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INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is April 22, 2014. This interview with Stan Bouslog is being conducted for the JSC Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Sandra Johnson. Thanks again for taking some time out of your very busy week to meet with us and talk about the Arc Jet. Looking forward to it. Give us an overview of your career at JSC, and how you came to be associated with the Arc Jet.

BOUSLOG: I first moved down to Houston and started working in the Houston area, I think it was 1988. I had graduated from school at the University of Texas [Austin] with a master's degree, and actually worked for Tracor Aerospace, up in Austin. I'd worked there for about five years, and they, like most other places, were doing defense work. They were filing for bankruptcy, and so I thought, "Well, okay, maybe it's time to move on." My professor at the University of Texas, Dr. John [J.] Bertin—he had some contacts down here at NASA Johnson Space Center. I contacted them and asked if they had openings. They brought me down. It was actually through Lockheed Martin, who had the engineering support contract for NASA. I was interviewed and got the job, and it was in the area of aerothermodynamics. One of my first mentors was Carl [D.] Scott. Carl Scott was at the Johnson Space Center, and part of the work I was doing for him was associated with the Arc Jet facility. Most of it was looking at the lifespan changes of the ceramic tiles that were on the Space Shuttle Orbiter. You remember, at that time period, we were just starting to get back to flight after the *Challenger* accident [STS-51L], which happened in 1986. This is the end of ’88, when I came in.

ROSS-NAZZAL: Tell us why you were looking at the life cycles of the tile. Hadn’t that been proven in the seventies?

BOUSLOG: Not really. Every time you fly in space and come back, you learn. We were learning, still, with the Space Shuttle Orbiter; we were still learning how to operate that vehicle. The intent was to have it fly—each one of the Orbiters—at least 100 times. We didn’t have a lot of information on what would happen to all these tiles which are part of the thermal protection system and how long they would last, or how they would change over that many uses. Obviously, we had some history already because we’d gone through a few flights, but we didn’t know if they’re going to last 100 flights or are things going to change. We started looking at especially the surface properties of the tiles. We were concerned about how they may degrade, over time, and technical things such as emissivity and the catalycity of the tiles specifically. That was one of my first tasks when I came here, to start looking at that. It included using the Arc Jet to expose those tiles to the simulated re-entry environments.

ROSS-NAZZAL: Had you used an Arc Jet facility before coming here?

BOUSLOG: No, I had not. I’d done quite a bit of wind tunnel testing, flight testing, as a matter of fact. I did wind tunnel testing at University of Texas, and actually at Texas A&M [University, College Station]. I’d use their wind tunnels mostly in support of Tracor Aerospace, when we were developing airborne counter-measures, but I had never used an Arc Jet. I'd done re-entry survivability analyses, because I had a lot of background in aerothermodynamics and hypersonics at school, so I'd looked at the survivability of objects re-entering Earth's atmosphere from space. I'd looked at that analytically, but as far as an Arc Jet specifically, no, I did not have any experience.

ROSS-NAZZAL: How was it different from using a wind tunnel?

BOUSLOG: Wind tunnels tend to be better characterized. The flow tends to be more uniform. There's a lot of systems that have been set up over the decades that people have been using wind tunnels to actually understand the flow field which you're exposing your test article to. Not so much with an Arc Jet, and, of course, the energy levels are so much higher. Wind tunnels, some are subsonic, some of them are supersonic, some of them are hypersonic, but you go to an Arc Jet and you're talking megawatts of power. The power level is much, much higher, and the flow fields are not well characterized. You're not quite sure what you're exposing your test article to.

ROSS-NAZZAL: That's quite a change.

BOUSLOG: Yes, it's a big change. The other part of it, too, is that your options for determining or characterizing that flow field are much reduced, just because of the survivability. You cannot stick everything in the flow field and expect it to survive; it won't. There's many a time when we stuck probes in, and there was not adequate cooling water or somebody forgot to turn the cooling water on. Of course, then you lose the probe or whatever very quickly. Water leaks generate snow cones in the Arc Jet. There's a vacuum chamber, so you dump a lot of water in there and generate snow.

ROSS-NAZZAL: You generate snow?

BOUSLOG: Yes.

ROSS-NAZZAL: I wouldn't think that [was possible].

BOUSLOG: Yes, you can get a lot of it real quick.

ROSS-NAZZAL: How does it generate snow?

BOUSLOG: Just because it's a near-vacuum. We don't get down to vacuum, but we get very low pressure in the test chamber, and then you dump water into that and it wants to expand very quickly and cool off the water. So it just freezes. You get little particles of ice everywhere, so it sort of looks like snow.

ROSS-NAZZAL: That's interesting because, when I was listening to everyone [at the videotaping], I thought you went up to about 3,000 degrees.

BOUSLOG: Right, when the arc's on, that's correct. Of course, that's only in the core of the flow field, and the 3,000 degrees Fahrenheit, that's not even real high temperatures for an Arc Jet.

That's actually surface temperatures. The flow field itself is much, much higher. Unfortunately, we always use inconsistent units, but we usually talk about 5-10,000 degrees Kelvin in the actual flow field itself, where the test articles are placed. We shy away from temperatures after a while because temperature is just a measure of your energy. It's very confusing and not very accurate to talk about temperatures when you get to real high temperatures. The reason being is that a lot of chemistry goes on. Now, a lot of energy is tied up in the disassociation or even ionization of the gas, so it's not real accurate to talk about temperatures. We shy away from temperatures, except for surface temperatures, of the test articles. There, yes, we still talk about it. Even that's very difficult for test articles that ablate, that change state, but we still try to get a measure of the surface temperatures but it's much more difficult.

ROSS-NAZZAL: Any memorable tests when you were working with Carl Scott?

BOUSLOG: Yes, we did a lot of testing. I think there was some reluctance amongst some of the folks that operated the Arc Jet to do a lot of diagnostics of the flow field, to better understand the flow field—part of it because they just didn't understand that. So, myself and Carl Scott really helped moved that along to get all sorts of diagnostics in there. When I talk about diagnostics, first of all, we looked at pressure probes and heat flux probes that we would sweep across the flow field, so that we'd understand what the flow field would look like. A lot of times, it would have a lot of gradients in it, the pressure gradients and enthalpy gradients. By sweeping those probes across, we would have a better understanding of that. I remember specifically some runs where we had heat flux probes in the flow field, and somebody forgot to turn the cooling water on. You'd start the test and insert the probe, and it was gone pretty quick. Everybody would be looking at each other, going, "Okay, that was not good." There was a few times when that happened; those are sort of memorable times.

ROSS-NAZZAL: What did you learn about the tiles from your tests out at the Arc Jet?

BOUSLOG: It was really complicated. We did a series of tests in the Arc Jet, and we saw some degradation, but it was sort of within the noise. So we really didn't come up with conclusive evidence that we were seeing any degradation of the performance of the tiles with the tests that we did. There's another parameter called emissivity that you also take a look at, and that's how much radiation comes off the surface, re-radiated from the surface. You'd get some evidence that at some of the temperatures we were getting a reduction in emittance, which could cause your surface temperatures to rise a little bit, but it was not a big issue for us.

ROSS-NAZZAL: You mentioned you were using different probes—was this when you designed the mass spectrometer probe tip?

BOUSLOG: We did do that, also. The intent there was actually to try to get measurements of the species concentrations in the flow field itself. Like I said earlier, when you expose these gases to an electrical arc, then quite often, you disassociate the gas. For example, nitrogen and oxygen molecules get disassociated into nitrogen and oxygen atoms. The problem is, you don't know how much, and of course, you don't know if nitric oxide—you don't know how much of that there is, either. A lot of chemical reactions going on, very high temperatures, so you wanted to get an idea of the exact quantities of these different species there was in the flow field.

We did get with a company and started designing a mass spectrometer. The intent for that was actually to extract some of the flow field. You can imagine, you've got an extremely high temperature gas, and now you're trying to stick a probe in there and pull off some of that flow, some of that gas, and then measure its species concentration with the spectrometer. We did generate lots of snow. You can imagine, you're very susceptible to water leaks, over-temping various parts of the hardware. That process actually was not working very well, and that was, I think, one of the lessons learned was that we never really got good data out of that. We got some, and we really pretty much abandoned that mass spectrometer. What we did do, then, was we turned to laser diagnostics, which is much better in the sense that it's non-intrusive, which means that you can actually get a measurement without putting something in the flow field.

