# NASA STS RECORDATION ORAL HISTORY PROJECT
# EDITED ORAL HISTORY TRANSCRIPT

STAN M. BARAUSKAS
INTERVIEWED BY JENNIFER ROSS-NAZZAL
DOWNEY, CALIFORNIA – AUGUST 24, 2010

ROSS-NAZZAL: Today is August 24th, 2010. This interview is being conducted with Stan Barauskas in Downey, California, as part of the NASA STS Recordation Oral History Project. The interviewer is Jennifer Ross-Nazzal, assisted by Rebecca Wright. We are also joined today by Bob [Robert] Sechrist, who videotaping the interview for the Aerospace Legacy Foundation. Thanks again for joining us today, we certainly appreciate all the effort you put into preparing for the interview. I thought we would talk briefly about your career with North American Rockwell [Corporation] and now [The] Boeing [Company].

BARAUSKAS: My career began with North American Aviation [Inc.] in 1963 after I left General Dynamics Astronautics Company in San Diego [California] to join the Apollo program. My job in Apollo was working as a propulsion systems engineer on the rocket engine system for the Service Module. That activity lasted until about 1972 when that program completed with the last Apollo flight, Apollo 17.

At that point a new program started, Skylab, and I worked on that a little bit. The same equipment that was used on Apollo was used again in Skylab, the only difference being that the time duration was much longer. Apollo, the vehicle only flew roughly seven days roundtrip to the Moon and back, where the Skylab had periods of time of 28, 56 and 84 days in flight. We had to certify all the hardware that was Apollo hardware now for the Skylab missions.

What followed after that was the Apollo-Soyuz Test Project, ASTP, where the Command and Service Modules united with the Russian spacecraft, the Soyuz. That program was completed and the company was bought up by Rockwell Corporation in 1967 [forming North American Rockwell Corporation]. By the 1970s the [Space] Shuttle program came into being. Lucky for me, that Rockwell Company was awarded that contract to build the Space Shuttle.

When I moved over from the Skylab and ASTP programs to the Shuttle, my job continued in propulsion and power systems. My first introduction to the auxiliary power unit [APU] came about when I started working on the Shuttle program. My initial desire was to continue working on propulsion systems, but the job that was available at that time was on the APU. Today I'm still working on that. [I've been] working 37 years on the Shuttle program, still working the APUs part-time.

ROSS-NAZZAL: It's amazing. You must have an encyclopedic knowledge of the APU.

BARAUSKAS: I say to these new people coming in working the APU, "I forgot more than you'll ever know." Sometimes they ask me questions about the condition that the APUs were in or the beginning of the program, what took place, what was development like. Sometimes it's really hard to recall that far back. I'm having to think back 37 years, and it's difficult. But I'm a packrat and I actually retained a lot of the documentation from back in those days, so I can always find a reference to back in those years and usually come up with the answer.

ROSS-NAZZAL: Well let's start with the easy question. Where are the APUs located and what's its purpose?

BARAUSKAS: The APUs, there are three of them. They're located in the aft end of the orbiter vehicle and they're installed on the 1307 bulkhead. That's the bulkhead that separates the payload compartment from the engine compartment, [Space] Shuttle main engines. On that bulkhead are mounted the three APUs, two on the left side and one on the right side. The function of these APUs is to provide the hydraulic power that's needed to control the flight surfaces and the flight controls of the orbiter during its ascent stage as well as descent.

The APU itself is actually a fairly small unit. It's only like 100 pounds in weight and it's maybe three feet tall, about two feet wide or so. It's not really huge. But it does operate the hydraulic pump that drives the hydraulic pressure from roughly 500 psi [pounds per square inch] to 3,000 psi to control flight surfaces. During ascent it supplies power to the Shuttle main engine valves, turn them on and off and to throttle them. Sometimes the engines are throttled down to 67 percent, and sometimes all the way up to 104 percent. That's done hydraulically, and that power comes from the APU.

Once ascent phase is over, the APUs remain dormant. All the fuel and the water systems are maintained within the very narrow temperature environment through heater systems that are installed on board. Then the APUs again are required to operate in the descent phase, where they power all the elevons and the vertical tail and the speed brake. And finally upon landing, the landing gear, the nosewheel steering and the brake system, also hydraulically powered through the operation of the APU. The APU is very busy during ascent and descent, but then they're dormant during the on-orbit phase. Simply remain ready to support the orbiter for return to Earth.

ROSS-NAZZAL: I've heard that calling it the APU is a misnomer.

BARAUSKAS: I have to make a point of that, yes. When I first heard that I'd be assigned to work on the APU I thought, "Oh, auxiliary power unit doesn't sound very important to me." Auxiliary means you may need it, you may not, it's an occasional use type device. Then the more I learned about it, the more I knew that actually it's a misnomer. It should have been called the primary power unit because it does provide all the power for the orbiter to operate like an aircraft on landing, and it's got a critical phase during ascent where it controls the actuators that move the Shuttle main engines and also operate the Shuttle main engine valves. Its responsibility is far greater than what an APU has to do for an aircraft for example. On an aircraft, typically an APU starts the engines and it does provide auxiliary power for operating the air conditioning system, lighting, that kind of thing. But the APU on the orbiter is definitely not auxiliary.

ROSS-NAZZAL: What were the requirements for the APU when you came on board in 1973?

BARAUSKAS: Those requirements were pretty amazing, they demanded quite a bit of the APU. The total operating hours that were needed in the original procurement specifications—250 hours of operation with maintenance. Also the horsepower requirements were quite high, 195 horsepower. Those are the requirements that went out to the potential bidders for that contract; the response from the potential suppliers was based on those. Once the winning company, Sundstrand [Corporation], began its development phase, we found out fairly quickly that this 250 hours was not going to be manageable. That was a dream, not going to happen.

The horsepower requirements were reevaluated over time, and [we] found that the hinge moments which determine the rates that are required for the elevons to operate at were not as great as originally predicted. So the requirements for both the life of the unit and the horsepower peak requirements were reduced quite a bit. The life of the unit was reduced initially down to 20 hours, and the horsepower peak requirements went down from 195 to 135. It was quite a drop, and that was determined to be very adequate.

ROSS-NAZZAL: I understand that at the beginning of the program everyone was monitoring components. What were some of the components you were monitoring for the APU?

BARAUSKAS: Of course when you speak of the APU you really are speaking of the APUS [APU system]. The APU system is composed of the APU unit itself, which is supplied by the Sundstrand Corporation, and the rest of the system that supports the APU is the fuel system and the water system. There are multiple other components, like the fuel tank, the control valve, filters, servicing QDs [quick disconnects]. All of those come from other suppliers to make up the entire subsystem.

My responsibility was not to concentrate on any particular component of the APU system, I was responsible for the entire subsystem as a whole. When it came to certifying it, putting it through its qualification test phases, I was responsible for the APU as a component, as well as a participant within the entire subsystem to certify it for both the Approach and Landing Test [ALT] phase and also the orbital flight test phase.

ROSS-NAZZAL: Quite a big task for one person. Tell me about the design phase. I understand for instance at one point there were supposed to be four APUs.

BARAUSKAS: Yes. As a matter of fact, the original plywood mockup that was built as a device that engineering would use for installation purposes—you could look at it even today and you'll see four APUs installed on the aft 1307 bulkhead. That was the proposal that was made to NASA originally. Matter of fact, I worked on that particular proposal where we evaluated 14 different APU system designs. Some of them included interconnecting fuel tanks and a whole variety of different kinds of configurations.

