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JOSE VERA AND JAMES MILHOAN
INTERVIEWED BY JENNIFER ROSS-NAZZAL
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ROSS-NAZZAL: Today is September 30, 2009. This interview with Jose Vera and James Milhoan is being conducted at the Johnson Space Center [JSC] for the JSC Facilities Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Rebecca Wright. Mr. Vera begins today by talking about the Radiant Heat Test Facility.

VERA: The importance of the radiant was that it was instrumental in selecting who was going to make the Shuttle tiles, initially. We tested them and Lockheed Martin won the contract, because their tiles performed better, and that was done in Building 13. Then in late ’74 and 1975 we moved to Building 260. It was the Radiant Heat Test Facility. Then we started preparation for the nose cap and part of the wing for the Shuttle testing. We had a chamber to do that over there. It simulated the reentry temperature and pressure profiles. That’s why I deemed it important that somebody mentions that part.

ROSS-NAZZAL: Let’s start with each one of you giving a brief overview of your career at NASA and how you came to be associated with this building, the arc jet.

VERA: Go ahead, Jim.

MILHOAN: I started in the arc jet facility around February of 1967. At that time they had an operable one-and-a-half-megawatt facility that they brought online in 1964 and that facility operated until about 1975. When I first came in they were still constructing this building. They were just able to occupy the offices and brought the furniture in. We were still constructing the power supplies, and they were putting wiring in and wiring the consoles. We monitored that activity. They were installing the vacuum system and the boiler, so the facility was only just partly constructed. Most of the technical items weren't really installed yet.

AVCO had the contract. As Don [Donald J. Tillian] has probably already mentioned in the write-up there, they had two arc heaters that they designed for us. They also had a radiant lamp bank that was four electric arc lamps with real deep dish reflectors. Those were mounted very tightly around a five-inch nozzle that would go in a vacuum chamber and that had combined radiant heating and convective heating. It met its specifications but unfortunately the reflective surfaces would get contaminated so quickly that we abandoned that as a practical method. If we'd been in the Department of Defense, we would have just bought a warehouseful of the reflectors. We abandoned that effort and tried to revisit the radiant heat a little bit later on. We combined with the convective heating, and so far we just never had the impetus to really do that.

We got the facility operable. We ran arc heaters in the atmospheric conditions to begin with, no vacuum chamber. It still exists, there's a firebrick-lined chimney with a big high temperature stainless steel exhaust fan. We would exhaust the arc heater for short periods of time into that exhaust. That was back in the day, so nobody paid much attention to environmental concerns with NOx production. Arc heaters make copious amounts of NOx.

ROSS-NAZZAL: What is NOx?

MILHOAN: It's oxides of nitrogen. The air gets so hot that the oxygen molecules get broken apart. They're very reactive and the nitrogen molecules will get broken apart, and you can have the N and the O combine and make various combinations of nitrogen and oxygen, and that's the NOx that you'll hear [about] that's like automobile exhaust. It makes a lot of it. We'd run for very short periods of time, just a few minutes, in the atmosphere out here. The whole test cell would get so orange you could hardly see through it, but we only did that for short time periods until we got our vacuum chambers put in. Once you're in the vacuum chamber you can't even hear the arc jets then, but if they're out in the atmosphere you can see all the shock diamonds coming out of them. You might have 15 or 20 shock diamonds.

The original facility ([Building] 262 the one-and-a-half-megawatt [arc jet])—they installed with Plasmadyne; it was atmospheric operation. It's like being next to a jet aircraft. It's very loud and also you had the NOx contamination problem. We got a vacuum chamber and put a one-megawatt General Electric heater on that chamber. It was what's called a dual constrictor, where it had flows that came through these two devices, and they met head on and would mix in a plenum chamber and then come out of that plenum at a 90-degree angle from those two flows and through a nozzle. We ran some tests with that heater, but it was prone to some shorting problems. So that was the Plasmadyne and then the General Electric and then we got an Electro-Optical Systems [EOS] heater.

It's a pin anode heater. It has a lot of small downstream electrodes that are located in the nozzle. The nozzle is a unique design. It's segmented into very many segments. I think it was like about a dozen that had insulators in between them so that it's really made up like a sandwich of about 12 different segments.

That heater would get up over 50,000 Btus [British Thermal Units] per pound. That's very high temperature gas, and that gets up in the range to where you can easily hit the gas temperatures you'd have coming back from Mars. That facility was actually built as a prototype for this facility. The people that were originally in management here, really even the technicians all basically came from Langley [Research Center, Hampton, Virginia]. Langley was where they built the first supersonic electric arc heater. All the people at Langley in management and engineers were very interested in the arc jet. They all came over and visited it and had tests run in it, like Max [Maxime A.] Faget. They were very aware of the capabilities of this type of facility, and they wanted to build a large one.

They had plans when they first started this Center to build a multimegawatt facility, and they were thinking something in the range of ten megawatts or so. They felt that they wouldn't get that facility online quite in time for the initial part of your Apollo tests. It would be easier to get a one-megawatt facility online, and they could learn. That facility was designed and assembled by NASA employees. At that time there were no contractors involved in it. It was the first operating facility at the Center. As soon as they got that place operating, and they were running tests, they concurrently were designing a new facility and writing the contract specs [specifications] for that. AVCO got the contract, and the Corps of Engineers for construction.

Meanwhile, we went into arc heater modifications at the one-and-a-half-megawatt facility. It's called one-and-a-half-megawatt facility, because the basic facility could handle the power of one and a half megawatts. You could put an arc heater and it could be like a half megawatt, but the facility had a one-and-a-half-megawatt heat sinking capability. We never put more than a one-megawatt arc jet in it.

There were literally thousands and thousands of tests run in that facility. There were other tests run besides the Apollo Program and some of the early orbiter work. When Pioneer got far away from the Sun, you had to keep the electronics warm, so they had nuclear heat sources, canisters. These were devices that were shaped about like a cold capsule, only they're about 12 inches long. Outside of them they've got this high density carbon hexagonal-shaped heat shield that was bolted to the leg of Pioneer.

At that time, [Richard M.] Nixon was President. The nuclear sources that go into orbit, they have to be signed off by the top guy so Nixon had to sign off that it was okay to put that thing in orbit. The then Atomic Energy Commission [AEC] was in charge of that. They were pretty nervous about whether it was going to work or not. So the final test for it was to run it in arc jet at very high entry heating conditions and then take the test articles, take them in a plane out at some Air Force base out west. They would take it and drop it from many thousands of feet, like 10,000 feet or something like that, and try to hit a runway. They'd try to find the biggest widest concrete runway so they wouldn't miss it, and we ran those tests. In fact Don Tillian was in charge of running those.

I had to design a pyrometer system that could measure those temperatures, because you couldn't get thermocouples that would work. I think it was between 5,300 and 5,500 degrees Fahrenheit. I built an optical system with a little periscope set of mirrors, where we would get up close enough to it. The windows we had to blank off, and we only left one small window on it. The light was so bright that the light coming through that window would hit a wall and it would blind you in the control room. You couldn't see the instruments, just the light on the wall. We had to put up a barrier so we couldn't see the light on the wall.

That was a very important test. If you didn't get that test off, then they couldn't fly the program. We pushed it all the way to the wall and that was an air-cooled chamber. It was a steel chamber, and it had a sheet metal jacket on it. There was a fan on top, and you'd draw the air-conditioned room air around the outside of the chamber to cool it. Since the test was so important, we pushed things very hard. We cooked the paint off the outside of that chamber from the heat that was spilled off of that test article. We got the test run and the test article survived and they took it out and dropped it on the concrete. The AEC was very happy.