We used a laser-induced fluorescence. Carl Scott and another man, Dr. Sivaram Arepalli, were very instrumental in starting that at NASA JSC. I was helping them, mostly on the analytical side, but they were very, very good about setting up the instrumentation and getting the hardware, the lasers, et cetera. Again, the intent was to do various measurements of the flow field. They were getting velocity measurements very early on, and then they were trying to get atomic oxygen concentrations measured. Over the years that system had been developed and, up until just recently, we were getting good data out of that. We called it a LIF system, the Laser-Induced Fluorescence System. We transitioned to that system and pretty much gave up on the mass spectrometer.

ROSS-NAZZAL: Is this system going to be used in a different facility, or is it also going away with the demolition?

BOUSLOG: Pretty much it's going away. NASA Ames [Research Center, Moffett Field, California] had had one of these LIF systems, previously. They pretty much dismantled it. We have requested that they resurrect it, and so, to our understanding, that is in process. There was a lot of work done from about 2006 to about 2009, where both JSC and NASA Ames were co-developing their respective systems in both of their facilities. We made a lot of progress. I'm not sure why NASA Ames abandoned theirs, but since that time, since ours is going away, we've asked them to resurrect theirs. I do not know the status of that, but apparently, they are going to do that, at least in a couple of their test positions.

ROSS-NAZZAL: You've given some examples of what I think are technological developments as a result of the Arc Jet. Are there other ones that come to mind?

BOUSLOG: One of the things we often talk about is missions to Mars. Of course, we've sent Rovers there, we've sent probes to Mars, but of course, we also, at some point, would like to do a crewed mission and let humans set foot on Mars. The problem with that is, of course, you have to enter the Martian atmosphere, which is carbon dioxide. We have never really tested our thermal protection systems in carbon dioxide. We're all pretty much convinced that if we're going to send humans to Mars, we better have much more confidence in our thermal protection systems than we do today. To do that, we would have to test our thermal protection systems in a carbon dioxide-based re-entry atmosphere. What was done just a couple of years ago at NASA JSC is we developed the techniques and the capability to actually test with carbon dioxide in the Arc Jet.

There were several issues associated with that, a lot of them safety issues. There's also a lot of nitrogen there. The Mars atmosphere is a little bit nitrogen, but mostly CO_2. We were running about 10 percent nitrogen and the rest CO_2. For example, if there's various concentrations of carbon monoxide, if you get that, that can be an explosive mixture. Obviously, we didn't want that to happen; that's mostly in the heat exchanger, downstream of where the Arc Jet core is. We had to monitor the species in the diffuser and the heat exchanger, and make sure we were not getting close to those concentrations.

The other issue was the formation of cyanide, since, again, you have carbon dioxide and you've got nitrogen. You can form cyanide, and we were concerned about that depositing on all the hardware in the test chamber. We had to slowly work our way up. After every run, you'd call in the safety folks, and they'd go in, in their bunny suits if you will, and wipe things down and look for traces of cyanide. In combination with that and with the gas analyzers that we put in the chamber to look for the carbon monoxide, we slowly developed that capability to test in carbon dioxide, which to me was one of the first times we'd done that especially the power levels that we were testing at. We were testing at 2-3 megawatts of power and getting heating rates on 4-inch diameter models of a couple hundred watts per centimeter squared. That was really a technological development that we did recently that's sort of gone unpublicized.

ROSS-NAZZAL: Why do you think that's the case?

BOUSLOG: Not sure. I guess part of it's because our plans for NASA going to Mars are not really very detailed or set in concrete, and so I guess maybe it was before its time. If we had been earnestly working towards a mission to Mars, people may have been more aware of this capability.

ROSS-NAZZAL: Any other technological developments that stand out?

BOUSLOG: No, not the ones that I can say that really stand out. There's all sorts of minor ones. The people at the JSC Arc Jet facility were very good about modifying the arc heaters, et cetera, to get them to generate environments that we were looking for, as test engineers. They really looked for flexibility in the hardware and trying to get the capability to change things quickly to produce the test environments we were looking for. Again, people wouldn't say it ranks up there real high as a technological advance, but it was very important to us to be able to have that flexibility in the test hardware.

ROSS-NAZZAL: That building was open in '67, and you start working out there around '88. Have things changed over time? Do things look different since you started working out there?

BOUSLOG: Yes. While I've been involved in that Arc Jet, they actually did install a new test chamber. That was a big event. I think it was, I forgot, exactly, right around 1990. Right around there is when they installed a new test chamber. That gave us a lot of capability, to have that bigger chamber, so that made things look a little bit different. Then, the addition of the laser block house for the LIF system, the Laser-Induced Fluorescence System, that was added on. Over time, yes, things changed a little bit. The basic high bay there and, of course, the one test chamber was the same one that was there when I arrived.

ROSS-NAZZAL: It's an interesting building, when you walk in and think it's been there since '67.

BOUSLOG: Right, and of course, the control room's changed quite a bit. There's a few things that are very similar to back in the late eighties, but a lot of the control systems have been upgraded. You start going to your LCD [Liquid Crystal Display] monitors, as opposed to the old CRT [Cathode Ray Tube] monitors, et cetera. A lot of that had been upgraded over the years, little by little. You notice that, especially if you're sitting in the control room during a test.

ROSS-NAZZAL: Did things change in terms of testing, or have they pretty much been consistent since you've been there?

BOUSLOG: When you're operating a very high-power facility, there are safety issues. There's always this balance of taking risks but being safe, and sometimes the safe part would take over so much, it would constrain us. I think over the years, we've gotten a pretty good balance of that. There'd be times when I think they would go a little bit too far because the paperwork, et cetera would slow us down so much, we couldn't get tests done quickly, for example. That's good. You have to balance that. You want to get your testing done, and you need to do it in a timely manner, but you also have to protect people. Protecting the people, I think, was always very important, was forefront in everybody's mind.

Sometimes, they also were worried about the hardware, protecting the hardware, but in these type of tests, hardware is going to get damaged. You don't want that to happen very often, but sometimes, you have to risk that happening. Sometimes, they were a little bit too worried about hurting the hardware, and people would get upset. They felt like they had been chastised or whatever because a test article was destroyed. It may or may not have been through any negligence of themselves, it just happens. You don't want to degrade people because that happens. Test articles were sometimes expensive—$100,000 for a test article, sometimes—especially when we were doing Space Shuttle Orbiter testing. Sometimes we'd have a failure in one of the systems during testing, so we'd lose the test article.

ROSS-NAZZAL: Could you actually re-use a test article that was $100,000?

BOUSLOG: Some of them. The one I'm thinking about, no, we couldn't have. It was damaged too badly. Some of them were. That's one good thing about the Space Shuttle Orbiter tiles, of course, they were built to be reusable, and so we could quite often get multiple tests off one test article. Sometimes, we were testing large arrays of tiles, about 2 foot by 2 foot, so there's a lot of tiles there. There's a lot of instrumentation, and there's a lot of labor that goes into building that test article. Sometimes the test articles could be pretty expensive, and you could damage them.

ROSS-NAZZAL: Wow, I had no idea. I was just thinking they were those little hockey pucks that we saw.

BOUSLOG: There's some like that. We call them stagnation testing, but over in test position one, we tested arrays of tiles. Some of those were on the order of 1 foot by 1 foot; others were 2 foot by 2 foot. We did a lot of testing with that, and actually I helped do a lot of that testing. That was associated with the Return to Flight after the *Columbia* accident [STS-107]. We were looking at damaged tiles and what could they tolerate, because we all know that we were getting hit by material coming off of the external tank, or, sometimes, the solid rocket boosters during ascent. Because the tiles were delicate, and sometimes there was ice, also, but between the foam or ablators or ice that would come off during accent, they would impact the tiles and damage them. We were very concerned about what was the tolerance of damage that the tiles could handle. The only way to do that was actually to run lots of Arc Jet tests on all sorts of different types of damages, and then build a thermal model that could validate through these tests, so we could evaluate each and every damage that happened. That was a large part of what we did in Return to Flight, after the *Columbia* accident in 2003.

ROSS-NAZZAL: What sort of damage did you simulate? How large were the chunks?