Ultimately we decided on the configuration that we thought served the needs of the orbiter the best, three normally operating APUs and one APU in a standby mode as a backup. It was deemed that three APUs were more than adequate to satisfy all the requirements for the orbiter for its flight, and that we needed one other APU as a backup. In case one of the three went down for some reason, failed to operate, then the other one would be brought online. That standby unit was ready to be put online within a period of a few milliseconds, and would be tied into the fuel system of the other APUs and would take over the function of the one that failed.

This is the proposal that went in to NASA. NASA accepted it, they approved it, they gave us contract go-ahead with the four-APU system. Within a short time, maybe five to six months after that, NASA had a change of heart. They reevaluated their needs and they said that the weight is too great, we can save ourselves quite a bit of weight, over 100 some odd pounds, if we eliminated the standby unit and just go with the three units and operate what is called a fail-safe system.

The previous system would be considered fail operational/fail safe, meaning that you could actually take on say two failures and still have a safe landing. Now NASA decided that they may well do with a single system failure, which is a fail-safe system. Have one APU fail, then the other two APUs remain operating and allow the vehicle to land safely, bring the crew home. They decided to accept an additional risk.

One thing was a curiosity though. The way NASA stated [the requirement] in their contract led to some confusion early in the program. The confusion stayed in the program throughout its entire 30 some odd years and was never completely resolved. NASA wanted to know the capability of a single APU. In other words they hinted that they'd really like to have one APU ability to land the vehicle safely, but they never came straight out and said that.

The way they did it is that they'd like to know what was the capability of a single APU. Is it positive or negative, how much margin did the APU have if two APUs failed? Well, that was never put to the test. There were some simulations done later when it became clear that under really nominal landing conditions, where the wind velocity was acceptable and there was no storm going on and everything was fairly benign, that a landing could be made with a single APU. But it had to be under really perfect weather conditions. Luckily for us we never experienced two APU failures, so we never had that fully tested.

ROSS-NAZZAL: Looking back, do you think it was a good decision on NASA's part to go from four to three for weight reduction?

BARAUSKAS: Yes. I think the weight savings was well worthwhile. I think that sufficient redundancy was built into each of the three strings of the APU system. Only maybe one instance that I can recall where one APU did go down and we had to make a landing with two fully operational APUs. We were concerned that maybe a second one might fail but that never happened. I think the redundancies that we built into the program really served us well. That was a good decision on their part to eliminate that additional APU and reduce the weight, with that benefit.

ROSS-NAZZAL: Tell me about some of the technological challenges that you faced while developing the APU.

BARAUSKAS: There were quite a number. One problem that the APU had was its heat soakback. That was one of the conditions that were very evident we had to overcome. The APU reaches steady-state temperatures at roughly ten minutes of operation. If the APUs were to be shut down after that and needed to be restarted, they couldn't be restarted safely. We found out through development testing the system had to be allowed to cool down to acceptable restart temperatures.

I'll give you an example. The gas generator operates at well over 1,000 degrees [Fahrenheit]. Once it shuts down it begins immediately to cool, but what happens is that the temperatures soak back into the rest of the APU hardware, specifically into the valve and the fuel pump, and those components reach fairly high temperatures. We found out through development testing that if you attempt to start the APU at the elevated temperatures, the fuel is so explosive and contains such high energy that explosions actually occur.

We knew we had a temperature problem that had to be overcome. The way we did it was introduce a water spray system so that immediately after APU shutdown, the fuel pump and the valves would have a spray—as well as the injector. We had three different water cooling systems. Each of those would be cooling the components to a point at which they could be quickly restarted if an emergency arose without any damage to the hardware.

Another problem that had to be overcome was the seal design. The fuel pump seal design was a common seal between the fuel and the oil systems. We found out that was quite an error in the design, because depending on the pressure balance between the two, sometimes the fuel side of that seal was higher pressure than the oil side, allowing some small seepage of the fuel into the oil. Those two are completely incompatible. The fuel would go into the oil and form a wax-like substance, and we came to find out the chemical name of that is pentaerythritol. Depending on the ratio of the fuel and the oil mixing, that waxy substance could be as fluid as molasses, kind of milky, or could be as hard as candle wax. It would even fracture. If you were to hit it with a hammer it'd fall apart in granules.

That's the material that would go into the oil system to plug it up and prevent proper cooling of the high speed bearings within the gearbox. That was a critical thing. It was overcome with a redesign of the seal to separate the seals completely, and also have backup seals, which are called lip seals, that prevent leakage. So we had completely separate sealing between the oil and the fuel. That problem never occurred again after that design feature was introduced. Those are two major ones.

The other one I could say briefly, the original gas generator valve module, the GGVM, that was produced had very hard material, tungsten carbide. It was very good because it would seal very well and prevent leakage. But it has a tendency to fracture, that's the problem. Because it had to cycle so frequently, about two to three cycles per second, the seal and the seat would beat against each other to the point sometimes where the seat would fracture and we'd lose pulse control of the APU. The APU typically shuts down when that event happens.

We had a spectacular case of that happening during the very famous Hubble [Space] Telescope launch. I'll never forget, it was STS-31. There the APU started up like normally, and continued operating for less than a minute when this fracture occurred in one of the pulse control valves. In that event the APU automatically goes into what they call a secondary speed control mode. That's detectable by the data that you see. All the pressures, the chamber pressure and the speed control, move into a different range. You could spot that very quickly.

The crew was immediately notified of that event, and they very quickly—it's amazing how quickly they reacted, they were well trained—shut down that APU. That APU had to be removed and replaced because of the seat fracture, so that Hubble Telescope launch was delayed by several days. Of course subsequent to that the APU went ahead and worked fine, and we have the Hubble Telescope today still in orbit.

Another major problem that occurred was a fracture of the injector tube within the gas generator. The gas generator is the heart of the APU. That's where fuel is directed, and that's where the catalyst bed is. The fuel goes in and is sprayed onto the catalyst bed, and immediately on contact of the catalyst the pressure reaches as high as 1,400 psi and the temperatures reach about 1,200 degrees or so. That happens in seconds. The hot gases then are directed to the turbine to speed it up from standstill, from zero up to 72,000 rpm [revolutions per minute] in about three and a half seconds. It's a really high powered unit, those fuel tubes are sensing pressures of 1,000 psi or so.

On one particular occasion, STS-9, fuel tubes in two APUs cracked and it caused a leakage of that fuel into the hot portions of the APU and resulted in an explosion where the two

APUs actually blew up. It did not become widely known within all the news agencies because the explosions happened post-landing, after rollout and after wheel stop. Lucky for us it didn't happen just before landing. If that actually occurred even a minute before touchdown that would have been catastrophic. The vehicle would have lost total control and it would probably have totally demolished the orbiter and potentially killed the astronauts. It was really that close. That was something that we were very concerned about, and there was quite a bit of effort made to redesign the injector tube to eliminate that problem in the future.

ROSS-NAZZAL: Pretty significant challenges that you faced. I also understand you were working under pretty severe time constraints, that the APU had to be ready for the Approach and Landing Tests. What impact did that have on the design, development and testing of the APU?

BARAUSKAS: We were in a rush, like you say. Many subsystems did not have to be operational for the ALT. As the title indicates, Approach and Landing Test, it's a test of the orbiter's ability to perform a controlled landing. The orbiter would be lifted up on the back of a 747 [aircraft] as high as between 20,000 and 23,000 feet and then released and allowed to land on its own to illustrate its flight control abilities. Of course the APU played an important role, because the APU provided the hydraulic power to allow the orbiter to fly like an airplane.