ROSS-NAZZAL: So you have worked in this facility since 1967, this and [Building] 262?

MILHOAN: Yes. We ran both of these—that one-and-a-half-megawatt facility until about 1975. We were running tests over there. We had a crew running there, and we had two shifts over here in 222 at the same time.

ROSS-NAZZAL: What about you, Mr. Vera? How long have you been working out here? How did you come to be associated with this facility?

VERA: I started out in the Air Force. I put [in] four years, and then like I said I started with the radiant heat. When they started a C of F [Construction of Facility] project in '78, and it ran into when we finished in 1992. I started working prior to finishing because I was involved in setting up the control system for this facility. We still use the same kind of control system. Developed the screens for all our systems and made sure everything worked after we got done. There was a lot of instrumentation.

Prior to that, they had different stations. We integrated the systems so that one system could handle the test gas, the coolant pump, the pump down of the chambers, and monitoring instrumentation for the testing. During that time, we had two chambers. The chamber that was here was called TP2 [and] was taken to the Radiant Heat [Test Facility]. We started using it over there. Like we said earlier, we were running both the radiant and the arc jet so we were involved in both facilities. I worked the radiant heat from 1975 until I came over to the arc jet. I worked with the guys here off and on, but Milhoan knows more about the arc jet as far as the initiation of the facilities, because Milhoan worked for NASA at the time. I've always been a contractor.

I've been involved in test setups and setting up test articles to run and the instrumentation control system and troubleshooting systems and making sure the facility is kept going. That's been my job. Also, I've been test conductor at the radiant facility in here.

A test conductor makes sure the facility is ready for test operations. The test director is in charge of making sure the test runs with the parameters that were set for that test and makes sure the test article gets the best testing it can. We, on the other hand, make sure the facility is ready for support. I just stayed here since that time period and continued working both facilities through a series of many many test programs. We've upgraded the control system since then. It's probably good for another eight years, the one we have now. We have all the systems just to run a test. We haven't talked about that yet. We have hydraulics for model insertion. We have the boiler that produces steam so we can pump down the chambers. We have an ejector system that controls the steam so we can get the vacuum inside the chambers. We have coolant pumps to cool the lining of the chambers.

We make our own test gas, our own air. We have tube trailers with nitrogen, oxygen, and we have a start gas of argon. We installed a faster method of setting the mass flow in the chambers to test different test articles. We installed some digital valves and that helped us out. It used to take something like maybe ten minutes, Jim, to set up the mass flow.

MILHOAN: Oh, yes, easy.

VERA: Now we're just pushing the button and the digital valves will gives us a mass flow. We're mixing oxygen and nitrogen to make air. Nominally but not always, we use 77 percent nitrogen and 23 percent oxygen to make pure air, because we don't want any impurities. The argon is just used as a start gas to start the arc.

In addition, we have a high pressure water system. We use deionized water to cool the heater. Minimize arcing is the reason we use deionized water. We have a ten-megawatt power supply, which is a rectifier, it's a power supply. We have high voltage, and we convert it to DC. We use DC for the arc. So all the systems come together to run the arc jet test. I think I've covered most of them. We also have a data system to acquire data, and we have 256 channels so we can acquire data. Nominally we don't run that many, but we have that capability.

ROSS-NAZZAL: Tell me again, when did you start working in this facility?

VERA: This facility, it was about 1978. Then I went on until the end of the construction of facility, which finished in 1992.

ROSS-NAZZAL: That was the upgrade of the integrated systems?

VERA: No, I'm sorry, it wasn't '78, it was '87.

ROSS-NAZZAL: [In] '87 you came to this facility?

VERA: Yes.

ROSS-NAZZAL: Well, then maybe, Mr. Milhoan, I should ask you. What changes did you do in the building to support the Shuttle program itself?

MILHOAN: When I first started out we were still running Apollo, and we had the AVCO heaters. A lot of management was aware of the problems you'd have developing heat shields without adequate test facilities, and that's why they built this place. Joseph [N.] Kotanchik, Aleck [C.] Bond, and Max Faget were all big supporters. We got funding to tailor this facility to support low Earth orbit for the orbiter.

The first test we ever ran for the orbiter was maybe the first test that was ever run for it; [it] was 1969. These gentlemen that I was just talking about had a meeting with our branch chief and that weekend we worked overtime. Over in the NASA shops they built these little Teflon orbiter models. They were only about like five or six inches long. The original concept for the orbiter had straight wings so these models had these straight wings on it. The wings were made out of Teflon also. They had them hustle up and build those models, and we ran them on a weekend because they were having a meeting that Monday or Tuesday. They wanted some input on what the effects were of having straight wings with respect to the shock impingement, because you'd have the shock come off the nose of the vehicle, and it would impinge on the wing. They just wanted a quick qualitative but a little bit quantitative answer about how much that would increase the heating so we built these Teflon models and ran them.

What'll happen with Teflon is when you heat it it doesn't melt, it vaporizes. People understand the rate at which it erodes. They can relate that to what the heating was. We ran those guys, and there was shock impingement. You could see an erosion on the wing, and it was about where people thought it might be. It looked like the heating was double due to that heating. In fact later on wind tunnel tests confirmed that. It was about double the heating rate because of the double shock. So actually the first test we ran was in 1969, very early on.

In fact if you go back further than that, Don Tillian was involved in the Apollo Program. We had an unmanned vehicle. I forget which one. I don't know if it was 6, might have been Apollo 6. Apollo 6, I think, was designed to prove out the heat shield. What they were supposed to do was put it into orbit and then they had rockets that would move it further away from the Earth. Then it turned around and burned coming back so that they could try to simulate the high velocity you'd get coming back from the Moon. Don got a piggyback experiment. Since it was unmanned, they didn't need any windows. He had these test articles built that went in the windows. The idea there was to get very lightweight heat shield material.

These gentlemen I was talking about earlier were thinking ahead, what comes after Apollo. They were thinking well, we've got to get the weight down, and the heating on the back of the vehicle was less so it was a benign thing. They could take the risk. Don designed and built these panels that fit into the windows, and they had a foam in there, like what they got on the Shuttle tanks. They had balsa wood, which was very early used for some heat shield work.

They had Apollo ablator in there but they lightened it up by drilling a lot of holes in it. In a way, that's a precursor to test for the orbiter, because in the beginning people weren't thinking about reusability. It was just get lightweight ablators and they thought well, they'll just change them out from mission to mission so that may actually be the real genesis for the first orbiter test, I would think. It really didn't have the name or the concept yet, but people were already thinking along that line about post Apollo and this is where we need to go.

Like I said the first test we ran with those Teflon models in 1969. So they got busy, and then around 1972 we completed the C of F project that was tailored to get this facility right into the ballpark where you need to be for the orbiter. We got new arc heaters, and these arc heaters were designed by Aerotherm. They were the same basic design that Ames [Research Center, ARC, Moffett Field, California] arc jet facilities were using.

These were segmented constricted arc heaters. They were in a way very similar to the EOS pin anode heater from the one-and-a-half-megawatt facility, which was a segmented constricted arc heater. We'd had quite a bit of experience with that. It looked like that was the way to go because they have a lot broader operating range in a single setup than you'd have with—the AVCO was a Linde type heater, which was similar to what's called a Hüls heater, which is basically a couple of big water-cooled tubes. Once you get a certain size diameter and length of those type heaters, it's very difficult to change the enthalpy in them. You try to put in more power and the efficiency just goes down. You wind up with the same test condition.