BOUSLOG: Small ones were on the order of an inch square. Some of them were probably almost an entire tile, so that's a 6 by 6 tile. We would look at large damages. Also, what we'd look at is the repair techniques for repairing those tiles, which we developed after the *Columbia* accident. Those capabilities were carried on board the Space Shuttle Orbiter in flight, so in the event that it was needed, we would actually ask the astronauts to go out on an EVA [Extravehicular Activity] and repair the tiles. After the accident, we set up what we call a Damage Assessment Team, that was the DAT team as we call it for short. There were quite a few people; it was mostly USA [United Space Alliance], Boeing, and NASA folks that were involved in that. What we did was after launch and the ascent, during the approach to the Space Station, lots of photographs of the Orbiter were taken and downloaded to the imaging folks here at JSC. They would go through with a team of TPS [Thermal Protection System] folks and look at all those photos to look for damage.

The other thing, of course, we did is put the Arc Jet on standby. If we had to go test anything, we were ready to go. We had generic test articles ready to go, and as a matter of fact, in some of the flights, we had to execute the Arc Jet tests to evaluate damage or repair. Most notably, we did that in STS-117, when we had a blanket come up off the OMS [Orbital Maneuvering System] pod, and also during STS-118, when we had ice damage to a tile on the belly of the Orbiter. We knew we were in trouble when we first saw the photograph, because we saw red. Red is the RTV-560, which is the adhesive that bonds the tiles to the Orbiter. If you look in the damage and you're seeing red, that pretty much means the damage goes all the way down to the bond layer. That's bad.

We were very concerned about that damage, and so we took out generic test articles. The crew on board the Space Shuttle actually went out there with their scanner, a laser scanner was on the arm, and scanned that damage, so we had good geometric measurements of the damage. Downloaded that to us, and then we sent that information over to the machine shop here, and they actually simulated that damage in several tiles. We went and tested them in the JSC Arc Jet, and then, of course, we used our analytical tools to assess those to determine whether they were safe to re-enter without any repair, or if they had to make a repair to that damage.

ROSS-NAZZAL: Do you think repair would have worked? It's my understanding that they never ended up using that capability.

BOUSLOG: Right, we never did use it. We had enough testing under our belt that we thought yes, it would work. There was a DTO [Detailed Test Objective], where they actually had a dispenser that the astronauts would use, and a little gun to inject—essentially, it's like an RTV-like material—into a hole, a cavity of a tile. We did get a DTO on orbit so they actually had, in the back payload bay of the Orbiter, a tile array with some real damage. We actually shot some particles at a tile, and then just bonded it to a plate, so we actually had some real damage. That was taken up on orbit, and then the astronauts, during the EVA, took out the repair kit and repaired those tiles. Then, they cured on orbit. They brought those tiles down, when they came back from their mission, and we actually tested some of those tiles in the Arc Jet. That was pretty much the final test. We said, "Hey, yes, we really think we're good to go as far as having the capability to repair those tiles, at least for small damages, up to the size of an entire tile."

ROSS-NAZZAL: Really?

BOUSLOG: Yes.

ROSS-NAZZAL: Were you involved at all in the investigation prior to the Return to Flight?

BOUSLOG: Yes, that was 2003. I had left this area in 1996. I'd left Lockheed in '96, went to Goodrich Aerospace in California and worked on the X-33 program. Unfortunately, that was canceled in the year 2000, and so I moved back here to Houston, so I returned to my old job at Lockheed. I was working on the X-38 program, and, unfortunately, that was not going well either. I remember specifically, just before the *Columbia* accident, when things were not looking good. The X-38 looked like it was going to be canceled, and they were trying to cut back people supporting Space Shuttle Orbiter. Then, the accident happened on February 1, 2003. I remember that really well because that was a Saturday, and we immediately got called in, a bunch of us. The first thing that we were asked to do is to help them locate the debris from the accident. Then I supported the aerothermodynamics team to help figure out the failure investigation, about what exactly happened.

The big breakthrough that came for us was when they found the MADS [Modular Auxiliary Data System] data recorder, almost intact, just a dent in it. Don't know how that happened, you just imagine a data recorder showing up in East Texas in some grassy field. They found that. They extracted the data from that, and that gave us a lot of information of what happened. We got those data [points], and we started piecing together what could have happened. One of the things we found out was that the spar had been breached with hot gas coming in, and probably severed some lines, some electrical cables. To test that theory, we actually fired up the Arc Jet and built some hardware. The spar on the Orbiter is aluminum, so they had pieces of aluminum and we would expose them to the Arc Jet and see how long it took to generate a hole through that. It had the model of the electrical cables behind that, to see how long it took to melt through all those cables.

We very quickly generated all that hardware and got them tested in the JSC Arc Jet to support that investigation, to support some of our theories. That went on quite a while, and we had a lot of informal meetings with the CAIB, the *Columbia* Accident Investigation Board and would brief our results to them. It was a combination of Arc Jet testing and also analysis. We did a lot of analysis, looked at the ingestion of the hot gases through the wing leading edge, the various holes, where it would go, and how it would impinge on the insulation and in the spar:

the whole story of the failure propagated, to the point where we lost the Orbiter. It was really a serious time. It's hard to explain to people. I think all of us look back—we were all very depressed about the accident, but we all worked very hard and enjoyed our work and thought it was our responsibility to find out what happened. It was shortly after the accident investigation that then I was hired on as a civil servant at NASA JSC.

ROSS-NAZZAL: That's good news.

BOUSLOG: That was good news for me, yes. It was good news for me, but as I tell my kids, seven people had to die for me to get a job at NASA. You think about that. I don't know. If that accident had not occurred, would I have gotten a job at NASA? I don't know. I just don't know. I couldn't tell you yes or no, but I know that my participation in the accident investigation was one of the reasons that I did get a job.

ROSS-NAZZAL: If I remember correctly, on the first Return to Flight, Eileen's [Eileen M. Collins] flight, there was more damage to the tile.

BOUSLOG: It wasn't so much damage to the tile—there was a gap filler that was hanging out on STS-114. I forgot how many tiles—there's like 20,000 tiles on the Orbiter, something like that—but between quite a few of those tiles, there's obviously gaps between the tiles. In some areas on the vehicle, you don't need to fill those gaps, but there's various reasons when you have to fill the gaps. During installation, for example, there will be gaps that are larger than are acceptable, so they have to fill them with something. They used what they call gap fillers.

There's other regions of the vehicle where there's high pressure gradients, so all the gaps are filled, because they know that those high pressure gradients can result in the very hot gas getting down in the gaps between the tiles and over-temping the structure. Over the years, we'd have lots of gap fillers installed on the vehicles. Unfortunately, we also had lost lots of gap fillers during flight. Sometimes, even on landing, they'd find them on a runway.

We knew we were losing them, and I guess the processes for installing them had not been revisited. We also knew that if they did stick out or come out during re-entry, they could trip the flow field or the boundary layer. When you trip the boundary layer, it transitions from laminar to turbulent, and turbulent boundary layer is much hotter than a laminar boundary layer, so everything downstream of that trip, that protuberance sticking out, which is gap filler, can get very hot. We knew this has been happening for years. My first involvement with that was on, I think it was STS-50, when we saw what we called early boundary layer transition. That may have been caused by a gap filler. In that particular instance, the reason we knew it was that one side of the Orbiter had transitioned before the other side. It actually caused a moment on the vehicle, and the pilot had to go in and correct for that moment and was surprised by it. Nothing crucial, nothing critical, but people wanted to understand it.

We did start investigating that in the nineties, so we did start looking at the boundary layer transition. It was just something we ended up living with. When we got to STS-114, we saw this big gap filler hanging out when we did our on-orbit inspections of the photography, and the quick analysis that was done was saying, "Hey, we may be causing some problems of heating to the wing leading edge." Everybody was very sensitive to that because we had just lost a vehicle due to an impact actually to the wing leading edge. Not that we had an impact, but we certainly didn't want to overheat it and over-temp the hardware. There was a lot of consternation on what to do, so they did send out an astronaut to go pull that gap filler out. Of course, you can imagine, that was the first time ever that an astronaut was sent on an EVA out on the belly of the vehicle, and you're just in a sea of tiles, so it can be sort of disorienting. The gap filler was actually very easy to pull out, and he did. [Stephen K.] Robinson was the astronaut who actually did that. He pulled that out and brought it back, a matter of fact. That was the big issue.

There was actually a blanket that was damaged up towards the crew cabin. They were also concerned about it coming off. It was obviously by the window, by the crew cabin. The concern there was that that blanket would detach itself during re-entry, and then go back and hit, for example, the vertical tail or the split rudders there. We actually did do some wind tunnel tests with damaged blankets to see if we were going to lose them. Of course, we also did some impact tests to say, "Okay, what if it does come off? What's going to happen to the rudder?" We convinced ourselves, after doing all that testing, that we could just leave it alone and we'd be okay, and we were, even though it got sort of torn up. …

ROSS-NAZZAL: Wow, that's pretty cool.