The other systems like the SSMEs, the [Space] Shuttle main engines, were not needed. The RCS [reaction control systems] were not needed. A lot of the environmental control systems were not needed because everything happened just relatively a short period of time, just from 20,000 feet down. The orbiter drops at a rate of 10,000 feet a minute, so you can see the total flight time was like two, three minutes long, that's it. All of these other subsystems did not have to be functional, but the APU did. So there was a rush to make sure that the APU was certified to support the Approach and Landing Testing.

I had a role to play in that. We had the integrated test article, the ITA, and we made use of two test cells within Sundstrand Corporation in Rockford, Illinois, to test the capability of the APU system to support the ALT. This ITA is quite a huge, massive test fixture because it actually had a portion of the aft bulkhead. We didn't have to simulate that ALT operation with all three APUs; one was sufficient because they're all very similar, so we reproduced a system number one on the aft bulkhead. We routed the fuel lines, we had the heat exchanger for the oil cooling, we had the water systems, fuel tank, the QDs, everything exactly the dimensions that they would be inside the orbiter.

All of that was installed in cells 11 and 12 at Sundstrand, and there we had the capability to do temperature control. We had liquid nitrogen systems, could drop the temperatures to equate what the temperatures were at a 20,000-foot level. We did environmental control tests, and we did mission duty cycles to simulate the mission of the APUs from the time that they would separate from the 747 to the time it would land. All of that was done in quite a hurry, but everything was done very properly and certification came through fine.

We demonstrated the full capability of the APU. The APU operated very well throughout the entire ALT program. The landings were very successful and the orbiter was in full control. Not to say we did not have failures. We had gone through different kinds of failures, that were not the kind though that prevented a safe landing each time the orbiter was separated from the 747.

ROSS-NAZZAL: I understand you spent time out there for every mission. Would you tell us about your involvement there?

BARAUSKAS: Yes. Because of the proximity of Dryden Flight Research Center [DFRC] within Edwards [Air Force Base, California], it was relatively close to Downey where I worked. My assignment was to be at DFRC to support all the activities that preceded the flights. Typically it would be oil servicing, fuel servicing, functional checkout—make sure all the valving operated properly and the APU operated properly—all of that.

We had tests that are called captive-inactive and captive-active, meaning that the orbiter would be attached to the 747 and fly and not be released. We had multiple flights like that where the systems would be simply dormant and not operated, then we had the active portion where the APUs would operate. Again, the 747 would still have the orbiter attached. Then we had five more flights where the orbiter would be released and actually landed. For every one of those tests I was at DFRC. I enjoyed that.

Matter of fact, one highlight of my whole visit there was to be able to meet with Deke [Donald K.] Slayton, one of the original Mercury astronauts. He was assigned the position as chief of all the astronauts involved in the program. I had an opportunity to meet him in the cafeteria one morning, and we had a really wonderful discussion, about 45 minutes or an hour, while having a leisurely breakfast. He was getting ready for his T-38 [aircraft] flight. I knew later that astronauts all take these proficiency flights they would do periodically. He was getting ready for his flight, and he spotted me in the cafeteria and invited me to have breakfast with him, and it was a wonderful meeting. That was a very enjoyable part of that whole experience.

ROSS-NAZZAL: Did you work closely with the pilots who were still astronauts in the program?

BARAUSKAS: Yes, I got to know quite a number of them. More so during the orbital flight experience, because the ALT there were only like five flights. I didn't get to know them except maybe Deke Slayton on a person-to-person basis. Some of them really interesting to get to know.

One person was Bill [William F.] Readdy, who ultimately became Associate Administrator for the Office of Space Flight for NASA. He was the second in command below the Administrator. He flew three missions. Every astronaut had a certain responsibility, and he was assigned to follow various contractors around the country. Bill Readdy had the APU assignment, so I got to meet him at meetings, and had meals together with him. Every time I would do mission support I would go to Building 4 and go to his office, and we'd have really lengthy discussions about the state of the space program and just things happening in the world.

Another one was Eileen [M.] Collins. I met her a short time after she was graduated from astronaut training, and before she even had her first flight. I got to know her very well because of her visits to Sundstrand in Rockford. We got to be on such a friendly basis that at one point she actually helped my daughter with her high school project. She was really wonderful, and [one of the] friendliest people. Very knowledgeable, really expert. Of course she was the first woman pilot in the history of manned spaceflight and the first woman commander.

When it came time to continue the flight program after the *Columbia* [STS-107] accident, they had to pick the best astronaut they had in the program, because they had new requirements imposed on them they never had before. They picked one astronaut out of all 105 or how many they had, and it was Eileen Collins that they picked to be commander. I thought that was a great statement that NASA made about how much they depended on her expertise to do that mission. So she was commander of STS-114 [return to flight]. She was really wonderful person to talk to.

ROSS-NAZZAL: She seems like a very wonderful person. Were there any changes made to the APU as a result of the ALT program?

BARAUSKAS: I mentioned before that the ALT program was very very successful. Everything went well, the APUs operated like they were supposed to. But let me say this also, that not a single component on the APU unit was left standing. Every piece of the APU hardware was revised, redesigned. The valves, the fuel pump, the gearbox, the exhaust housing—everything was all redesigned. Primarily to provide the APU with the added life that was needed for the orbital flight test program. The ALT was very successful, but that APU that flew for those missions would not have lasted very long in the orbital flight test program or the orbital flight program, which was supposed to be 100 missions for each vehicle, so massive redesigns were put in place.

It still remained what we call the baseline APU. But subsequent to that we realized we had other problems that needed attention, and so Sundstrand proposed an APU that we began to call the improved APU. The original baseline APU was already improved, but this one had that title officially, improved APU. That program was begun through NASA contracting directly to Sundstrand, which is an unusual way to do it. NASA had a separate individual contract with the company directly, not through Rockwell.

Although Rockwell had responsibility over Sundstrand with the baseline APU, NASA had full responsibility for the improved APU program. When the development was completed and the company was going to go into its qualification phase, that's when NASA invited Rockwell to participate. We came into play only [when] the APU was ready for its certification. That's where I came into the picture and began to work with Sundstrand on the improved APU.

The improved APU features—one of the main features, the problem I mentioned before about the fuel and oil mixing. The improved APU program was where the two seals were actually separated, where there's a total separation between the oil and the fuel. The other thing was the fuel pump design was revised. Its gears, other aspects of the seals in the fuel pump, to increase its longevity. The exhaust housing went from a Udimet [metal alloy] to a Stellite [metal alloy] I believe.

Another major thing that actually saved quite a bit of weight was the water system. I mentioned before we had to install a water system to cool the gas generator valve module and the fuel pump down to temperatures to where they could be restarted safely. Sundstrand devised a passive cooling system where they put additional fins and standoffs and isolators, that kind of thing. That helped to reduce the peak temperatures on the pump and the valves to a point where the water system was no longer needed. So the primary and secondary water tanks were removed and all the valving that went with it. All that totally was removed from the aft bulkhead and it was a tremendous weight savings.

The thing that they retained was the injector cooling. That was still considered critical. The injector cooling tank was a fairly small tank. It only contained about nine pounds of water, as opposed to 20 pounds of each of the other tanks, so that was considered a small weight penalty. That was retained only as an emergency in case the APU had to be restarted within seconds or minutes of its shutdown. Which, by the way, never happened. We never needed to restart the APU in an emergency. The system was operated, but only accidentally. The crew sometimes flipped the wrong switch and there was water spray, but there was no damage done with that. It never was needed to use in an emergency mode.

ROSS-NAZZAL: When was the improved APU design started?

BARAUSKAS: The actual design was started fairly early, in 1985, ’86. It wasn’t until three or four years later they had developed it to the point where Rockwell was brought in to do the qualification and certification of that new improved APU. There was one other very important thing. NASA always wanted and desired a life extension of the gas generator. The gas generator in the baseline APU was only good for like 20 hours, and there were plans made to increase its life up to 40 hours with some redesigns, some minor things. But NASA still was not content, they wanted additional life.