The segmented heaters don't have that problem, so we bought these Aerotherm heaters. We started running tests with them. Then we started modifying them a lot, because there were a lot of practical issues with them, and so we highly modified those. The original Aerotherm heater, the whole column was nitrogen. You would inject oxygen into the plenum. Except for the acceptance test, as soon as that was over with, we said, "Well, that's got to change," because you probably won't get the oxygen hot enough before it can get out through the nozzle. You've got to have dissociation, that is you've got to have the oxygen molecules torn apart because the atomic oxygen is much more reactive than the molecular oxygen. If you want to simulate conditions on materials, especially ablators, then you would need to have that. There's no facility that can duplicate exactly reentry conditions, but you need to err on the conservative side and make sure that you're much more dissociated, that is have a lot more atomic oxygen, than you would have in flight so that you're conservative in your test.

We moved the oxygen injection way up into the middle of the heater and that did the trick. Once you're up into the arc, the oxygen dissociates very easily. Since then we've never put so much as one molecule of oxygen down a plenum right in front of the nozzle.

We had that construction of facilities, and in that process we needed to get more capability. The original vacuum chamber we put in, I think it only had about I think about a .5-pounds-per-second pumping capability. It could probably handle a lot more, but I think it was designed for a five-megawatt heat load. That was in what's now Test Position 2.

We put in a larger chamber with a bigger flow capacity and that was up to a pound and a half. The chamber was bigger, and it could take up to ten-megawatt heat loads. The original power supply was ten megawatts. We also had another Electro-Optical Systems heater. It was five megawatts. We ran quite a few thousand tests with it. Had a five-megawatt in Test Position 2 in that five-megawatt tunnel, and then ten-megawatt heater in the ten-megawatt Test Position 1.

Of course we ran a lot of orbiter tests. In '72, Fluidyne Corporation built a channel nozzle where we could run one-foot-by-one-foot and two-foot-by-two-foot test articles. It also had an eight-inch-by-ten-inch section. The reason why we did that is the facility was originally configured with conical nozzles of different diameters. You could stack on sections and expand those and get larger and larger and larger nozzles. Those conical nozzles are good for stagnation heating, where the flow comes along and impacts right square onto the leading edge surfaces, and then you can put wedge-shaped holders, that are water-cooled, and put panel-shaped test articles inside of the wedge. You can change the angle of attack and that gets you conditions that are similar to parts of the vehicle where the flow is coming at an angle of attack.

When you look at the belly of the vehicle, the flow is parallel. Say it's coming in at a 60-degree angle of attack. The flow that comes up and impacts the nose turns and comes down the vehicle surface, and then the additional flow that comes all along there gets turned. It's really flowing next to the surface, it's flowing parallel to it. We needed a facility that could simulate that in large enough acreages to do systems tests.

We did that with the channel nozzle. It has a ten-degree expansion. What happens is it's the same arc heaters with the conical nozzles but the heater has a round outlet so you have a special throat that slowly changes that round into a square shape so your throat is square. That was like a two-inch-by-two-inch square throat. You allow one dimension to expand at a ten-degree angle on each surface, and you hold the other two-inch dimension constant. The inside of the nozzle is all lined with water-cooled copper plates, and then your test articles go into these openings in the nozzle. The surface of the test article is flush with these copper plates so the flow comes across down through the duct. It's like an expanding rectangular duct. It'll smoothly transition over the test article and out past the test article so you get this parallel flow.

There are a lot of tiles. The flow comes in at all kinds of angles with respect to the gaps between them. Then the question comes up well how wide can the gaps be, what about the depth of the gaps, what about the run length. All of that affects the aerodynamics and makes a difference how much energy finally winds up getting down to the aluminum structure of the vehicle. If your gap is too wide, you can get too much flow down there. So wherever you've got a pressure difference along those gaps, that hot gas can be driven down into the gap and overheat the structure.

Also a forward-facing step like you're putting tiles in and maybe the one behind the tile you just put in it is raised up. If the flow is coming across and that looks like a forward-facing step to the flow, it raises the pressure, and it drives this high energy gas down in those gaps. The rear-facing step can be like suction. They used a lot of wind tunnel tests. Ames was involved in it and Langley was also running arc jets at the time; everybody was interested in how you should design these gaps, because most of the energy coming into the structure is through those gaps, not the tiles.

We ran hundreds and hundreds of tests with all kinds of different gap configurations in both wedges and the channel nozzle. Other facilities were working on this problem and so were wind tunnels. The great bulk of the tests that were run were run here. The majority of the data for what those gaps and steps and all that should look like came out of this facility.

Other things with the tile development was coating losses. What if you had a bunch of coating gone, an ice gouge, or what if a whole tile was missing? We ran those tests. In the Apollo Program, there were literally hundreds of arc jets in the United States. Everybody was fascinated with the program. There was all kinds of money. Every university worth its salt tried to build some sort of little plasma device. They might be ten kilowatts or 100 kilowatts or something like that, many of them. They could run some considerable number of valuable tests with it, but in order to do anything of any consequence you had to get into the high power ranges.

Aerotherm was selling arc heaters, and they had arc jet facilities. I think the maximum they had was about two megawatts. AVCO had a ten-megawatt facility and I think GE, I think theirs was also ten. It might have been larger. McDonnell Douglas had a facility in St. Louis [Missouri], and I think it's around ten. Boeing took that over, and it's now called LCAT.

Why am I telling all this stuff? Because there were many thousands of tests run for Apollo; Aerotherm ran a lot of them. Ames, JSC—of course it was MSC [Manned Spacecraft Center] at the time, and Langley. All three of NASA's arc jet facilities at ARC, JSC, and Langley—we were running two shifts constantly, and they were running probably at least 50 percent I would think in overtime. We never did really run all the tests that we wanted to run.

For example the first flight, they had a burned filler bar problem. The filler bars are at the bottom of the gaps, and they're similar to the SIP [Strain Isolation Pad], it's a high temperature felt. They didn't understand that because none of their tests showed that that would happen. There was suspicion that the filler bar was burning where we didn't run tests, which was well after peak heating, but when the pressure is higher. Those tests weren't run because there wasn't adequate facilities in the time span to really do it. They had to set priorities and just get done what they could.

In the channel nozzle there we set up tile arrays and ran through a program and showed that we got burned filler bar right when they were suspecting it might happen. The capability we had there was pretty impressive. We were able to run entry pressure and surface temperature profiles that very closely matched a whole entry cycle, except for the very low heating parts. We ran a lot of development tests there.

We tried to automate things and improve the facility in our 1990 C of F. You'll hear people call it '89 and '90 or '91 or something because it took so long to get it done. At the very beginning of that period of improvement was when we got into the Asea Brown Boveri control systems that Jose was talking about. Originally, we had a gas system that had used nothing but gas turbines, and in order to get it accurate you had to have those turbines running in the right range. They had narrow operating ranges. We had three sets of separate flow loops for nitrogen and three separate ones for oxygen: low, mid and high. You'd have to select between [the three]. You'd have to guess now this is the way I want to run my test and I need to use that one.

It would take two technicians; one of them would have to operate the oxygen and one of them the nitrogen. They would have to have these thumbwheel controls, and they would have to adjust them all during the runs to keep you correct. It was high tech for the time, but we thought it was archaic so that's when we installed this digital valve system. It has a very broad operating range. I've run tests down to like less than .03 pounds a second and up to a pound and a half with it. It has a very broad operating range. You just key in a flow rate and punch a button and in like two seconds that's what you got.

ROSS-NAZZAL: Do you want to add anything more about those efforts?

VERA: That's when I came into play. We're just going to call it the 1990 [C of F] even though it went from '87 to '92. It was a little difficult. We had to do a lot of instrumentation. They didn't want to stop running. I always give an example. It's like trying to change your alternator while going down the freeway. It's hard to do.