BOUSLOG: Yes, there were two things that happened on STS-114.

ROSS-NAZZAL: You guys were running those tests, you mentioned?

BOUSLOG: Yes. In that particular test, we really didn't need the Arc Jet, even though it was still there. If we needed it, we were going to use it. After that, with the gap fillers, there was a big push to go in, first of all, to work on a better method for installing the gap fillers, and then to pull the old gap fillers and install them with this new technique so that they wouldn't come out. There was regions of the vehicle that we started identifying, of which ones were critical to get done. Then, of course, we had more than one vehicle to do that to, so you had to work that within the flow between flights. We were going in there, and the KSC [Kennedy Space Center, Florida] folks were going through and pulling the old gap fillers and putting in new ones, using a new technique. With the new technique, I don't think we ever experienced one coming off, not that I remember.

ROSS-NAZZAL: With the Arc Jet, you were testing which gap fillers were most significant?

BOUSLOG: Yes. We did a little bit of testing in the Arc Jet, but not a lot for that. We still had specifications where we knew we needed to have gap fillers in certain regions, and so we weren't going to change those specifications. It was more developing the technique for installing the gap fillers, such that there were going to stay there. The problem was, you can imagine, it's a thin piece of ceramic material, and you're putting some adhesive on the thin edge and then trying to slide it down a gap, so you're not getting a really good bond. A lot of times, what would happen is the RTV-560 adhesive would just slide off as you were sliding it down the gap. So by the time you got it down to the surface, to the structure, there was no adhesive left. You were getting more of the RTV on the sidewall of the tile, and of course, during re-entry, that would heat up. The adhesive capability would just go away. They had to develop a different technique so that they could get a good bond down towards the bond layer, down towards the structure. They did, but it's a very painstaking process, to go in there and start pulling the old gap fillers and putting in new ones. They did do that, after 114.

ROSS-NAZZAL: How did operations change out at the Arc Jet as a result of the *Columbia* accident?

BOUSLOG: One thing was that first of all, we got what we called generic test articles built, and we had a cage where we kept all of those, and a lot of TPS supplies we kept. We had a lot of hardware that was actually dedicated to supporting flight. The other thing, of course, right before flight, we would make sure that everything was operating fine in the Arc Jet. We wouldn't suspend testing; we would just not do any risky testing because we didn't want to damage the facility. Then, of course, put people on standby to say, "Hey, you could get called in," and that was engineers and technicians. Of course we did several times, and usually people were put on around the clock, 12-hour shifts, so we had crews supporting the Arc Jet. If there was an inkling that something was going wrong, then we'd start manning the Arc Jet facility, just getting preparations.

There's a few times, I don't remember the specifics, where we would actually get some test articles ready, put them in, install them, and get ready to do calibrations. That's always the first thing you do in an Arc Jet test is do a calibration to get the test conditions you're looking for, before you actually expose the real test article. We would do that. We would get the technicians, et cetera, ready to go; we'd get the test articles ready to go. Sometimes install the calibration models in the facility, and maybe do a couple of runs to support a flight, just to make sure that we were ready to go if needed.

ROSS-NAZZAL: This continued all the way to end, through [STS]-135?

BOUSLOG: Absolutely, yes, absolutely.

ROSS-NAZZAL: How did you report—you did a test and here is your findings—did you go to the Mission Management Team [MMT]?

BOUSLOG: Yes. I mentioned earlier, the Damage Assessment Team, the DAT team; all the Arc Jet testing was coordinated through the DAT team. The results of the Arc Jet test, then, would be included in the Damage Assessment Team report and reported out to the MMT.

ROSS-NAZZAL: Did you ever have to go to any meetings?

BOUSLOG: We had to go quite often. The way we're operating there, Boeing was actually the lead from engineering for the thermal protection system. The subsystem manager at Boeing was essentially the head of the DAT team. He was the person that usually did the briefings to the MMT. So it was usually a Boeing person or a USA person, and usually, we were there as backup, the NASA folks. There was a couple of times that myself and others had to go in there and just support them.

ROSS-NAZZAL: Any memorable discussions that you recall?

BOUSLOG: Some of them you probably don't want to admit.

ROSS-NAZZAL: You don't want to put those on the recording?

BOUSLOG: Somebody could do some sociological study of it. Groups of people can work very effectively together, but sometimes they joke around. People on the outside, if they heard that, they'd think that's not appropriate. It's just the way people work together, and it didn't degrade or deter from their capabilities. We would try to get people to say certain phrases, even during an MMT, just joking around. It's not a matter of disrespect, it was just the way people handle crises sometimes. We did that also; we would go in there and joke around, and just the way some people handle stress and crises.

We had a good team. We had lots of food in our DAT room, [which was] very close to Mission Evaluation, the MER. We were always notorious for having lots of food there, and the big bosses, [N.] Wayne Hale and Bill [William H.] Gerstenmaier would come by and eat some of our food. We'd talk to them, and they probably also wanted to come and find out what was going on. That was really, I think, good and exciting times. It was a good team of folks; they all did their job very well, even though we joked around.

ROSS-NAZZAL: You had mentioned you worked on the X-38. Were you doing testing out at the Arc Jet for that?

BOUSLOG: No, I was not doing Arc Jet testing for the X-38. I was actually doing hypersonic wind tunnel testing for the X-38. The one job I had on X-38 was to develop the aero-heating model for the body flap that was on the X-38. I actually helped design and conduct a test up at CUBRC [Calspan-University of Buffalo Research Center, New York], up at University of

Buffalo, and we actually did those tests. It was a pretty good-sized model of the X-38 with the body flap on it. I forgot what scale it was. It's very difficult to do those tests, so I helped design and conduct that test. I actually spent time up there doing those tests. We were testing at very high Mach numbers in this tunnel, the shock tunnel that they have. The model was almost like 20 inches long, so it's a good-sized model. We also had some tests done at NASA Langley [Research Center, Hampton, Virginia], in their Mach 6 and Mach 10 facility, and there was another set of test data that was obtained in Europe. I don't remember the facility. If you remember at the time, X-38, we were doing a cooperative effort with ESA [European Space Agency] during that time period. My job was to take all those data [points] and come up with an aero-heating model to predict the heating on the body flap during re-entry.

That was what I did do, and that was actually a lot of fun. Unfortunately, I felt like I really did make—I call it a big contribution to the technology at that time point—but they wouldn't allow us to publish it. It's one of those things where you just get satisfaction from knowing what you did, and not getting the, I'll call it the public awareness, of the importance of what you did. Nevertheless, it was a lot of fun. Unfortunately, X-38 was shutting down right before the accident, and I was still documenting my model and my results from all the testing. There had been some Arc Jet testing for X-38 but I was not involved. As a matter of fact, for the body flaps, specifically, the Europeans had developed that and they'd done some Arc Jet testing and actually did a very good job. It was a carbon SiC [Silicon Carbide] material that they were using for the body flap. A lot of that development for the body flap itself was done by the Europeans.

ROSS-NAZZAL: That brings up another question. Over the years, of course, there are two, I guess, other Arc Jet facilities that NASA has, and other facilities within the U.S. and around the world. Would you talk about working with some of those other facilities?

BOUSLOG: If you go back to the Apollo days, boy, there was a lot of Arc Jets. A lot of companies had their own Arc Jet. After Apollo, it pretty much got down to three at NASA. There was one at NASA Ames, one at NASA Langley, and one at NASA JSC. Then, also, of course, there was the Air Force facility at AEDC, the Arnold Engineering and Development Center [Arnold Air Force Base, Tennessee]. The AEDC facility was more set up for ballistic re-entry vehicles, and so, very high pressure, very low enthalpy, lower energy, but very high pressure, which was not appropriate for a Space Shuttle Orbiter mission. All the testing and developing of the Space Shuttle Orbiter TPS was done at the three NASA facilities: at JSC, at Ames, and at Langley. After the development phase, the Langley facility was shut down. Some of that hardware was actually shipped here, to NASA JSC.