We worked closely with the gas generator producer, which was Rocket Research Corporation. Later I think it became known as Aerojet. That company came up with a design that would substantially increase the life of the gas generator and we proposed to NASA that we would make it a 75-hour gas generator, almost doubling the previous 40 hours. The way end of life is measured is the roughness of the chamber pressure, the roughness meaning the hash that you see at the peak of the trace.

It has quite a bit of peaks and valleys, and if it measures to as much as 300 psi from peak to peak that’s considered end of life for the gas generator. Normally it’s a fairly smooth curve and the roughness is only maybe 20 psi, 30 psi. When it reaches about 300 it could potentially begin spiking, meaning the pressure could rise up to 1,900 or 2,000 psi, potentially causing great damage to the gas generator and could totally destroy the APU. That was the criteria that was used.

To my knowledge, to this day no operational APU has ever reached that 300 psi criteria, mainly because many of the APUs are nowhere near that 75-hour life limit. Right now I think the highest one could be as much as 35 to 40 hours. Even nearing the end of the program, the APUs still have a great deal of life left in them today.

ROSS-NAZZAL: Let's go back to the baseline APU. I wonder if you could tell us about some of the more interesting qualification or certification tests that were done really all across the country—at Sundstrand and White Sands, at JSC [Johnson Space Center, Houston, Texas], in California.

BARAUSKAS: That's a good point. The testing was spread out quite a bit. Sundstrand of course was the supplier and manufacturer of the APU. It had its own test facility, but that facility had its shortcomings. The altitude capability is very limited. Only maybe between 40,000 to 50,000 feet altitude equivalent. They attached an exhaust device onto the exhaust duct itself, and it created a vacuum to simulate the altitude environment internal to the APU, not to the exterior. That was a drawback.

The Thermochemical Test Area, TTA, at JSC offered a really large vacuum facility. A big, about 23-foot diameter sphere that could actually create a high altitude environment around the entire APU unit itself, not just the internal portion of it. So that became the test bed place where a lot of the qualification and certification testing was done. We made an agreement with

NASA JSC at that time to make use of that facility and be able to demonstrate all the qualification requirements.

The [NASA] White Sands Test Facility [White Sands, New Mexico] also came into being, initially only as a test bed for heater testing of the APU unit itself. It had a really high altitude facility but it could not handle the exhaust products and still maintain a vacuum. They could go as high as 300,000 feet or so equivalent space vacuum and it was considered a very very good test of the heater system. Later on, years later, TTA finally could not do hot fire testing anymore of any kind. They had some safety restrictions imposed on them, and they could not do any more hot fire testing or anything to do with really hot gases.

That was the point at which White Sands came into being. A test facility was provided where APU could do hot fire testing there. They could create a really high vacuum around the exterior of the APU as well as the exhaust, but they had limitations. I think the highest equivalent altitude was roughly 200,000 feet. But anything over 45,000 to 50,000 feet is considered adequate vacuum simulation for the APU to be equivalent to space environment. The last few molecules between 40,000 feet and 200,000 feet, they're relatively really few, so there would be no thermal considerations that are critical at all at that altitude.

The other facilities around the country, Saugus/Newhall [California] and another facility in Virginia, had the capability to install the APU in their test facility and do hot fires while the APU was vibrated. That was not a vacuum, it was not a thermal environment. It was simply a vibration environment, allow it to hot fire while it's being shaken at the vibration levels that the orbiter would see. That was done in two places, and that program was very successful.

Matter of fact, it was so successful that NASA decided that the improved APU, even though it had undergone quite a number of design changes, the vibration test was no longer needed. The vibration testing done on the baseline APU would be completely satisfactory, and that test was never repeated. There were quite a number of facilities across the country that were involved in the certification, and I was involved in most of them.

ROSS-NAZZAL: How long did the tests last? Were you running the APUs as the test occurred? Obviously the vibration test might only last eight and a half minutes [duration of SSME operation], but were they lasting 90 minutes in other places?

BARAUSKAS: Typically, as you mentioned, the mission duty cycle for the APU is 90 minutes long. It's composed of the ascent phase—which in the APU case starts prior to T zero. Most other systems begin to operate at T zero, but the APU is required to turn on at T-minus five minutes. It operates for five minutes and throughout the entire ascent. It's about eight minutes until the main engine cutoff takes place. The APU continues to operate for about five more minutes to purge all the lines of the main engines, and then the valves are shut off. That whole activity there is roughly 20 minutes long during the ascent phase.

Then the APU remains dormant in orbit. The heater systems are operating to maintain the water systems and the fuel systems to prevent them from freezing. They're not allowed to decrease below 45 degrees so APUs would be ready to start. Only at one point in time the APUs are required to operate in orbit. That is when they do the flight control systems checkout roughly 24 hours before entry. That's a way to check out all the flight control systems and make sure that everything is operational, the elevons and the vertical tail—all the systems are functioning normally before the orbiter commits to entry.

The commit to entry happens a day later. One APU out of the three is required to turn on at T-minus five minutes, before the deorbit burn of the OMS [orbital maneuvering system] engine takes place. One APU is turned on to make sure that at least one APU is fully functional before they commit to deorbit burn. Roughly at entry interface minus 13 minutes, EI-minus 13, the other two APUs are turned on. All three continue operating well past wheel stop. That's fairly unusual. Most of the subsystems in the orbiter, they're pretty quickly shut down after wheel stop upon landing.

When you're in the Mission Control Room in Houston [at JSC], you'll see the various engineers at their consoles get up and leave shortly after the orbiter's wheels stop. But the APU engineers are intently watching their data for another 15, 18 minutes or so, because the APUs continue running after wheel stop for quite some time. That's to allow the systems to be reconfigured into what is called a rain drain configuration, meaning the body flap has to be allowed to go down to allow the engines to go down. The reason they call it "rain drain" is in case rain does happen on the runway, the rain does not enter into the injectors of the main engines.

The crew is busy doing other things to safe the systems. They have to safe the OMS system, the RCS—all of that is going on while the APUs are operating. The APUs continue to operate because they're needed to operate the hydraulic systems for the actuators for the main engines and body flap. They're shut down 15 to 18 minutes after wheel stop.

ROSS-NAZZAL: You were testing them at that length to ensure that they would operate safely in orbit and for launch and entry.

BARAUSKAS: Right, exactly. All this activity that I mentioned, the entry and the postlanding—90 minutes became our standard for the mission duty cycle. The testing would be a whole series of these 90-minute tests. Sometimes though we'd throw in an AOA, abort once around. We had to demonstrate the APU would be capable of continuous operation of the APU without shutdown for at least 128 minutes. That's about the longest mission that we have because the vehicle lifts off and it comes back and lands without reaching orbit. Of course that was never done, because every flight so far the orbiter has reached orbit.

ROSS-NAZZAL: Any memorable tests that stand out in your mind that were dramatic or just didn't turn out quite the way you'd hoped?

BARAUSKAS: The mission duty cycle tests were mostly uneventful. There were some tests at the system level which were a little too exciting for my taste. In the system test we were getting ready for the Approach and Landing Test program. The fuel tank isolation valve that we had installed in the system blew up. It exploded one time for no apparent reason. We couldn't tell what happened, but the failure investigation showed us.

The valve itself had a design which is called a bellows design. It would be able to move horizontally, it had convolutes. It was a design such that the surge pressures that were generated by the gas generator valve module while it was operating in a pulse mode—the valves actually close and open about three times a second. When they did that they generated a high peak pressure wave, roughly 300 or so psi above tank pressure. So if the tank pressure was say 400 psi, which it was at the beginning, the peak pressures that would be generated would be on the order of 700 psi or so.