MILHOAN: That never changes.

VERA: We want to put the stuff in, but we don't want to stop running. So we wound up working a third shift to do a lot of the wiring and instrumentation. It was a lot of work to develop all the screens to get what the test directors needed to run their tests more efficiently. It improved the facility turnaround for testing quite a bit at that time. We could monitor more areas with temperatures, pressures, and flows. It was a benefit to get that system installed. We're still using an upgraded model since then. But like I said it's still good for another eight years, and we'll have to do another upgrade after that. It's been a plus having that system in there, with minimal amount of problems, nothing we couldn't resolve, and great support from the company when we needed parts.

ROSS-NAZZAL: Which company was that?

VERA: It's called ABB, Asea Brown Boveri, but at that initial time it was just Asea. Asea meant general electric company of Sweden, but now it's Asea Brown Boveri. It's a good integrated control system. It's got a lot of capability. We also improved not only the test gas but setting the pressure for the coolant pump and improved on the pump down of the vacuum chambers with that system.

MILHOAN: Before we got this automated system, 25 percent of our tests were aborted with problems with the vacuum system. We were inserting like 400, 500 models a year, but we were pushing against problems like that. That's another reason why we did the automation was to eliminate the startup problems we were having.

It says here, "How do we support the Space Shuttle Program." Well, we were involved in the design, development, and certification. That meant we had to run materials tests and we had to find what their degradation modes were, what kind of thermal conductivity they would have transferring energy to their back faces, and what the upper temperature limits were.

We'd run systems tests on things like windows, lost tiles, lost coating. There was a certification test that was supposed to be run and was run at Ames. There's a rub tube in the wing, and an aircraft has an elevon on it, it'll look like a flap. With the orbiter, it's a little different than an aircraft in that the gas is real hot, so you can't just let air leak through where the pivot is on that flap, or you get hot gas and you get it trapped down in there. There's no way for the surfaces to radiate the heat away. The parts try to come to the temperature of the gas, which is going to be like 10,000, 12,000 degrees Fahrenheit. There's nothing that'll survive like that so you can't let the hot gases flow through.

There's this tube, a fairly thin metal tube, that had a Vespel rub tube on it, just a long strip that was spring-loaded that would go against this tube. That was supposed to be a gas seal to keep this flow from going through the wing. Ames wound up running the cert test on it, but Max Faget was very worried about that tube causing a burn-through and the loss of the vehicle. He didn't want to wait until they ran a certification test to find out about it.

He commissioned us to run some definitive tests that would tell him if the design was okay or not. We designed a test article that had this rub tube in it and had tiles on it. It had the inlet which is called a cove that goes smoothly into the rub tube. It was instrumented heavily. We could run it in our channel nozzle inside the chamber and the vacuum from the vacuum system in the chamber would be applied to the back of this test article. It was like having your hot gas at the right speed and enthalpy on the input side, like the bottom of the wing, and then this vacuum being applied to the other side of the test article was just like the low pressure you'd have at the top of the wing when you're entering. We measured the flow rates through there and temperature rises in the materials and then we would adjust the gap between this rub seal and this tube.

Winston [D.] Goodrich, that was one of the aerodynamics people, along with Carl [D.] Scott—in fact we wrote a paper on this. We came up with a parameter that could take our test data and correlate it to flight and so that's how they got confidence that that elevon cove design was good, long before they ran the real cert [certification] test they already knew what was going to happen. We were involved in things like that all the time.

There's high pressure gradients like I was talking about with driving the flow down in these gaps. There's the chine region, which is where the wing goes into the fuselage. That's a pretty large radius, and it has tiles with gaps. Because the flow is going around there, it'll be high pressure on one side and low on the other. We built a large model of the chine region and ran a lot of tests and would put gap fillers in it and made a lot of measurements to determine what flow angles were acceptable with these gaps and again the width and depth of them. There's just dozens and dozens of different kinds of systems tests that we were involved in.

ROSS-NAZZAL: Mr. Vera had mentioned the importance of his facilities in terms of selecting the tile. You had mentioned that early on they were looking more at ablatives and different types of—

MILHOAN: In fact the first orbiters had Apollo ablator on them. There was an area between the fuselage and the elevons. The elevon is moving up and down, well, there's a gap between it and the fuselage and so there's no seal you can put in there. You just have to let the hot gas flow through there so the original designers were originally designing with tile in there. Then the analysts said, "Well, that's going to melt off and you're going to lose the vehicle." They said, "Well, we'll put Apollo ablator in there." Those gaps were originally lined with Apollo ablator. Well, Apollo ablator, that stuff is not cheap, and every mission they had to refurbish it. The orbiter is an expensive thing to turn around, but that was one of the highest cost areas, was that Apollo ablator in those elevon gaps.

We used our channel nozzle, and we attached hardware to the exit of the channel nozzle. If you look at the end of the channel nozzle from inside the chamber it just looks like a rectangle when the hot gas comes out of that rectangle parallel to all of these copper plates. What we did was we built a test article that went on one side of this exit. It had the shape of an elevon with this Apollo ablator. Then because this vacuum that I was speaking of earlier was on the bottom of this gap, flow would come along like parallel on the vehicle and then it would wrap over and expand down through this simulated elevon gap, just like it would in flight. We ran that and got some good pictures of that. That was to certify that you could even do it that way with the Apollo ablator. Then when the cost issue popped up, we went in and used high density tile, reran the test, and showed that the analysis was too conservative, and that it would work, so then they switched from the Apollo ablator to high density tiles.

ROSS-NAZZAL: Were there different materials that you were testing for the tiles though until this TPS [Thermal Protection] System that we have now was put into place? Were there different types of materials?

MILHOAN: In the very beginning Don Tillian had the original contracts. They had sections back then, and you had section heads. Don worked in the section that was in the arc jet. He wrote the original contracts for the tiles from different companies, which included Lockheed. He did that right out of our facility. We stored them in lockers out here and ran the side-by-side tests that were the basis for selecting Lockheed as the fabricator of the tiles.

ROSS-NAZZAL: Were they pretty similar materials?

MILHOAN: Some of them were made out of mullites and different materials like that. In fact we had one, I forget who made that; we went to run it and it degraded on the shelf just sitting there. The Lockheed materials were obviously superior and so it was an easy selection once we started running tests. But like I said the very original tile procurements were out of our group.

VERA: While they were running some here we were also running at [Building] 13. Don Tillian was involved over there.

MILHOAN: Radiant tests.

VERA: The radiant tests. There were just two different facilities, just different kinds of heating. We were also testing them in Building 13. It's an RHTF (Radiant Heat Test Facility). Then in '75 we went to [Building] 260. That's when the big tests started for the nose cap and for the wing over there. Jim was involved in that also. It was difficult tests. We got them done.

MILHOAN: The name of the group is Experimental Heat Transfer. So it wasn't just arc jets. It was whatever it takes. We used arc jet facilities, convective heating, and radiant. There's some exceptions to it, but generally what you want to do is run the test where you see how it performs. Does it reach some temperature limit and degrade? How does it behave with a flow on it, like gaps, and optical properties of the surfaces, because you have to have good optical properties where you can have high emissivity, that is where you can radiate heat efficiently, because some materials don't. If they don't radiate heat very efficiently then Mother Nature drives their temperature up until they get rid of the amount of heat you need to get rid of. When it does that, they may exceed their temperature limit. The arc jets are mainly used for surface phenomena, flow phenomena, and then systems, when you've got a system design and you want to see what's the response at the base of the heat shield.