However, they did set up a small little Arc Jet we call HYMETS [Hypersonic Materials Evaluation Test System]. It's a very low-power facility, on the order of 400 kilowatts, and it's essentially for material screening. You can test articles that are about 1 inch in diameter, and that's about it. After that, then, it was essentially the NASA Ames facility and NASA JSC. Those were the two main facilities for the rest of the Space Shuttle Orbiter program, the beginning of the Orion program, and, of course, supporting various other technology initiatives and commercial entities that wanted to test in there, too, to support their development. That's sort of the background to all of this. The Ames facility, I personally have worked with, when I went to go work X-33 for example. I was pretty much the architect of all of the thermal testing for the TPS for X-33.

At the time when I started working it, most of the testing was scheduled to be done at NASA Ames, but based upon capabilities and scheduling, et cetera, then some of that testing was shifted over to NASA Johnson Space Center. We pretty much kept both facilities busy just doing X-33 testing. We did a lot of testing at NASA Ames. In this case, it was metallic TPS we did a lot of testing with. We were looking at doing a lot of large arrays, literally 30 inch by 30 inch test articles. We did a lot of that. We did some at JSC on those and then quite a bit at Ames.

ROSS-NAZZAL: How is JSC's facility different than the one at Ames?

BOUSLOG: There's all sorts of different things. For example, at Ames, it's a little bit older facility; they have more power, more air capacity or vacuum capacity, so they can blow more gas at higher power than we could at JSC. They have two facilities. One is the workhouse, which is what they called the IHF [Interactive Heating Facility]. It's rated about 60 megawatts. Then, they have another one, which is called the Panel Test Facility, which is smaller test articles. It's just for panels on the order of 20 inches by 20 inches you can go test. Then, they have the AHF, which the Aerodynamic Heating Facility. It's about 10-20 megawatt facility. Each of those are essentially test legs off of a bigger system of boilers and power grid. They have a footprint that's much larger, if you will. At NASA JSC, there was usually only just two test positions, and we were rated at about 10 megawatts, so a little bit lower power. Both of those test positions fed off of the same steam injector system, the same power supply, et cetera, so we just switched between the two.

The infrastructure was a little bit different. Obviously, much less infrastructure at JSC. Over the years, the testing folks had developed different arc heater systems. Ames tended to go one way with their design for arc heaters, and JSC tended to go a different way with their arc heaters. There's benefits, pluses and minuses, to both. It was just different, so that led to different test capabilities. Part of the problem with the Ames facility was a lot of their hardware was very hard-wired, if you will. Plumbing connections, et cetera, were just pipes bolted together, right? If you wanted to make a change, you got to un-bolt all those pipes and bolt them back up, which takes a lot of time. You're always worried about leak checks, et cetera, where at JSC, for example, they had flexible tubing for their water-cooling. You could move the heater, for example, without having to un-bolt a lot of pipes, so we were more flexible in making nozzle changes, et cetera.

Also, I mentioned the arc heaters are different. At Ames, it's a little bit more amenable to higher power, which is good if you want to test at those higher power conditions. To protect the electrodes, for example, what they had to do is they had to feed in argon very close to the surface of the electrodes, and that contaminates the gas—potentially, it can—which you're testing in. At NASA JSC, we mixed nitrogen and oxygen; in our electrodes we'd dump in nitrogen and then mix it, so we came up with the right concentration of nitrogen and oxygen. We didn't have any argon. We used argon to start the arc but then quickly switched over to a combination of nitrogen and oxygen. There was capability there that we had that was different.

The other problem that the Ames facilities had was since they were trying to actually split the electrical arc between different electrodes, they had to actually control the resistance, the resistors. To get certain test conditions, you had to pre-set those resistors ahead of time to get the electrical arc to split and attach to different electrodes. That was not done at JSC. It was essentially a cathode and an anode, and yes, they were wear parts, and you had to replace them after so many runs, but we didn't have to pre-set any resistors. It was much easier to make a run, and then actually vary the power. During a run, we could go from pretty much bottom of our range to the top of our range in power within seconds, so you could actually do a simulation of a flight heating profile in the JSC facility, but just couldn't do that at Ames. You had to set up and say, "Okay, I'm going to go test these conditions, and that's it. If I want to test these other conditions, then I've got to shut down and reset everything, and then run again.

Again there was pluses and minuses to both approaches, but I think the way that happens—which is always good—is that you get different groups working to solve the same problem, right? We had this problem. You're trying to simulate re-entry, and some people are going to approach it one way, and another group of people are going to approach it a different way, so they come up with different solutions. Sometimes, they result in similar responses or similar results, or complementary. I think it ended up being pretty complementary. There was things that Ames could do that we could not, especially in the high power region. We couldn't hit real high heat fluxes or real high pressures. On the other hand, we could hit the real low heat fluxes and low pressures very easily. Also, of course, we had more flexibility in our testing.

There was some overlap of test conditions, which is good because then you get a comparison between the results in two different facilities, and you have more validity. If you get the similar results in two different facilities, you're more convinced you've got the right answer. Then, of course, there were capabilities that were different between the two facilities, and so that's good, too. A lot of it had to do with that approach. Ames folks tend to go and design an arc heater a certain way, and the JSC folks went a different direction.

ROSS-NAZZAL: In your opinion, was there ever any competition between the three Centers?

BOUSLOG: Yes, there'd be a lot of competition. I think at the working level, it was not so much of an issue. It was more at the higher levels. Never really understood that. Of course, when there's not a lot of resources, everybody's competing for resources, so that can force people that may be even our friends to be enemies. Yes, there was a lot of conflict. In my tenure here, there's been a lot of conflict between JSC and NASA Ames over this, but again, not so much at the working level, it's been at the higher levels. Sometimes it's gotten really nasty, which is sad. We shouldn't be doing that. We had a program here that was working Constellation, and it was called ADP, the Advanced Development Program. We were looking at doing pre-development, if you will, of the heat shield for the Orion capsule.

We did have a fair amount of money, so we actually developed a lot of capabilities in Arc Jet testing at JSC and at Ames, and we worked very well together on developing those. It was very complementary and helpful for both sides. Once that was over and the resources started tightening up again, then the competition comes back and people are very wary of the other party, let's put it that way.

ROSS-NAZZAL: You mentioned Orion and I did want to talk about that because you're the subsystem heat shield manager, correct?

BOUSLOG: Yes, correct.

ROSS-NAZZAL: Talk about some of that testing that was done. How did you determine which material you were going to use, and were there challenges in making that selection?

BOUSLOG: Yes, there were. First of all, [in] the very early days, what we did is we put out a request for proposal [RFP], just surveying industry. "Hey, what would you propose to use?" I can't remember how many materials we got, but five or six, so we got a pretty good response. We finished that phase and did some early on testing, and of course, you can imagine, there was problems and the materials were not behaving well. Some were behaving very well. Then the next phase was to go take that a step further and say, "Okay, now, we're going to put out an RFP." Now you've got not just a material, it's a system, so you've got to show that you can actually build this to some scale that's applicable to the Orion capsule, which is big. It's 16 feet in diameter.

We put that out, and we got one response. It's like, "Uh-oh." That was not good, right? You don't want to have a competition with one group and that's it. Boeing had responded, but they were actually using PICA [Phenolic Impregnated Carbon Ablator]. After the fact, we realized the schedules were such that we were giving penalties in the contract for not meeting schedule. Some of the companies just were unwilling to risk that. Other companies just didn't have the capability, especially the smaller companies, to build something that big. I'll say it's good or bad—we had a schedule slip in Constellation, and because of the slip, that allowed us to submit another RFP, and then we got a couple more responses. We ended up with three companies that we were working with for the development of the heat shield. This was actually during the Advanced Development Program.

Boeing was the one that was the early one with the PICA system, and PICA stands for the Phenolic Impregnated Carbon Ablator. Another Boeing proposal, but it was with their own material, which was the BPA, the Boeing Phenolic Ablator. Then, of course, the third was Textron, with the heritage Avcoat material that was used on Apollo. We worked all three of those, and each one of them separately. Obviously, we had a head start on the PICA system because we'd gotten the contract to them earlier, and the other two systems were lagging. The Boeing Phenolic Ablator, we did some testing of that and really were liking its performance. It was really good. Unfortunately, when they started scaling up their production and looking at building bigger test articles, they were experiencing a lot of cracking. They couldn't resolve it in the timeframe that we had, and so that contract was terminated. At that point, it pretty much left Textron with Avcoat and Boeing with the PICA system.