On the failure analysis we found that the tank isolation valve had been experiencing pressure surges in excess of 700 psi, and many thousands of them during a typical mission. As a result, the bellows suffered a fatigue stress fracture. This fracture allowed fuel flow into the valve's electrical system. As a result, the reaction with the wiring system within the valve created such a high pressure that the valve finally exploded and blew off the electrical components from the valve itself. Luckily when that happened, there was no one inside the test cell.

There was some attempt made to recover from that accident by introducing an accumulator into the system that would dampen these peak pressures. That worked very well. The accumulator reduced the pressures down to 10 percent of their peak, down to 30 psi instead of 300. That was really very acceptable, but it meant an introduction of another component within the fuel system. It created paths for additional leakage, and we had to have additional sensors to make sure that we had provided sufficient gas pressure within the accumulator. So it became much too complex a system at that point, and the decision was made to remove the isolation valve and seek out another valve that didn't have that feature.

We put out bids for valve suppliers. The Consolidated Controls Company [Inc.] valve was removed in favor of a Hydraulics Research [Division of Textron, Valencia, CA] valve because it did not have the particular design feature. That valve stayed in the system for quite a long time—until we began to have trouble with that valve, it had its shortcomings. It had a microswitch that indicated its open or closed condition, and the microswitch malfunctioned such that it gave erroneous data to the systems. We tried to activate the valve and the microswitch would indicate the valve was closed when it was open. Sometimes the valve would close and it would indicate it was continuously open.

The valve also was very sluggish over time. It began to operate outside its response requirements. It didn't have the bellows design any longer, but it did have a system where there was a very thin separation, 15/1,000 or so thickness wall separating the fuel and the electrical system. If a leak occurred there it was considered a Criticality 1, meaning that if that failure happened the valve would explode and maybe take down the whole orbiter.

That was considered unacceptable, and we proposed to NASA another redesign, a brand-new valve. We went to another supplier called Moog [Inc.] in Buffalo, New York. That valve was considered a much better design. It didn't have that thin wall, and we paid a penalty of a little over a pound additional weight for every string of the APU system. By paying that penalty we made the valve much more reliable and much safer. NASA accepted that and we qualified it, and it continues to fly today. Excellent performer, has never given us any trouble.

ROSS-NAZZAL: When was that valve replaced?

BARAUSKAS: The most recent one was in the 1992 timeframe.

ROSS-NAZZAL: Were there any other changes made to the APU as a result of the original testing program? Any significant changes, or they were just minor tweaks?

BARAUSKAS: The baseline APU was subjected to numerous changes, and that's how the improved APU came about. The exhaust housing, the fuel pump design, the gas generator valve module, and quite a bit of the components were changed out within the APU unit itself. Beyond that, there are other components within the system. Specifically the servicing QDs. Those things were relatively benign, you would think.

The servicing QDs were unpowered, they didn't have any electrical equipment internally, they had no solenoid valves. Everything was completely just a mate and demate device, and it should have given us no trouble. But it did. Pre-launch, a number of times it would leak liquid fuel, and sometimes it would leak GN2 [gaseous nitrogen]. It became such a problem. We traced it to the ground system itself, the ground QDs that service the flight hardware. The filters within the ground QDs were corroding and the mesh was deteriorating, allowing large particulates into the fuel system, into the QD system.

After many many years of headaches, we proposed to NASA to eliminate that design. We had other servicing QDs that were used by a neighboring system, the RCS. It had shown a history of excellent performance, very little, if any, leakage. The requirements for the RCS were different in a couple of areas, in the temperature area and maybe vibration, so we had to do a very minimal number of tests in order to certify those QDs for use in the APU system. Every one of those were changed for every vehicle. They've been performing very well ever since, and that's over six, seven, eight years ago.

ROSS-NAZZAL: Looking back over the original design, development and test effort, it was very compressed. Do you think there's anything that NASA could have done to improve that period?

BARAUSKAS: Yes, that's a good point. The time compression hurt us in the end. NASA's interest was to complete the qualification and certification program as quickly as possible, because of cost and to demonstrate the APU readiness to support flights. There was an urgency, and time was an important component within the qual [qualification] test program.

What we didn't realize at the time was that downtime between flights was a critical factor in the APU's operation. The exhaust gases actually created a very very harsh environment for the APU internally within the injector system. There were chemicals like carbazic acid played a role in that. Also, any slight leakage from the GGVMs into the gas generator created these gases as well. They may be very minor amounts but over long periods of time, like months in between, they came to be so corrosive that they would actually attack some of the materials within the APU itself.

Notably where that was felt was the injector tube, as I mentioned before. Ultimately the combination of that particular attack by these gases, as well as the installation procedure that was used, created a highly stressful environment for the tubes. Over time that's where the crack occurred in that STS-9 mission and caused severe damage post-landing. There were two APUs found to have these cracks and that resulted in both of these APUs exploding. That was traced to these chemicals that are in the vicinity of the APU at that time.

After we discovered that, any future qualification test program included a time component where the APU would be hot fired, and then it would not be hot fired again for four months to make it similar to the time period between the orbiter's flights. Like if the *Columbia* were to fly in a given month, January, it wouldn't fly again until maybe April or May. That downtime period was then duplicated within the test environment. I think we got much better performance out of our APUs once we evaluated that time factor.

Over time we took operational APUs out of the vehicles just to examine the injector tubes to see how much degradation they had suffered over that time period where they were down. We took samples out on occasion and confirmed our life limit for the APUs. That was very successful and we still do that even today. We do maintenance on these APUs when these are inspected on a periodic level. Every four years APUs are completely removed from the vehicle and returned to Sundstrand for inspection.

ROSS-NAZZAL: When were the baseline APUs finally certified for the first flight?

BARAUSKAS: It was in March of 1980. That was fairly early in the program, years before the improved APU program was begun in the mid ’80s. That baseline APU flew for quite a number of missions all the way through the early ’90s. The baseline APU performed very well over that entire length of time. Then once we had the improved APUs in place, we could extend the life of the APU such that we didn’t need to replace them as frequently as we had to with the baseline. With the 75-hour certification period, none of our improved APUs have approached even near our life limit for the APU.

ROSS-NAZZAL: What role did you play in the testing and checkout of the APUs on board *Columbia* [OV-102] before it flew?

BARAUSKAS: The *Columbia* was of course the first vehicle to be processed through all the testing. I was involved in the certification of the APU for the first orbital flight. Matter of fact, very heavy report [demonstrates document].

ROSS-NAZZAL: It’s what, about four inches?

BARAUSKAS: This is the certification that we submitted to NASA to demonstrate that we are ready for orbital flight. This is my report, I authored this completely myself. And I oversaw all the testing involved in that activity. We demonstrated that we could certify the APU for orbital flight. The *Columbia* was the first one to receive the certified APUs. I made frequent trips to Palmdale during the testing phase, post-installation. Other people had design support that supported the manufacturing personnel to make sure that the installation was done properly; that was not my role.

Once the installation was completed, testing was done under the requirements of the TRSD, test requirements and specifications document. That document controlled all the pass/fail criteria for every test that we did as far as the valve responses, the leakage allowable, and all the APU heater operations. All of those were documented within that TRSD document. I was there for every one of the tests that were conducted before the orbiter was flown again on the back of the 747 to Florida [NASA's launch site].