The radiant heat is used mainly for getting thermal properties. You could look for something like tiles cracking of the coating. You'll get that in arc jets. You can get all this surface kind of response in arc jets, but it's the thermal conductivity that you get out of the radiant heat. Jim [James A.] Smith was our thermal branch chief. He had this plot that he called the anthill. When they were first trying to design the orbiter with the tiles, they went out to very many companies and there's a process called a guarded hot plate. They would get the thermal conductivity of the material, which is of course important, because if it's too high you're going to overheat your structure.

The tile is made up of very small fibers and still the best insulator in the world. The reason why is it's very small fibers. There's not much advantage to it at atmospheric pressure, because the air in the tile, in a lot of these insulators, is the dominating factor at atmospheric pressure. But when you pump it down and you get rid of the air, then having more fibers is what counts because those are then radiation barriers. These real small fibers are more effective.

VERA: Just to elaborate, you were talking radiant and what the temperatures do through the tile down to the structure. That's what the radiant does.

MILHOAN: Right. This anthill plot of his had temperature on one axis, it had conductivity, and then it had pressure, because the conductivity is a function of pressure. He had whole sets of these anthill plots, and it's temperature versus thermal conductivity at this pressure and another plot at another pressure. If you put all those together from all those different manufacturers, they were all over the place except they had an upper bound that looked like the top of an anthill, like a volcano shape. The data plotted looked like an X-ray of an anthill and those were all the tunnels. It was just a nightmare because nobody could analyze the vehicle because they didn't know what the conductivity was.

There were some gentlemen working in [Building] 13 that came up with a method with our radiant heaters. We would run tests at different constant pressures with a tile array. We had very fine thermocouples at precisely known depths, very small gauge. They were at the surface all the way through the tiles at different depths. We would run tests at a constant pressure and a constant temperature and hold that temperature very constant on the surface. You'd measure all the response. They would have to guess what all these thermal properties would have to be to make it behave that way at each one of these sets of a bunch of different temperatures and pressures all constant. When they got all their guesswork done, then we would run a profile to where we would have a chamber pressure changing as an entry profile, plus the temperature changing, because the conductivity of the tile is highly dependent on the pressure.

VERA: Simulating the Shuttle reentry.

MILHOAN: Right. We'd do that and run these profiles and then the temperature response back here at the bond line where the tiles were glued down—when that matched, then they had confidence. That's the way that every tile that's ever been flown on the orbiter was certified in that little radiant heater over there. But see, that's the radiant heat. You got the high quality as you use it, thermal conductivity and then in the arc jet you'll get like the surface properties. Is the active oxidation a problem, or are the chemistry effects correct?

ROSS-NAZZAL: You had mentioned models. Is that something that you made in house for these tests?

MILHOAN: Most of them were brought in, but we used to build our own test articles in the early days. Just like I was saying like that rub tube model, we'd just go build it. Back in those days we had people at Building 13 that could make tiles. They could cut them out and coat them and fire them in whatever shape you wanted. We would build our own test articles here if they were real custom.

ROSS-NAZZAL: Would you both walk us through a test before the orbiter flew and then a test today that you would run? How does it work? How long does it take? What's the process? How many people are involved?

MILHOAN: Right now what do we have? About 22. I think the peak we had was around 27 or 28 back in the '80s.

VERA: We have two shifts, but a lot of times, not always, we can run some testing during the day and then testing in the evening. There were some issues during the summer with power usage at NASA here, so we were running after 5:00 p.m. sometimes. We have a test requester that says, "We need to run a test." Then the branch decides yes, we can run it, and they schedule it in. They approve it. We have to set up for it, and we have a test readiness review. Safety is involved, NASA safety, and environmental at times. Safety because [of] outgassing of test articles, they give off fumes. As a facility we make sure all systems are operational, everything's ready to support test.

Then sometimes we just have one model or test article to run and sometimes we have 20 or 30 or more that we have to run for somebody requesting tests at different pressures and temperatures, or they just don't want one because they need to do more to see if the data is going to be correct and repeatable. Once all the systems are go and we can start testing, they either come in for the test or they assign one of the NASA test directors to say, "You call it if you have some onboard parameters and we can abort at this level." We're trying to meet their temperature and pressures.

There's different distances we run at and at different temperatures. That's why sometimes they have many multiple test models. Then after it's all said and done there's a test report that's written. Every test goes through a very similar process. It takes sometimes a little time to set up. If we don't have to do a lot of fixture changing, there's different kinds of tests we run, different kinds of holders, different kinds of cooling, preparation in putting a model into a holder and then going into the arm takes some time. They have to change nozzles sometimes. So we have to change the heater configuration, how long is it going to be, is it going to be a short or long heater, and then what kind of nozzle. It all depends what kind of temperatures and pressures you need as to what we use.

ROSS-NAZZAL: Is this request normally from the Orbiter Project Office or Engineering [Directorate]?

MILHOAN: It may be like a subsystem manager, or it could be the Orbiter Project Office. We do real-time flight support. So, for example, you remember when they had to go out, I think it was STS-117, and the blankets over this carbon honeycomb were pulled up, and they wanted to find out [if we] should we go repair it. They found some stainless steel pins and staples and said, "Well, we'll go push it down and we'll staple it and pin it." But nobody knew what those metallic things were going to do during reentry at the location that they were at.

You've got to move pretty fast. They built test articles and got the pins over here. Right here at this table where we're sitting, the astronaut would come over and have a glove, and they would read the script that they were going to have them follow when they repaired it. They folded it down with the glove and put the pins in it and the staples. Then we put that test article in a water-cooled wedge holder that we'd already precalibrated and knew what conditions to run. We ran that and then people were able to see it and say, "Hey, that looks pretty good," and then they said, "Okay, now go out and repair it, because we know it's going to work." We do real-time support like that.

VERA: They repaired it while they were on orbit. After they came back the astronaut who did the repair in space came over and gave his thanks.

MILHOAN: Gave us that guy up there. [Points to wall hanging from the flight crew.]

ROSS-NAZZAL: Who was the astronaut?

VERA: Danny [John D.] Olivas. He's the one who repaired it and he said, "Thanks a lot."

ROSS-NAZZAL: I'm sure he did.

MILHOAN: Even years before that, I forget what mission it was. They had these white deposits show up on a vehicle, I think it was on the runway at White Sands.

ROSS-NAZZAL: At Edwards [Air Force Base, California]?

MILHOAN: Edwards. Then they started looking at all the vehicles and they go, "What is this white stuff?" Scrape it off and try to analyze it. It's calcium carbonate. They thought is that going to cause a problem, where'd it come from. They had a vehicle, and I forget which mission it was. They had it sitting on the pad. They didn't know whether to roll it back and study this problem or what. They said, "We'll run an arc jet test and show that this material is okay if we can for one mission. Then they'll give us time to work the problem."

They got samples of it and we had these RCC [Reinforced Carbon-Carbon] sample pucks. Astronauts flew a T-[38] down there with a puck, and they contaminated it with the stuff off the vehicle. They flew it back. Meanwhile, we had the test point identified and put it in, ran it, and everything looked okay, and said, "You're okay, you don't have to pull the vehicle back." From the time they asked us to run that test until we had the results was 36 hours. We were working round the clock and had to get everything quick because they had to make that decision. They didn't want to leave it sitting out on the pad longer than necessary.

VERA: We get on standby for every flight in case they have problems.

ROSS-NAZZAL: Is it unusual for you to be called?

MILHOAN: Just depends on whether they have a problem. Most of the time, it's okay.

VERA: After they find out they have a problem, we'll have some time before they reenter. They have to do all their space experiments so we have a little bit of time. Sometimes they're up there ten to 14 days, whatever they're up there. It's not like, "I need the information by tomorrow."