The Avcoat had some problems at first, but then it looked like we got those resolved, so then we actually had both Boeing and Textron build what we called manufacturing demonstration units, where we had full-scale, stainless steel structure, in which I think it was about quarter of a pie of their material to that, showing that they could actually build that hardware. It was on top of all the Arc Jet testing and mechanical testing we were doing of the material itself. After that, we were getting data from both systems. A big problem with the PICA system, of course, is it's what we call a tiled system. You can only build blocks of it or tiles of that PICA that are so big, and then you bond them down to a structure, but what do you do with the gaps in between? As a matter of fact, I helped lead up a trade study on different what we call gap fillers for that system and really never could come up with a candidate that solved all of our problems.

We looked at all sorts of things. As a matter of fact, I think one thing somebody submitted a patent for, we called it PICA on edge, where they actually pre-crushed the PICA so it was sort of spongy and bonded that into the gaps between the PICA tiles. That had structural issues, it was cracking. Performed very well thermally, but we were experiencing cracking during the testing, as a matter of fact, both mechanical testing and Arc Jet testing. We were concerned with that. When you bond down these blocks, it's very hard to verify that you've got a good bond.

Going back to our history on Space Shuttle Orbiter, most of the tiles, we did what we call a bond verification run. We actually take and bond the tiles on, and then you actually use a vacuum chuck and pull that tile to make sure it's well bonded to the structure. The PICA blocks were so big, you couldn't do that, plus the PICA material is very porous. Yes, we could paint it, and we did. We put a paint on it and tried to do that to some extent, but it was not working very well. Then, of course, the material itself, PICA, is relatively weak. It's not much stronger than the higher density tiles, so we were very worried about it structurally failing.

One failure mode is for an in-plane crack. In-plane cracks are always, I'll call it the nightmare of a TPS person, because then you're losing a whole chunk of material, almost all the way down to the bond line. If you have a through the thickness crack, we're less concerned about that because most of your material's still there. You can get a little bit of hot gas in the crack, but you're not going to overheat your structure very readily. That was the weak link, if you will, of PICA, was those two things: its strength, especially its in-plane strength, and then of course, also the gap fillers to go in between there.

When we went to the down-select, we actually had an official down-select, I think it was 2009. We looked at Avcoat and PICA, and at that time Avcoat was selected. It is a pretty laborious system. The good thing is that you really get a good bond to the structure. It's a honeycomb material that's actually bonded down, and we are able to do pull tests to make sure that honeycomb is well bonded to the structure before you fill the honeycomb with the ablator material. Since then, we have built a heat shield with Avcoat. It's very laborious. You've got to bond in the honeycomb, you've got to fill all the cells, and it takes a lot of time and a lot of labor to do that. The other thing is that we know that we have a risk of cracking, but it's through the thickness cracks, but nevertheless, it's still cracking. In our experience with our EFT [Exploration Flight Test]-1, that can happen during processing. We didn't understand that. We knew Apollo had had similar problems, but we didn't know the details; it's not well documented. Even today, we are predicting the potential for cracks, through thickness cracks, for Avcoat. Every TPS material, there's issues with, so it's a real challenge to deal with them. There's no easy solution.

ROSS-NAZZAL: Would you talk some about the Arc Jet testing of these materials?

BOUSLOG: For the initial screening, you're mostly doing the small pucks that are about 4 inches in diameter. That's just to get some idea of the material response. We look for two things during that: we look for recession, and we also look for the in-depth thermal response. We actually put what we call thermocouple plugs in the material so that we have thermocouples that are at certain depths inside the material. We take those data [points] to validate our ablation models. Obviously, we want to do that over a large range of conditions, so we build a lot of those and expose them to the Arc Jet in different heat fluxes, in different pressures, and different enthalpies. You're trying to define your flight space saying, "Hey, here's my flight envelope, and now choose a bunch of points over that whole envelope that I can test on to validate my model and make sure it's working correctly.

We did that for both Avcoat and PICA. When you're going through and saying, "Okay, it's not only got to perform thermally, but it's got to perform structurally, too," there was various things we had to go do. For example, we ended up having to change the honeycomb vendor. The one honeycomb vendor we had was not performing very well; it was costing us an arm and a leg, so we decided to change to a different honeycomb. Of course, then you've got to go back and retest because there's different material. It's very similar, but nevertheless. The other thing is that when you put the ablator material inside the honeycomb, you have to prime it, so we changed the priming material. We had to go back and re-test that. That's all been done, now, but you can see that that caused a lot of additional testing over this flight envelope that you're looking at, just to get the thermal performance down.

On the PICA side, the PICA material itself is actually easier to model, but of course, we still had to do that. It's essentially a phenolic and a carbon; it's a little bit easier to generate the ablation model. The Avcoat has glass in it, actually glass fibers for strengthening up the char, and, of course, that glass complicates the ablation performance and the modeling of the material itself. On the PICA side, we still had to test the material over a large range of simulated flight conditions, but then also we had to deal with the gap fillers. That was our big challenge, so we started off with 4-inch diameter pucks, and pretty much split them down the middle and put different types of materials in between, to evaluate the recession of those materials, and then also the thermal performance. That's where we started having lots of problems, especially the PICA system, since it's an array of tiles. Then we actually had to do other testing, too, so we had to test in wedges, et cetera, and we also tested the Avcoat in wedges. That gives you sort of a shear flow on the material, as opposed to just a stagnation. The flow is impinging directly on the material.

So, we did a lot of testing, probably more with the PICA than with the Avcoat, in wedges. We tested them out at AEDC, at JSC, at Ames. AEDC, we went there because we knew that for some of the re-entries we had pretty high pressures and shear on the material—aerodynamic shear. They could hit those conditions at AEDC better than we could at our NASA facilities. We did a lot of the testing at Ames, also, on that. We're still doing testing on Avcoat. Since Constellation was canceled, and we moved to the MPCV program, with the Multi-Purpose Crew Vehicle, we're concentrating on the EFT [Exploration Flight Test]-1 flight, which is the flight that hopefully is going to get off by the end of this year. We're building that flight hardware right now. We concentrate all of our testing on that flight envelope. Now we also have to move on to the next mission, which is a lunar-centric mission, so we're talking about going around the Moon and coming back from the Moon, or close to the Moon. Different set of flight conditions—re-entry environments are different, so now we'll have to expand our flight envelope and test additional models at that those conditions to further validate our ablation model.

We don't always get good results from our Arc Jet testing. It's always a learning experience. We've tested some materials at Ames, Avcoat, in particular, and PICA, and gotten different results, when we thought they should be the same. We don't understand that, sometimes why we get different results. We also know that we don't characterize the flow field real well in either facility. It's always a challenge. We know that enthalpy is a very important parameter, and the enthalpy is essentially the energy in the gas. Knowing that is very important and has a very large impact on your recession rates and predicting your recession. Probably heat flux and enthalpy are the two biggest drivers in how much the material recesses as a function of time. We would get different results from different facilities. We didn't know if that's because various test conditions were different, or just because our knowledge of the test conditions were wrong. That's why we've continued to encourage folks, "Hey, you need to spend money and time to understand the flow fields," and that includes the laser-induced fluorescence, and other systems, other probe systems, to back out the enthalpy.

The enthalpy in the flow field is not a directly measurable quantity, so you have to go through alternate ways to back that out. Heat flux, on the other hand, is. You can get a heat flux gauge, expose it to the flow field, and get those measurements and pressure also. We did a lot of testing for those, for PICA and Avcoat, and we're going to continue to have to do it for Avcoat for the EM [Exploration] Missions.

ROSS-NAZZAL: That's interesting that you said you get these different results, after more than 50 years of using these facilities.

BOUSLOG: We don't have a very good understanding of even the flow fields that we're exposing it to, and especially the interaction of those flow fields with the materials. In a lot of ways, it was neglected after Apollo. There was not many people working that. NASA had moved on to the Space Shuttle Orbiter. We had reusable thermal protection system materials, so the ablators, which are necessary for the real high-energy re-entries, that development just stopped. NASA didn't need it. They still used it for some planetary probes, but that was very empirical, probably because people were willing to take risks because there was no crew on board, or they were not mass-critical. They'd go in there and say, "Okay, well, based on our experience, here's how much material you need. Why don't we just double it and go fly?"

The basic understanding of the material behavior, when it's exposed to the re-entry environments, was not progressing much at all. If you go back today and look at what a lot of those people did in Apollo, you're just like, "Boy, they were really smart." It's like we're trying to play catch-up. We're trying to do what they already did in the late sixties, and in some ways we're still chasing them. We're not quite there. That's in testing and in analysis. I have the utmost respect for the folks that worked Apollo.