Once the *Columbia* arrived in Florida, those tests were—100 percent, all of them—repeated again. You'd think it was unnecessary, but it was really very very thoroughly tested. The idea being that what happens during its transit from Palmdale to Florida might have done something to the integrity of the system—maybe it created leakage or knocked insulation off or caused damage to the heater system. That's why KSC [Kennedy Space Center] imposed on it all the testing that Palmdale did all over again.

Before that, it was my responsibility to go to KSC in the late '70s and help create something called the OMRSD, the orbiter maintenance requirements and specifications document, the counterpart of the TRSD. The TRSD was the Palmdale version and the OMRSD was the Kennedy Space Center version. From the OMRSD they prepared actual procedures called OMIs, orbiter maintenance instructions. OMIs controlled all the checkout, the fuel servicing, the oil servicing, the water servicing, all of that. I helped to write many of those.

At KSC I was one of the what's called D squares [$D^2$]. That was the name given to design designees. These are people who were the design representatives for each of the subsystems. That was my role in processing the orbiter *Columbia* through all of its checkout and all of its activities in the VAB [Vehicle Assembly Building] all the way out to the [launch] pad.

I really felt—how should I say—very good about having the ability to be at Kennedy Space Center for the first launch of the Shuttle. I was in the Launch Control Center at the APU console in Firing Room 1 among the guys who actually gave the final go for launch. I was very very honored to be in that spot. I could see the orbiter out on the launch pad. Of course we had to be focused on the screen in front of us watching the data very carefully, because we had to make sure all the systems were operating normally. Otherwise we'd have to call a hold to the launch count before T zero ignition.

Immediately after T zero all the eyes focused on the window to see the actual liftoff. Everybody was cheering, that was a great experience. Having worked on Apollo for almost ten years and never having been at the Cape [Canaveral] to see my hardware be launched into space, that was a great thing for me to be there and actually see my APUs working on their way to orbit.

ROSS-NAZZAL: I can imagine, I'm sure it was quite a feeling. Did you go then to Houston at the MER [Mission Evaluation Room] for the rest of the flight for STS-1?

BARAUSKAS: Yes, I did launch support. I was part of the launch support team for the entire orbital flight test program, which was four flights, and beyond that. I witnessed as many as nine flights from Kennedy Space Center. Once I completed that, I was assigned to go to the MER in Houston to support all the launches and the rest of the mission from the Mission Evaluation Room. I did that for a number of missions, maybe nine or ten.

After that I no longer traveled to Houston and I would be in the Mission Support Room at Downey. We left the Downey facility in the year 2000 and moved over to Huntington Beach [California]. Then I was assigned the Engineering Mission Support Room at Huntington Beach for all the Shuttle flights until I think STS-108.

I think after that all the responsibility for the launch support reverted back to Houston, so the Mission Support Room in Huntington Beach was shut down, was never used again. We did support from our desks. We're just on standby in case there was a need from our Boeing counterparts in MER to call on us for any assistance. We're available, but we do not have direct responsibility for any of the launch support or mission support or landing.

ROSS-NAZZAL: On STS-2 you played a particularly important role. There were some delays caused by the APU and you ended up having a conversation with the [NASA] Administrator [James M. Beggs] about that problem. Can you tell me about that?

BARAUSKAS: That was memorable. Of all my work on spacecraft, all the way back to Apollo and all the way up through all of the Shuttle program, I think those were the most difficult ten days of my entire career when STS-2 occurred. STS-1—as typical of a new system there were some problems along the way, and it finally got off the ground and went through its few orbits.

Everything was fine, the landing took place and everyone was happy. Getting ready for STS-2, we expected a similar uneventful launch. I was there at my station waiting for the countdown, and the countdown went smoothly all the way down to T-minus five minutes. The APUs were started and I was watching the data.

Apparently there was some concern for the PRSD [power reactant storage and distribution]. The cryogenic tank pressures were below normal limits, and the engineers were asked if they should hold the launch based on the violation of the launch commit criteria for the cryogenic tanks. The engineer I heard say that it was okay, that even though there's a violation it's not significant enough to warrant a launch hold. So he advised the engineering staff at NASA to continue on with the launch.

The integration console has responsibility to mask those limits if they're considered okay to be violated. They right away punched into the computer, tried to mask that limit, and they ran out of time. When they reached the T-minus 31 second automatic hold point, the ground launch sequencer system noted the violation and automatically stopped the count. They were too late to mask that limit. Then there was a lot of conversation on the net, "At what point do we recycle? Do we go back to the T-minus 20 minutes, or when?" In the meantime people had taken a hard look at some of the APU data.

At that point I was in what they called the RPS, the record and playback station. This is where we looked at strip charts showing the performance of the APUs, specifically chamber pressure. That was our critical parameter demonstrating how well the APU was performing. I noticed there was some slight violations of our lower limit. It was dropping about 20, 25 psi below—on occasion, not continuously. But I knew the reason for it, and I knew that it was all right for the APU to do that and I thought it would operate normally throughout the rest of the mission. So I gave my go-ahead to my counterpart at the APU console in Firing Room 1, there's no problem to continue with the launch count. We did so, and then we stopped automatically at T-minus 31 seconds because of the PRSD problem.

Then people started looking more critically at the rest of the APU data, which I didn't have at my strip charts. We're not looking at the oil pressure—some people noticed that the oil pressure was increasing to near the unacceptable limits of over 100 psi. So somebody said, "Well, it looks like it's hovering around our limit. We better not take a chance, we need to make sure everything is okay. We should just go ahead and replace those APUs rather than continue with the launch because of this high oil pressure."

Ultimately the failure analysis showed that it was the problem I mentioned before, where the oil and the fuel mixed and the fuel got into the oil system and created pentaerythritol and it was clogging up the filtration system. It was causing restriction in the oil flow and causing the higher pressure to appear. They decided at that point in time to replace those two APUs. It happened on two APUs, which is incredible. The third APU was fine.

During that time it was decided if the APUs were suffering this contamination, what about the rest of the oil system within the orbiter, the rest of the lines that supply the oil. It came to me to come up with a procedure to clean all the rest of the oil system before we installed the new APUs. We didn't want those new ones to be contaminated again with the bad oil. After consulting with Sundstrand, I ended up writing the procedure to flush out and clean the oil system and reinstall the new APUs. We got all that done. It took us about ten days to recycle and install the new APUs, do all the checkouts, all the servicing. There's quite a bit involved in doing that.

We were under constant pressure to get that turnaround done. As part of that pressure—I didn't expect it to come from the NASA Administrator himself. He actually called for a conference call at the Cape. He wanted to have firsthand knowledge so that he could answer questions being posed to him by various news agencies, AP [Associated Press], UPI [United Press International]. Even the President himself [Ronald W. Reagan] was giving him phone calls asking the status of the launch. He sent his Deputy Administrator [Hans M. Mark] down to KSC to provide him that knowledge directly of all the activity that's going to turn the vehicle around.

Christopher [C.] Kraft, who was the director of the Johnson Space Center, had made a trip to the Cape. We had presidents of a variety of companies that were contractors who were there to witness the launch. I was invited into the meeting as the APU representative because the APU was giving the problem, not allowing this launch to continue. James Beggs, Administrator, had me on a conference call with him, answering his questions about what happened, what are we doing about resolving the issue, how soon can we begin the count again. It was unrelenting. He was a powerful man. He let loose with quite a few cuss words, matter of fact. He was really upset. He said he's got these people on his back and he wants this resolution right away and he wants this thing turned around.

He was really upset with everyone at the meeting, to such a degree that after he got off the phone Christopher Kraft actually had to—I swear this is true—apologize for Beggs's language to all the attendees that were there. Because we had some mighty powerful people, presidents of a variety of companies. The Rockwell president, the Grumman [Aerospace Corporation] president. All these people there. It was a pretty elite society and they were all, every single one of them were being cussed out by the boss. It was really hard to take. So I'm glad never to relive that experience. It was once in a lifetime.