MILHOAN: They'll be up there a little while you see before they make the scans and find out about it. Then when they get them, it might be the fourth day or something before you find out there's a problem. It depends on how bad the problem is about how quick you got to move.

ROSS-NAZZAL: How did the *Columbia* [and *Challenger*] accidents impact your facility?

VERA: We were involved in that.

MILHOAN: Of course that was two years of not flying. NASA turns all resources loose when there's a problem. We ran some tests that weren't arc jet tests, but people here were involved in them. For example, there was an infrared handheld pyrometer that the ice team measured temperatures with that day. It was real cold so they had that thing in their station wagon. They went out, and they waited at the pad there before they went out to inspect, and so this instrument was sitting in this heated running vehicle.

Because it was so bitterly cold that day, they waited until last second to jump out and go start making measurements. Well, the instrument is supposed to be stabilized in its environment first. It'll shift the readings and that shift is more important when you're measuring temperatures in the range they were interested in. If it was real hot temperatures they were trying to measure it wouldn't make much difference, but it made a lot of difference to the measurements they were making that day. The accident investigation board wanted to know, how accurate were these readings if this instrument was just pulled out of this warm vehicle?

We went into a mode where we bought a duplicate, and then we also got the instrument they used. We ran a lot of tests on them. I stood out in a field all night long taking measurements on the sky and then when the Sun came up, because the Sun was coming up that morning, and it was early in the morning. We had to know what the background radiation from the sky did to it and the Sun. Then we ran tests. We had a big box with a plate and the same type of paint that the SRB [Solid Rocket Boosters] or the fuel tank used. We had thermocouples all over it, and then they would calibrate it with an oxyacetylene torch trying to get the same predicted heating rate as what the analysts said that jet of gas from the solids, what it would have done to the tank, because there was some dispute among the analysts whether you could even burn a hole through the tank with all that cold liquid nitrogen on the other side.

These analysts were saying, "You can't do it because the liquid is so cold." Of course we were saying, "Well, sure you can, because it'll flash to gas, and then when it's gas you can't get much heat through it." Of course they hit it with the torch and bang, it goes right through it. So that was another input for the panel that showed that yes you can and despite the analysis, you can do it. We were involved in things like that to try to help them understand the thermal data better. Meanwhile, we were working on facility development while we weren't running orbiter tests.

ROSS-NAZZAL: Have you been involved in any of the tests with the goo gun and some of the other fixes for the tile?

MILHOAN: Oh yes, that stuff was developed here. In fact that's the second time around. There was an aborted effort at that early on with the same type of material. This last time they improved things. We've run very many tests on tiles with all kinds of damage with the goo gun, the STA [Shuttle Tile Ablator]-54, and also the overlay, which if you're familiar with that it's the plate. They have these augers, and they put insulation bags in the damaged cavity in the tiles. You take this thin high temperature plate, and you screw it down with these big large diameter augers into the tiles. We've run tests here, both in the channel nozzle and the wedge, developing and certifying that tile repair. We've run very many tests with the tile repair and STA-54 and also the RCC repairs, crack repairs.

There's a material that they spread in the cracks. In fact we're still running some tests on that. That's run in wedges. It's run in such a fashion that you get this pressure differential across it so that the gas coming through the crack will erode it like it would in flight and then also there's larger holes. They have a plug repair, which is high temperature disks of different sizes, they're curved, and there's a single bolt in the middle, and they're like a molly bolt you put in a wall. The bolt and the crossmember goes down through the hole then it springs over. Now you can just tighten the bolt down, and it'll fasten it. It's curved like a potato chip and it's flexible so that when you pull it down it conforms to the shape of the wing wherever you're putting it. We've run a lot of tests. Very early on the first tests that were run on it were run here. We've run many tests and proved that that system will work.

Also in the radiant heat, over the last year and a half we ran a radiant heat test on that plug repair in which we had a big thick wall, about a one-inch-thick wall graphite box that had a section of an orbiter panel about one foot by one foot that had an impacted hole in it. It's out of a real orbiter wing panel. They had put one of these plug repair devices in it. We had that heavily instrumented. We adjusted the heat losses in the bottom of that test article so it simulated a vehicle. We had an optical pyrometer system that used fiber-optic pyrometers that would measure at a number of points the temperature of that thin plate over the RCC. Those pyrometers did that by looking through small holes in the RCC from the back through the little holes in the RCC to the plate that's protecting it over the top. The target area that those pyrometers had to look at was like 1/100 of an inch in diameter and then the pyrometer is maybe about 15 inches away from it. The alignment was a real bear.

Why were we running those things? Well, it had two phases. One of them, we got all the thermal response of the system. The subsystem manager has a thermal math model of how it's supposed to behave on the Orbiter. He needs to validate that model so we built that test article to do that. It had all these temperature responses in it, and then what he did was add the graphite box and the other features of our test setup. He had his math model embedded in another overlay of a math model of our facility.

Some of that stuff, like the amount of heat that would go through the contact area between that cover plate and the RCC, you can't get that analytically, you have to do that experimentally. We got all that data, and he was able to correlate his math model very well with it. Then the second issue with that test was the load. There's that single bolt holding this thing down. As things heat up and metals expand, they're concerned that this curved plate that they compressed that conformed to a different curve shape of the orbiter wing, that if all that loosens up it'll lift up too much and you'll get flow under it.

We built these devices that would measure the load in that bolt and how much that plate would lift. They're very unique setups. Completely different than anything anybody else has ever done. We got that phase done successfully and showed qualitatively that the trends that they thought were going to happen happened. That test is run with the same crew of people we have over here. When people come in with a test request it just depends on what their goals are. A lot of times you can suggest things that they never realized that they could do.

ROSS-NAZZAL: What do you think has been the importance of the arc jet facility in relationship to the Shuttle Program?

MILHOAN: Well, the heat shields would have never been developed without it. The leading edges of the nose and the wing leading edges, the RCC, we got samples of that we can show you. Those are made out of a woven carbon material. It's combustible. It'll burn just like a charcoal briquette. The only thing that protects it is that they came up with this process where they pack fine powder of silica around it, heat it up with no air around it, and that silica will combine with the carbon to make silicon carbide. Silicon carbide does pretty good in air at high temperatures so the outside layer of this carbon shell is converted. It's not a coating you put on it. The outside layer of the carbon combines with the silica, it's converted over to silicon carbide that's your oxidation barrier. That's very thin, so if you get a hole in it, your primary heat shield at the highest heating level starts burning. It's very critical.

There are small cracks, millions of these little tiny cracks in this coating, and oxygen can sneak through there slowly and degrade the carbon, which is where your strength really is. We had to run many hundreds of tests with pucks of this material over and over and over and over and over again at the same conditions to get the subsurface mass loss rate on the RCC. Then there's a whole bunch of conditions to run. A program might take you a year and a half with one whole shift to get the data. They would have never been able to fly the leading edges or the tiles or any of those systems without the arc jets.

The FRSI, flexible reusable surface insulation, was developed here. It was developed in our Test Position 2. First tests ever run were run out there.

WRIGHT: You were talking about the orbiter vents.

MILHOAN: Yes. There was an orbiter vent box test. The orbiter has these rectangular-shaped vents on the fuselage on each side. If you look at it you can see them. Those have their doors that open and close. The purpose is just like what it sounds like. You've got all the structure. It's built like an aircraft, and it's pretty lightweight aluminum. There's cavities all over the place, and they have to vent. The orbiter gains altitude pretty rapidly. Air will come out of all these cavities and has to be able to rush out and get outside or you'll rupture your structure. Like the orbiter doors, you could just lift those or open them up or blow them open.

