in a vacuum. So right here is a nozzle that was used in the B Stand, and I will just use this right here as the rocket engine that, the thrust chamber that goes on top of this. This is where your combustion would be performed, here is the throat section where it switches from subsonic to supersonic, and then the expansion occurs in this large nozzle.

My involvement with the B Stand was not as a research engineer but the design of the facility. I designed the, in order to create this the chamber had to operate in a vacuum. In order to create a vacuum, one of the things that is used in the rocket industry is what is called supersonic diffusers. And these diffusers can be driven by steam or by nitrogen. And in the case of South 40, these were nitrogen-driven diffusers. Well, since you have exhaust gases that are in the neighborhood of 5000 degrees, this diffuser has to be cooled, and so I designed the, with my aerodynamic background, I designed the aerodynamic configuration, and the cooling channels of the cooling jacket for the supersonic diffuser. The diffuser was cooled with water, and that was my main involvement with that facility, was the design of the supersonic diffuser. And the particular nozzle or chamber that went on top of this was just a little combustion chamber that had a one-inch diameter throat. And this was expanded then out to 1000 to one. And so that was the purpose of the B Stand is to be able to operate rocket engines at a very high expansion area ratio in a vacuum which was required.

Getting back to some of the things that occurred in the South 40 facility, from time to time when we were doing work in there, especially when we were doing the low cycle fatigue work, we would get a massive hydrogen leak in the facility, and that would, during our cycling, the torch might set that off, and we would blow the entire roof off of the facility. Now the roof was made to blow up and then be put back together. They were fiberglass panels. In some cases, we blew the engine right off the stand, and people were saying, "Where did it go?" And then the next day the technicians would find the pieces of the rocket engine, or actually in some cases the whole injector out across the valley, and so we had a few situations like that.

I remember one time, and this is going back to when we operated Plum Brook, we blew an engine off the stand, and we were looking at it. We were running at night, and we were looking at the TV, "Where is the engine?" We had this gigantic explosion. We looked at the engine, and we’re looking at it, couldn't figure out what was wrong, the engine, all that was there was the injector. The steel engine that we were using at the time was blown into a million pieces, and they went out the next day with a broom to sweep up the pieces. So we had things like that. There were other things you have to be concerned with at a facility like that. There can also be dangers involved. We had one of our dewars[3] down in a pit, which had liquid nitrogen in it. And then when there would be nitrogen fumes in there, if somebody climbed down into there, they either had to be wearing a respirator or only stay down there for a few minutes, because they could get asphyxiated. So we operated in a high pressure rocket engine facility, even though with things like hydrogen and oxygen which forms water when it combusts, you still have to be concerned with the safety of everybody in the facility area.

This piece of hardware right here, you can see the ribs in here. This is a high expansion ratio nozzle that was tested in the B Stand, in the Rocket Engine Test Facility. This particular nozzle, the ribs are open here now, but this particular nozzle is cooled with water. And they used a copper heat sink chamber for the combustion chamber part in the throat part. This particular nozzle I believe had a thousand to one expansion area ratio. When I was describing the work that was done by Rocketdyne, with this particular contour, oh, well, you can't see it, so... This particular chamber here is another chamber that was used in a low cycle thermal fatigue, and this is operated at very high chamber pressure and with this kind of configuration, although not this big, would fit on top of this nozzle over here. And this is just a nozzle here, not the combustion chamber part.... This is a copper liner that was used in the thermal fatigue work to characterize thermal ratcheting during cyclic testing of high pressure rocket engines. Again, this is just the liner itself. You can see the open cooling channels here. This would be closed out with nickel. And to contain the coolant inside the chamber.

[3] Dewars: Containers used to store and dispense small quantities of liquid nitrogen.