We turned around the vehicle in ten days and the APU flew fine. It was my responsibility to call the hold because of the chamber pressure problem, but I knew that was okay. The systems were demonstrating an infusion of bubbles into the fuel system, and I knew what the source of that was. The bubbles artificially depressed the chamber pressure value in our launch commit criteria. I knew these bubbles were temporary and they would go away over time and everything would be fine, so I decided not to call a hold.

One of the APUs that had that problem with the high oil pressure was returned to Sundstrand and installed in a test facility, and the bad oil was removed from the vehicle. That oil was removed from the system and was introduced into the test system at Sundstrand. Again this high pressure repeated itself. It continued on well past the T zero point and for about five or six more minutes until the temperature of the oil system became at its peak stabilized. And once the temperature stabilized, the oil pressures dropped off.

What we learned later through our failure analysis is that that material, the pentaerythritol, even though it's a waxy substance, would actually melt again at a high temperature. It was formed at the ambient temperature, 65, 75, 80 degrees. Then when it reached normal operating temperature of the oil, roughly 200 degrees, it would melt off and the filters would unclog and the system would operate normally. I felt relieved when I found out, I was vindicated that the oil system would not have caused the two APUs to malfunction. That would have been a major disaster if the APUs could not operate for entry.

ROSS-NAZZAL: It's left quite an impression on you all these years.

BARAUSKAS: Yes. Like I say, it's the worst experience of my entire working life, those ten days.

ROSS-NAZZAL: Were you a little nervous at the console, at the next launch attempt?

BARAUSKAS: Yes. I was hoping that my procedure that I introduced flushed out the oil system adequately, that it wouldn't plug up again because I didn't want a repeat of that. But everything went smoothly. Those ten days—as a matter of fact it was so bad, my director at that time, who was doing support of the mission in Houston, hopped on a plane and came and joined me at the Cape at the Kennedy Space Center. He and I would spend time together creating these procedures and working towards installing the new APUs. Our typical workday began between 6:00 and 6:30 in the morning and ended about 10:00 p.m. that night. Typically we would not even have time for lunch, just an exhausting period of time.

ROSS-NAZZAL: On the next flight, STS-3, one of the APUs registered some overheating. Was that something that you investigated while the crew was on orbit?

BARAUSKAS: Yes, that was another case. I think the failure analysis concluded that an underfill of the oil in the APU system experienced that high temperature. The lube oil temperature and the bearing temperatures as a result were increasing to near the limit that is designated within the flight rules for an APU to be shut down. If it reached beyond a certain temperature, the bearings would actually seize and discontinue operating. They would not function anymore, and the APU would have to be shut down. It was approaching those limits. It never reached that limit and continued to operate. I believe that the nitrogen-powered backup system that would control the main engine valves was used at that point rather than depend on the hydraulic system for main engine cutoff.

That's something that I think the Shuttle main engine people did not like to do, use the backup system. They were very very intent on having us review our limits to find out how realistic they were. So we consulted with our supplier Sundstrand and we did extensive analysis and some tests to find out how high a temperature could the bearings get to and still operate normally without causing an APU shutdown and therefore cause the engine valves to shut down.

The way the APU and the engine valves were configured is that each APU was in control of valves of each individual engine. One APU shutdown means that the valves on that particular engine would also—not necessarily shut down, they would actually remain in the position they were in last. So there would be no throttle control, there would be no valve control at all. They could be shut down by a nitrogen backup system, but they could not be throttled either to the low thrust, 67 percent, or the high thrust, 104 percent. That event never occurred, so I think the valves then were shut down by the backup nitrogen system.

Once the studies were made about how high a temperature we could go to with the bearings and still allow the APU to operate normally, we found out we could increase the temperatures quite high and still have good operation of the bearings and of the gearbox. Since that point in time, when the temperatures were raised up we never even came close to violating those limits. That was a good thing that we did, otherwise we would have had a near panic every time because the temperatures were typically fairly high, in the 300-to-350-degree range.

ROSS-NAZZAL: Did you have any concerns about reentry for STS-3? Or you had already performed the analysis and weren't too concerned?

BARAUSKAS: There was a big scramble going on to see how high a temperature we could allow the APU to go. There was some concern about entry. Sometimes when we have a troublesome APU we delay its start until the very last phase, the approach and landing. Roughly 70,000 feet before landing, the APU would be turned on if there's a potential problem. We may have done that [on STS-3], but I don't think we ever experienced that high temperature again. And everything was fine for the landing.

ROSS-NAZZAL: Did you take out that APU after that issue?

BARAUSKAS: That APU had to be removed. It was totally torn down and the bearings were closely inspected. New parts were installed because we were not comfortable with the high temperature that it had experienced. It was a good thing to replace, put in new hardware.

ROSS-NAZZAL: You had already talked about the problem on STS-9 where you had the explosion with the two APUs. Can you tell us about the investigation that went on following that flight?

BARAUSKAS: I was actually in the Downey Mission Support Room when that happened. My job was to watch the strip charts where we record chamber pressure, the APU speed and other parameters—the temperature, bearing temperatures, oil temperatures. I was watching very intently. The orbiter had completed its mission, already completed its rollout and it's at a standstill. Of course, the APUs continue to operate 15 to 18 minutes beyond that. I see this unusual indication that APUs 1 and 2—suddenly chamber pressures go down to zero. I said, "What the heck happened?" So sudden, in a split second. First one, and then a short time later the second one goes down.

I said, "Oh my gosh, this TDRSS [Tracking and Data Relay Satellite System] is acting up." This satellite system was supposed to replace the microwave relay systems, to allow downloading of all the orbiter systems data without depending on microwave relay stations around the world. This was the first usage of this satellite. I figured, "Ah, that thing is malfunctioning, it's causing us to lose data." But I looked at APU 3 and it's operating normally. That can't be the TDRSS, because how could one APU be receiving good data and the other two malfunctioning data transmittal? That can't be. We figured out a second later that there's got to be some kind of problem with APUs 1 and 2 both.

We decided to investigate what was going on with those APUs by sending someone up to Edwards Air Force Base where the landing took place, and see what happened. I was assigned that job. Luckily one of the Sundstrand engineers, [Gary Mionski], was with me at the Mission Support Room. We had an agreement with our supplier that they would provide us with an engineer to support some of the earlier missions, so he was on hand. He and I both made a trip up to Edwards that night and came upon the vehicle maybe 9:00 or 10:00 p.m. at night. While we were driving up, the personnel there made temporary provisions for platforms inside the APUs. They took off the 50-1 door on the right side of the vehicle and we could enter into the aft section and climb up to take a look at the condition of the APUs.

I was astonished, I couldn't believe what I saw. The fuel pump on APU 1 is totally blown to pieces. These are pretty heavy-duty walls, three-quarter-inch thick walls. They were totally broken, and parts were just all around. The valve covers had blown off, there was instrumentation cables that had burned off completely, there was evidence of fire all around the area around the APU 1.

Then I climbed up a little bit higher to take a look at the condition of APU 2, and the same thing all over again. The fuel pump had totally blown to smithereens. Quite a few pieces lying around, blown through some of the insulation. The exhaust duct indicated it had had an impact. One of the pieces, as it blew up, had put a substantial dent in the duct. The piece was flying at pretty high velocity that caused that to happen. There was quite a bit of damage. There was fire all around the APU, and I knew some major catastrophe had occurred.