When you reenter, gas has to go back in those cavities. When you're reentering you got the extra problem of the gas is hot. There's other problems in that the pressure changes according to your attitude of your vehicle at different places in this vent so that there's times when you're entering you could have air going out instead of in or vice versa when you're on launch. So they have to open and close these vent doors all the time.

The vent doors, on the inside of the orbiter they have a screen. It's a fine mesh screen. That screen, I suppose it's probably about 39 inches by 26 or 30 inches or something like that. They had a problem in that the early orbiter [days], the payloads were very small. The air coming in and out of those vents wasn't restricted. The day was coming when they would have a large laboratory with large structures that would almost completely fill up the orbiter payload bay. The size of those structures was such that they would get very near these vents. They didn't know if air would be able to get out fast enough on launch or come in fast enough on entry, that it might restrict it too much, or even if it didn't restrict it too much would the velocity of the air coming in damage the payload.

Even before that problem surfaced they were flying some payloads that had like goldized Kapton insulation on the outside that could get damaged by high air velocity coming in. Those were military payloads [and] were classified. It was getting pretty critical. There was no adequate analysis that could predict this. Even the computational flow dynamics could not predict these complex flows and what would happen.

So all they had available to them was a very rudimentary analysis that everybody knew was wrong, but it was the only thing that was available. That predicted that the air velocities coming in would be extremely high and it would tear up all these payloads. They were extremely interested in getting a cure for that. So the purge, vent and drain manager talked to me because I had discussed a different test but it had some capability of testing something like this.

He came and talked to me, and he explained the problem to me. I told him, "Well, no, we got to do it a little bit different way." What we did was we took the arc heater off, and we used the 40-inch nozzle just to inject gas. We just used nitrogen gas. We used the pumping capability of the chamber. I had them install a system on the repress part of the chamber where we could manually bleed gas into the chamber while we were pumping. That meant that I could adjust the chamber pressure to any pressure we wanted all the way from atmospheric pressure down to 1/1,000 of an atmosphere. At the same time that I could adjust this pressure to anything I wanted. I could flow calibrated amounts of gas up to six pounds a second into the chamber while I was doing that.

They had a vent box. It was a structure that had this vent in it with the actuator and the door. We mounted that over the diffuser inlet that goes to our vacuum system. It was mounted in the chamber over the exit into our vacuum system. That meant I could apply pressure differentials across it. I set up I think it was about 200 probes. They were like aerodynamic probes, the little small tubes. From the pressure impact on there you could calculate the velocity of the air.

I had 80 of them on a movable platform that was inside the diffuser so this test was run with the box mounted one way and then mounted the reverse so you'd get both inflow and outflow. I had all of these zillions of these pitot probes that gave them velocity profiles. I could move them and get it at distance from the test article. Also, we had big plates that simulated the payload, and we would get that plate closer, closer, and closer to the inlet of this vent box. I had pressure taps all over it and probes around it so I could get how hard is it sucking on the plate and what the air velocity was right next to it.

I started buying parts and designing things, and when I ran the last test, Christmas Eve I think it was, that was nine months. Most of that nine months we were running tests on one shift, sometimes two. We had boiler problems at that time that were really plaguing us. About every fourth or fifth run of that, we pumped down, we had to tear into the boiler and repair it, but we kept doing that all of that nine months because they had to have that data to be able to fly.

They came up with a parametric description of how the vents behaved. The venting is based on nothing but the data that came out of—it was Test Position 1 that we did it in. You couldn't do it analytically. It was all experimental data from this laboratory.

ROSS-NAZZAL: What year was this?

MILHOAN: Oh, man, I can't remember, all the years are beginning to blend together.

ROSS-NAZZAL: You mentioned being a test director. Can you share with us maybe one or two of your favorite tests that you ran or maybe missions that stand out in your memory?

MILHOAN: Well, there was a bunch of them. Let's see. Well, some of them I've already mentioned. I think that elevon cove test was real good. Of course the things that stand out are some of the disasters. We had one of these original AVCO arc heaters. It was a Linde type heater. It only had one insulator in it. We started that thing one time and it broke in half. The cathode that's connected to the power supply, it fell down on a thermocouple wire, and the best way it could find to get back to the power supply was through that thermocouple wire. So it vaporized that wire, just like a lightning bolt, only it's continuous. It vaporized that.

At that time, it was a long time ago, we had data on strip-chart recorders. I was standing between this stack of strip-chart recorders and a data system. I'd been standing there a while, and I thought, well, I want to lean on something. So I thought, well, I'll lean on that, or I'll lean on this.

Well, I leaned on the data system. I wouldn't be here if I'd leaned the other direction, because that thermocouple wire came into those strip-chart recorders. You want to talk about some activity. That thing lit up, and it was I guess about 15 inches from me. You could feel the heat from it. It lit up, and plasma was coming out of it and capacitors and parts were blowing up in it. It shot this fireball out, and it's about the size [of] a soccer ball. It's blue-white plasma.

It shoots out of there. Whenever those things touch something they just instantly vaporize whatever the heck it is they touch. When it vaporizes whatever it touches, well, that creates high pressures so when it hits a surface then it comes off of it faster than it hit it. A few of those bounces and the thing is really traveling.

It’s bouncing around the room. People are ducking. It vaporized the plaster off the wall down to the metal lath, just instantly. Maybe it contacts the wall a handful of milliseconds. It just vaporizes it. It’s shooting over the top of people’s heads. It’s the disasters that you really remember.

We had a leak in one of our insertion arms. They’re water-cooled, that hold our test articles. We couldn’t figure out what was wrong with the vacuum. Finally went out there and looked in the window. The water comes out, you see it freezes instantly. The way the leak was, it made a hose, okay, so the ice would form, and it’d make like about the size of a garden hose. Finally it came out and it hit the front of the chamber and then it turned and it went down. There was miles of that stuff in there. It would just go around and around and around. People were just watching it, fascinated with it, because it’s like 500 psi [pounds per square inch] water coming out of there. It’s making this tube, and it’s got several feet of it in the bottom of the chamber. You’ll see it move every once in a while. If it gets a crack in it, see, it’ll spray out there, and it’ll seal. It would come up like a snake, it would arc over, and it would go back down into the pile. Boy! So it’s just a lot of crazy things.

We had a vacuum problem one time. We didn’t know what it was. We didn’t realize it, but there was a failure in our vacuum system. It’s driven off this boiler. It’s an 80,000-pounds-per-hour boiler. If you just keep looking around for an hour you’re going to have 80,000 pounds of ice back in your vacuum system. So finally I went out there and I came back in. I said, “Hey, it’s all frosted over out there.” I said, “It’s like four feet off the ground it’s frosted up.” We put water hoses in there. It took four, five days to melt all that ice.

Then you’ll have things. Of course you got maintenance problems. The shell on the vacuum system, after a number of years of operation, it’s just—they build it as cheap as they can.

It'll just rust through and collapse. Then there was another test we were running that you've got this 10-million-watt power supply hooked up to your arc heater and you've got gas running through it. You go to shut down, and you can't turn it off. That gets important because what'll happen is eventually you can have a failure and it'll arc over. It'll start eating up the whole stand. It's just amazing. It looks like you got a piece of the Sun out there. It'll just eat its way all the way back to the power supply and then back to the grid. We finally got the thing open but it was a real challenge.

VERA: We had a pump come in and not on pallets so I had to get the riggers and call a work order in so it could go to 260 and unload it, P401. Well, here's 1,800 pounds with no pallet so we can't use a forklift. So riggers says, "We won't get there till an hour." We got a shift change going on at 3:30, but people are covering it.