ROSS-NAZZAL: Have you brought in some of those graybeards?

BOUSLOG: Yes, some of them we have, and we've worked very closely with them. If you go back then, you've got to put yourself in perspective, remember that people were calculating things with slide rules, not with calculators or high-powered computers. They were making plots by hand, not Excel or not some other software on your PC. Nobody had PCs [Personal Computers]. The end result of that is when you pull in people from Apollo, it's based upon their memory, and the documentation is just not there. Even the plots, sometimes we'll find plots that are hard to read. That's difficult. It's not like today, where it's so much easier to document things and save it. Unfortunately, a lot of the technical documentation was destroyed after Apollo, for one reason or another. Going on memories is not, sometimes, very good, but we've done that.

ROSS-NAZZAL: I wanted to shift gears a little bit and ask about day to day operations out at Building 222. Can you share some recollections of how things operated?

BOUSLOG: Remember, my role is more of what I would call a customer, so I was not involved in the day-to-day operations of the facility. There is, for example, a facility manager there, that's a NASA person. There are also what they call the test directors. The test directors are NASA people, and the rest of the crew are contractors. The contractors include what they call test conductors, and that's the orchestra director. He's the person that's actually turning the knobs, et cetera, trying to control the facility. Then, he has his support folks. They have a power operator, who actually controls the power, essentially it's the current, and then you've got quality folks that are just monitoring, making sure everybody's doing their job correctly on the contractor side. Of course, you've got a boiler operator that's out controlling the boiler, that generates the steam to generate a vacuum in the test chamber. You've got a data operator, which is obtaining all the data that's generated during the test. You have technicians that are maintaining all the facility hardware, prepping test articles, doing measurements on test articles, et cetera.

The test director, which is a NASA person, would be monitoring what the contractors are doing, would have to sign off on all the paperwork that would go through, and obviously, the contractors who are generating the paperwork, and that was work orders to provide instructions to the technicians on what to do. Whether it be prepping a test article, or repairing or maintaining some part of the facility, that would go on on a daily basis, as they would assess the facility, what needed to be done to keep the facility running safely and producing the environments we want. There was maintenance or parts that were broken, and you're a very high-power system, so you know you're going to have parts break. You have anodes and cathodes that degrade over time, they have to be replaced; somebody has to check them. Usually, it's a visual check. You have to look for potential water leaks all the time.

They're doing that on a daily basis, and also they are preparing test articles for test. They go in there and log in a test article, give it a number, photograph it, do measurements of it, weigh it, and then store it, using bonded storage. Then, of course, enter all that into a data system, so it's all stored. Some test articles require preparation before a test,; some of them have to be integrated into test fixtures, so the technicians would have to do that. For all those steps, work orders would be generated, instructions. The NASA person in charge down there would have to sign off on those and say, "Yes, that's the right thing to go do." Once a test article is prepped for testing, then, of course, they would have to install them in the test chamber, get them oriented correctly, positioned correctly, make all those type of measurements. It was sort of tedious. After that, you're ready to go test, but then their job's still not over because post-test, you have to pull the test article out of the test chamber. Pull it off of the fixture, photograph it, weigh it, quite often do geometric measurements of it, especially if we're talking about recession, to see how much it recessed. The data operator's pulling off all the data and organizing it.

Data can be facility data—for example, mass flow rates, water temperatures, current, pressures at different places in the arc heater—and then thermocouples on or pressure measurements on the test article itself. Also, they have optical pyrometers. Those are focused on the test article, and they use those to get surface temperature measurements. Got very high resolution cameras that they have to deal with. It takes a lot of set-up work, and of course, once you get the videos back from those, then you've got to process the videos. Some of those, we have what we call a photogrammetry system, where essentially, it's this pair of cameras, very high resolution cameras, that are synchronized so that between those two cameras, you can actually calculate the recession as a function of time during the run. It took a lot of post-processing to be able to do that.

There's all that work that goes on, on a daily basis. Once you get the test articles, then you have to store them after testing, after you've done all your measurements on them. Then, you have to track them for us, so there's a lot that goes into the daily operation in the Arc Jet facility.

ROSS-NAZZAL: As a customer, what sort of things would you have to do prior to and after an Arc Jet test?

BOUSLOG: The big thing, of course, that we were responsible for is generating what they call a customer-based test plan. That's pretty much a description of what test conditions you want the test articles exposed to, any special handling that you want [of] those test articles. For example, some of them may have to be kept in bags with desiccant. If they pulled them out of that bag for attaching thermocouple connectors or taking photographs, they'd have to actually log how long it was out of the bag because we're worried about moisture absorption into the test articles. Things like that, you have to generate in the plan. We would write that plan and provide that to the facility. They would take it and then write what they call their detailed test procedures.

They would also take that and send it over to the safety folks. They could provide an integrated hazard analysis. Just to be aware, for example, most of these materials off-gas quite a bit, so we usually put in there that after a test, you would keep the test chamber evacuated for 30 minutes, just to take all that off-gas and get rid of it before anybody opened the doors. Sometimes, we'd repress and then re-evacuate a chamber, just to make sure we're getting all that stuff out of there. All of that information, the customer has to provide. "Hey, here's the type of material we're testing, here's how we want to test it, how to handle it." That all goes into the customer-based test plan. Then, we provide the test articles. It was often a negotiation, too, with the facility folks saying, "Hey, this is what we'd like to do, so what kind of test fixtures do you have?" We would work back and forth because the facility folks would actually take our test articles and integrate it into the test fixture, and so we had to know what they were doing and they had to know what we wanted. We would work together on developing that plan.

After we got the test plan, after we got the test articles manufactured and ready to go, then, as a customer, mostly what you're doing is just making sure that the facility is doing what you wanted them to do. There's times when you realize, "Oh, I forgot to tell them to do such-and-such," right, so you're having to correct them. Or things change. Every test, it seems like something changes. Some of it's because you test and you find something else out, so you want to change your test, and then you have to do a deviation. Even during a test program, you may have a dozen test articles, and you'd say, "Hey, okay, we got these first four done, but now I need to change how we're going to test the remaining." You have to generate a deviation to the original test plan and get that approved before they can continue testing.

Post-test, usually, you want to go in there and take a look at the test articles themselves. At that point, you want your data. Of course, the facility folks are usually busy trying to get another test program, too, the next one in line. It's always sort of prodding them to get the data that you are looking for, and they're busy trying to get their next test moving, too. It was always a challenge for them to satisfy everybody. That's a lot of work.

There's also test article design. There was a lot of interfacing with the facility folks. To this day, I can't say we know always how to design test articles. We get anomalies that we don't understand, and sometimes we think it is because of the way we are testing. For example, most of these materials are porous, and so, obviously, you put high pressure on them, there's going to be some type of flow through the material. That can affect our results because since we're not testing the exact same geometry as flight, then that can affect our results, and not be realistic compared to what we'd expect in flight.

We've tried to account for that sometimes and gotten results we certainly, to this day, don't understand. We keep on revisiting our test article design. For example, in wedges, quite often we would see what I would call local gouging in the test articles. We convinced ourselves that that was probably because you've got a water-cooled wedge, so it's cold. The flow field, it's going across this water-cooled surface, all of a sudden, it sees a hot surface, which is your test article. There's a lot of chemistry that goes on right at that point and that's not realistic because the flight vehicle doesn't have a water-cooled surface upstream of your material, right? We would get strange results, and so we'd have to put in graphite transition pieces, for example. All of that, we have to negotiate with the test facility because they're going to integrate the test article into the test fixture, so that takes a lot of back and forth between the facility folks, the technicians who are going to do the work, and the customer.

ROSS-NAZZAL: I noticed that you've authored a number of articles about tests or work that you've done in the Arc Jet facility. Have there been any breakthroughs that you've found as a result of Arc Jet testing, that you've let the military or aerospace industry know about?

BOUSLOG: I don't know if I'd call them breakthroughs. It seems like it's all incremental. We continually learn, but I guess none of them I would classify as a big breakthrough. It's sort of a continual learning basis, and unfortunately, since there's not a lot of continuity, we've tried to get that going, but nobody seems to want to fund that. You come up, you learn the stuff, and you publish it, and then that need's gone away for at least the time being. Five, ten years later, you go, "Oh, yes, I think that back then, I did such-and-such," and you're trying to go back to it and figure out where you were, and then continue on. Those of us working at NASA, unfortunately, that's sort of how we have to operate. It's a little bit different than academia, who a lot of times, they will choose a technical problem and then pursue it for years, maybe decades. It's the same problem—maybe different grad students working it, but the professors slowly developing that capability over time.