ROSS-NAZZAL: How many tests have you guys run in the arc jet facility for Shuttle? Anybody have that number?

MILHOAN: The run numbers have been changed a lot of times. That method that we've got for the run numbers was first started when the orbiter was in existence. I can go look at that, but it's 3,000 something. Now that's tests. Then you can insert models more than one time. I think I recorded the number of thermal cycles. You might have a model; you might insert it and let it cool down a number of times, it was like 540 model insertions one year. That was our peak.

WRIGHT: Mr. Vera, what are some of the tests or some of the events that happened while you've been here that really stayed in your mind, or something that you did connected with the Shuttle.

VERA: Well, after the [*Columbia*] accident we were involved. Of course every time they fly we're on standby and then we actually have to support them. After the last Shuttle accident, we were investigating what would happen if you get a hole in the wing to the stuff behind there and that was memorable to me. How fast things can burn after a little hole in the wing, and how fast the hole would grow. We did that kind of test also the bonding, fixing of RCC and tiles, if the holes need to be patched in space. To me, the fun part is setting up to run a test. Regardless of what the test is, just the setup. Also either modifications or difficulties—that is what's challenging.

MILHOAN: Our run number in there right now is over 3,500. Probably 90 percent of those are over and we had well over 1,000 probably before that.

WRIGHT: Mr. Vera, have there been times that you have started tests and then you've had to close them down because you had malfunctions for any reason or do you have a pretty good percentage of when you start you go all the way through?

VERA: A lot of times higher priority tests can come in, and we have to reconfigure. So we say, "Okay, well, let's stop this series and start another one." Or, "We've had enough on this, let's do something else." It's always in flux, and we're getting ready to run a test and spend maybe a day and a half and then they say, “No, tear that down, let’s do it for this other test,” so we have to set up something else, but it’s part of the job. It doesn’t get you down, it’s just stuff we have to do.

MILHOAN: They wanted us to schedule things better one time, so we hired this guy that all he did was the schedules, a Microsoft project. He would go around all day long talking to everybody, developing these schedules. You’d have a scheduled meeting once a week. He’d come in with these schedule stacks. It’s about an inch thick. The first thing he’d do was to lay it down. He had the top level schedule. We’d just grab that. Nobody ever looked at the rest of it. We said, “Well, this is wrong,” because things change.

Maybe half the time things change from 7:30 in the morning till 9 pm. It has never been any different from the day I ever walked in this facility. It’s because it’s the nature of the technological field we’re in, the requesters. The inputs that they have and the twists and turns in the analytical results and the contractual elements and the major contractors. The requesters are constantly wanting to change their minds all the time. We just dance on marbles, just keep doing it.

ROSS-NAZZAL: Mr. Vera, you’ll still be running the facility for that final Space Shuttle mission?

MILHOAN: They had that discussion recently.

VERA: Well, we’ll have to support the mission.

MILHOAN: They had that discussion recently and the result is you're going to have to be there for the last one, because we have this real-time mission support. There's a lot of history. For example, let's talk about just tiles. There's a lot of history of the way you can damage tiles and it comes back and it looks okay. Then there's great big damage that a guy can look at it and say, "Whew, we'll analyze it, but man, that's bad." There's a whole twilight zone in between there of lots of different kinds of damage and a lot of different locations on the vehicle where you can't easily make your mind up. You can't make your mind up with a test. You can't make your mind up with the analysis, but you can with both of them together. Like our channel nozzle out here, we've put a lot of effort into computational flow dynamics, studies of our particular test setup. Those same CFD people have CFD analysis of the vehicle, and they've gotten correlations between those.

When they don't have enough faith in their decision-making, they'll run a test. Over in our radiant heating facility there's a locked up cage over there that has prebuilt test articles of tile arrays that fit in our channel nozzle. When they make a flight and you hear "Well, they're going to go examine the tiles," they've got this laser scanner that goes out on the arm. When they take pictures from the Space Station, what they do is they get surface data that tells them x-, y- and z-coordinates of the surface. The computer has what's called point cloud data, that's data that describes this shape of the surface. So if they see damage in there they know all exactly how it's shaped.

Well, they send that data over here to Building 9. They have sitting over there right now a machine with a tool in it; we go get one of these test articles, or we go get three of them. We get one of them, we don't simulate damage on it, we just run it like this is—they tell us what conditions to run on it; we get the temperature response in it internally. Meanwhile, they've got this point cloud data in two of these other test articles over there and they're machining out the cavity in both of these test articles.

VERA: Simulate the damage.

MILHOAN: They take one of them and fly them to Denver [Colorado] where they have a box with a procedure and everything and astronaut gloves and all that under a vacuum. They put the STA-54 in it. Meanwhile, we've run a test on an undamaged one. Then when they're busy at Lockheed trying to simulate the repair we get the damaged one and we run it. Now you've got undamaged and damaged and then we get the repaired one, and we run it. You've got exact duplicates except one of them is not damaged, one of them is damaged and not repaired, and the other one is damaged and repaired.

You take that data, the volumes of CFD studies they've already done, and many runs we've made to support this on our channel nozzle, take that and their flight CFD, and their experience. Now you can make the decision. Now you can make the decision in the no-man's-land. That's the reason we're here. Meanwhile, we're running CEV [Crew Exploration Vehicle] testing part of the time, and we're transitioning over to that. If the orbiter is there we have to support.

VERA: We're optimistic. We're looking at five years from now and what we need. We have critical spare parts that we've ordered. As a matter of fact, what I just talked about, the pump came in, if one of our pumps go out we have a spare. So we can get our maintenance contractor to put it in. We look ahead and what we have to do to support future testing.

MILHOAN: You remember I told you about all these arc jet facilities there used to be? Well, there aren't anymore. There's only one commercial arc jet still operable. The size of the test articles they can run is limited. So you've got Ames, you got JSC. Langley was shut down. Now the AEDC [Arnold Engineering Development Center, Tennessee] has facilities, but those are high pressure facilities. ICBMs [Intercontinental Ballistic Missiles] dive into the atmosphere almost straight down. When they get to lower altitudes, where the density of the air is high they're still going very high velocities. They get very high heating and pressures on them, which is different than manned entry, because people can't take that acceleration. The manned entry is a different environment. We generally have lower pressures and higher enthalpy. Their heating is very high, but the environment we have can be more aggressive.

We've had materials that AEDC has run in their facilities for leading edge inlets to engines. They ran the models, and they still looked like they hadn't been run. Brought them here, and we just vaporized them. We got the temperatures up to the same levels, but our pressures are a lot lower. It's like boiling water. Water boils at lower temperature in Denver. Well, this stuff just vaporizes, it just turns to gas. In their higher pressure environment it doesn't do that. So it can be more aggressive than even an ICBM environment.

ROSS-NAZZAL: We should probably end our session, but we certainly appreciate everything you've shared with us today. Mr. Vera, did you want to add something?

VERA: One of the reasons I wanted Jim Milhoan to be here is that he's been very intimate with the arc jet longer than I have. Since he was a NASA test director he knew the ins and outs of the models and test articles and programs, where I have been more on the facility end and supporting. He has too. I've been here 41 years and Jim has been here longer.

ROSS-NAZZAL: We certainly appreciate this sharing of knowledge. If you have any sort of documents or anything about the arc jet in relationship to the Space Shuttle, if you'd be willing to share them, we'd love to get copies.

MILHOAN: This is the best condensed one, ["The Evolution and History of Arc Jet Testing Thermal Testing at the NASA Lyndon B. Johnson Space Center."] Don wrote that, and I modified it, modernized it a little bit more.

[End of interview]