Actually, in thermal protection system and in aerothermodynamics, it's sort of that way. As I mentioned earlier, we didn't deal with ablators much for probably several decades at NASA. We sort of lost our capability, and so now in the last five, six years, we've been regenerating that capability. I feel the same thing for a lot of stuff that I've worked on, it's been that way. It's been jumpstarts. We'd work on it for a few years and then drop it and go work something else. Luckily, we're a little bit better at documentation now, so it's easier to come back up to speed than maybe it was in the Apollo days.

ROSS-NAZZAL: Were you there at the last test out at the Arc Jet facility?

BOUSLOG: I was there right beforehand. I had to leave just before they actually started doing the testing because I had some conflicts and some meetings I had to be at. We call him the guru out at the Arc Jet, Jim [James] Milhoan, he's been a mentor for a lot of us. He was actually a NASA person who helped develop the Arc Jet capability at JSC. I forgot what year it was, but he retired. He's come back as a contractor and been supporting us for years. When he was there that last day, they asked him to talk, and he just said, "I can't because I'll just cry." I could see that, too. There was sort of a desire not to be there, in a sense. It was just something you didn't want to cope with because it was sad, which is our human nature, I guess.

ROSS-NAZZAL: What do you think the Arc Jet here at JSC has meant to you and to NASA, over the years?

BOUSLOG: To me, I sincerely believe that it was an Agency asset. That probably is not well recognized. I think over time, people will understand that, but it's going to take for it to be gone, for people understand that. You have to be very embedded in this area of technology, in aerothermodynamics and in thermal protection systems. Of course, there's not that many people involved in those areas. Luckily, some of the universities are actually building up that capability, but there's some universities, like my alma mater, University of Texas in Austin, they just don't deal with that much at all anymore. I don't know why—hypersonics in general. Some universities are building up that capability, so there's sort of a lack of recognition of how important that is. Even though right now, for example, in Orion, they say the heat shield is one of the top risks for the program, so there's an understanding that it is very risky.

I think that the JSC facility, obviously those who've tested in it over the years, have a lot of respect for it. Let's just put it this way: we were too busy working hard on it than to publicize its benefits. Literally, we did not spend time doing that. We were too busy getting the job done. We didn't walk the halls of [NASA] Headquarters [Washington, DC] or tout our capabilities to everybody and their brother; we were too busy just doing the job. Maybe it just went unrecognized a little bit. It's sad that we don't have that test capability. The other thing, too, is the JSC facility, they're a pretty lean, mean group, so we didn't cost a lot of money. NASA Ames has got, like I mentioned before, a lot of infrastructure, a much larger test team, so they've got to support all that, and that takes lots of money.

Now, there's no alternative. You've got to go to Ames, and you've got to pay lots of money. Time and time again, I just hear people saying, "Well, I can't afford that." That can be professors, it can be companies, it can be technology folks. They just say, "I can't afford that much money to go test." I'm real worried about how the progression of this technology is going to happen in the future because I just don't feel like the amount of testing is going to be there. You really do learn by testing, over and over again.

ROSS-NAZZAL: What would you say have been the benefits of the JSC facility?

BOUSLOG: I think just being a workhorse, first of all. Just getting lots of testing done. That's one of the big benefits and of course, working together with the Ames folks, et cetera, getting some of the diagnostics together on the laser-induced fluorescence, a lot of that work was done at JSC. Some of it was done at Ames. I think that test capability, its progression and technology development, a lot of it was because of what we did here at JSC. I think that was real important to the Agency, and to other people, too—professors, et cetera—they understand that. We don't deal too much with the DoD [Department of Defense] folks. Occasionally, seems about once a year, we talk to them and exchange some notes here and there. It just depends on where they're headed to.

I think that there's capabilities that the JSC facility has that they could have used more. Sometimes we had to turn them away, especially during the Shuttle program, since our top priority was supporting Shuttle with the JSC Arc Jet. I know that I personally was involved in planning some tests for the Air Force in our facility, and they never happened because we were just too busy supporting Orbiter. The Air Force just couldn't get it done then and said, "Okay, you can't help me; I've got to go someplace else or not test."

ROSS-NAZZAL: What impact is the closure and the demolition going to have on the Orion program?

BOUSLOG: I'd say we don't know. Ames, they did take some of our hardware and tried to get some of the capabilities that Ames did not have but we had. They tried to get that up and running. They were supposed to have that all done here, by the beginning of this year, and they're still having problems. There are schedule delays, so there's testing right now that Orion is supposed to be doing, and it's been delayed again and again and again. Part of it's just a learning curve you go through. The folks at Ames, their technicians and engineers, are not familiar with this type of arc heater system. Obviously, if you're not familiar with it, you're going to have problems with getting it going. I'm sure there's going to be delays in testing—already is. How that's going to impact us, it's hard to say. At some point, it won't be pretty, it'll be us technical folks saying, "Yes, but you need to get these tests done," and you get program management saying, "I can't delay my schedule; you guys need to solve this."

It's like, what do you do, right? At what point do you say, "Okay, I'm going to delay a flight because I can't get my testing done?" You have everybody and their brother on you at that point. I don't know where it's headed, and that could be pretty ugly. I also expect us to have to accept more risk because we'll be able to test less. Again, that's not a good position to be in because it's where us on the technical side are willing to draw our line in the sand and say, "I'm not going to approve us flying unless we get these tests done." You can imagine, that's a very tense and stressful situation to be in. It just depends on who's making the decision, whether they're going to cave or not, because of the tremendous program pressure to move on. They don't understand.

That's one thing that dismays me about NASA today, compared to Apollo days, is that if you go back to look at those folks who are heading up the programs and heading up NASA, every one of them was technically very, very competent. You could go have a technical discussion with them in detail, and they knew what they were talking about. Today, that's less so. Managers tend to be managers and not so technically competent. They themselves are not able to make those technical judgment calls. They're having to rely on their lower-level technical folks. That causes a problem because if they don't understand, then they're more willing to just take the risk without really understanding the risk. Then it depends on the lower-level technical folks to be more adamant to stick their necks out and yell and scream to say, "Hey, you can't do this, you really do need to test more," for example. That's sort of my crystal ball of what's going to happen.

Just to backtrack a little bit, too, I'll give you an example of the technical competence of our leaders. I'm not sure if everybody knows, but the first Center Director for, I guess it was the Manned Space[craft] Center at the time, was [Robert R.] Gilruth. He actually owns a patent for Arc Jets, so he himself, obviously, was instrumental in getting the Arc Jet capability going here at JSC. I don't think he'd be very happy with the situation today. You go look at a lot of these folks—Max [Maxime A.] Faget and Chris [Christopher C.] Kraft and all those—and how competent they were, technically, and understood the re-entry problem; different era, now.

It's hard to say what the future's going to hold, but two things, I think, to summarize: I think we're going to have more schedule delays because we can't get our testing done, and then also, we're going to have to accept more technical risk. Hopefully, it's not too much. We don't want to lose more astronauts.

ROSS-NAZZAL: I think everyone would agree with that. We're almost at 11:00. I had one more question, but I wanted to see if there was anything else you wanted to talk about, maybe we haven't discussed about the Arc Jet? Trying to be thorough and think about different aspects of working out there.

BOUSLOG: Offhand, I can't think of anything. I've been talking here for a while. Nothing's jumping into my mind at the moment.

ROSS-NAZZAL: I like to ask people, because I'm guessing in the future, people are going to wonder, what were things like in terms of camaraderie out at the Arc Jet? Anything you can talk about and share?

BOUSLOG: It's probably like every office. There's good times and bad times, right? There's different levels of competence. Some people are very competent at what they do and some are so-so. Learning how to deal with that is always difficult, but still being respectful to the people. I think there was a lot of camaraderie, especially in the Arc Jet Team, there's people who've been there for years and years and years, and so you get to know them and respect them. Some of the new folks that came in performed well, some of them didn't, but I would say yes, there was a lot of camaraderie amongst those folks. I always had a lot of respect for them. At least, I think they respected me and they usually treated me well when I walked in the door. I really liked working with those people. I think in general, they were really top notch.

ROSS-NAZZAL: I think that's a good note to end on. Thank you very much for coming in today. Appreciate it, enjoyed it.

BOUSLOG: No problem. Thanks.

[End of interview]