I climbed back down from the orbiter. We went back to the office there and reported that to everybody around the country who was on pins and needles waiting for our report. Some of them were well late into the night, 3:00, 4:00 in the morning when they were listening to our report. They were just astonished to hear what we found. It was really amazing. The thing that really threw me, astonishing to me, was no evidence of hydrazine in the aft.

We had a safety guy go in ahead of me and [Mionski] in protective clothing. He took samples of the air around the APUs and he had no indication of any hydrazine there. To me it's amazing because the fuel pump that contained all the hydrazine was totally open to the atmosphere. It was broken, it was totally smashed. The body was shattered completely. There was no evidence of any hydrazine; when it came time to drain the hydrazine from the fuel systems, both of them had plenty of hydrazine in the feed line and also in the fuel tank.

Later the chemists explained that possibly because of the air exposure, a thin film was created on the surface of the hydrazine that prevented the gases from escaping. Lucky for me, because I was not in any protective gear. Those APUs had to be very carefully removed and they were returned back to Sundstrand, the vendor. They were carefully inspected, and finally after extensive failure analysis come to find out that it was the tubing. The gas generator injector tube had cracked in each of the two APUs.

At first the thought was that one APU failure had somehow caused failure of the adjacent APU. The two APUs were fairly close proximity, but that wasn't the case at all. Some people even recommended afterwards that we should create a shield of some kind in case of a much more catastrophic failure of the APU. Maybe the turbine wheel might disintegrate and cause an explosion and cause damage to an adjacent APU. There were proposals made to do that but they never won any support. Instead we relied on the speed control redundancy to prevent that from happening.

The failure was found to be the cracking of the injector tube, and several improvements were made. There was a chromizing that was done, which introduced a protective layer in the internal part of the tube. A procedure was initiated that controlled very carefully the installation of the injector tube into the valve. They added very thin strain gauges at several locations around the injector tube and measured how much strain was being introduced into the tube as it was being assembled into the valve. They had to have special mechanical devices that inserted very carefully that tube into the valve to prevent these high stresses from being created, so it was under a stress-free environment from that point on.

There was some attempt also to eliminate the gases that would be created after the shutdown of the APUs within the exhaust duct. I worked on that and I certified that system to introduce a low flow of nitrogen gas interior to the APU to be supplied by K-bottles pressurized at 2,000 psi. It would have a slow dribble of GN2 throughout its entire processing, from the OPF [Orbiter Processing Facility] all the way through the VAB back to the pad prior to launch. But that system was determined to be too cumbersome and had its own faults. It couldn't be maintained, and so that was never introduced. Although one vehicle had provided an access QD into the tubing that would allow this GN2 purge to take place. I think *Columbia* was the only one that had that little tube inserted in it, but it never got in the rest of the vehicles.

That particular problem with the injector tube remains with us today, in that life of the APU is completely dependent on the integrity of that injector tube. There was a program that was put in place that would occasionally remove an APU from service and dissect, do a destructive inspection of, these injector tubes to see if the chromizing layer was intact and see how much potential there is for that injector tube to suffer any more stress cracks. So far we never found any.

ROSS-NAZZAL: I read on the next mission, STS 41-B, you went in and took all the APUs out of *Challenger*.

BARAUSKAS: I don't recall that experience at all. There were steps taken to guarantee for the next launch we didn't have that leak. We had installed in that vehicle small tubing with sensors to sniff any potential fuel leakage at certain critical points within the APU. I was actually a party to that. We had to direct the people, the technicians installing the tubing, to have the tubing placed in critical areas of the APU where there might be indication of fuel leak. We actually did a hot fire of all three APUs before that next launch to guarantee there was no indication of any excessive fuel leak in any of the critical joints. That was done, but I don't recall that we actually replaced all—we may have done that, but I don't know the reason why that would have been done. I do recall putting in those sensors and doing the hot fire test.

ROSS-NAZZAL: Tell us about your time in the Mission Evaluation Room [JSC]. How does it differ from working at the Launch Control Center [KSC] and the Mission Support Room [Downey]?

BARAUSKAS: The Launch Control Center was unique in that its responsibility was throughout the entire countdown. The public, I think, is totally unaware that the countdown actually starts days before T zero. The public always hears, "Ten, nine, eight, seven, six, five—" but the actual countdown is many hours, as many as maybe 100 hours or so before T zero. The launch countdown book, the actual document itself, is five volumes large and consists of 5,300 pages. This is how complete, how critical that countdown is. When I'm there at KSC for the launch support, we're very intent on the last few stages of the countdown period down to where the APUs start at T-minus five minutes. Your other activities, like the heaters powered on and checkout of the speed control unit and caution and warning system, are some hours before T zero.

I think once the vehicle clears the tower, which takes about seven seconds, then all the people at the Launch Control Center can leave their consoles. Their job is done. Not true of the Mission Support Room. There they watch. They have the same data that the people at the Kennedy Space Center watch, it's the same exact information. They're intently watching their screens at the MER as well as the Mission Support Room at Downey. We have all these people watching the same data to make sure somebody doesn't overlook something important.

They continue watching after the Shuttle launches into orbit, and throughout the entire mission. There's somebody keeping an eye on the status of the system throughout its operational orbital phase. The Cape is only concerned about the launches, and they go away and they get ready for the next launch. The mission support is totally different in that respect, that somebody has to be watching that screen all the time, 24 hours a day. Sometimes I would get the first shift or second shift. We have three shifts a day watching continuously every day of the mission.

Later on in the missions our system, the APU system, was so benign and under really good control with the heater systems, that pretty soon even the Mission Evaluation Room and all the various Mission Support Rooms did not support continuously—except for maybe entry, maybe the flight control checkout period. That's when the APUs are active. There was no need anymore to support throughout the entire mission because the heaters are typically operating normally. Other people watch the heater systems to make sure they operate normally. If there's any problem with the way they operate they would report to the APU guys and they would show up and take care of the problem. But in the later missions we got to be pretty confident in how well the heater systems are operating, so there's no need to do three shifts a day support.

The difference between the MER and the MSR is significant, from my point of view, in that the MER was much more sophisticated. They had more screens available that could focus in on some of the data more quickly. They had access to more features than the Mission Support Room either in Downey or in Huntington Beach. There's quite an awakening to show up at the MER and find out what capability they have compared to the MSR in Downey and the EMSR in Huntington Beach. It was substantial, it was a great improvement.

Of course I expect Houston to have the ultimate, because the MER is working very closely with the MCC [Mission Control Center], which is just one floor below them. They constantly communicate, so their data must be very similar to what the MCC is looking at. In Huntington Beach or Downey we never quite duplicated what the MCC looks at. They have capability to call up data faster—to review data, go back to previous data, go forward, look at the data parameters real time as they're being created. The MSR in Downey and Huntington Beach can only recall data that's minutes old; they could not watch the data real time.

ROSS-NAZZAL: Was there ever a time when you were in the MER where you were called on to handle something real time with the APUs?

BARAUSKAS: One thing that comes to mind right away. The APU system depends very much on a water spray boiler, which is a component of the hydraulic system. It does not belong to the APU system, but we depend on it because the oil cooling is done through a system that's contained within the water spray boiler [WSB]. There are cooling tubes within the WSB that control the cooling of the oil. Sometimes the water spray boiler malfunctions such that it doesn't cool the oil lines adequately, so the temperature rises to levels above where we feel comfortable. That event happened at least on one occasion when the water spray boiler malfunctioned.

Then we would have to program a test on return. We didn't do anything on orbit except for the flight control systems checkout. We would test that system, allow it to operate a lot longer than the normal five minutes that checkout requires. We'd run it for maybe ten or longer just to see that the cooling is adequate. The APU system requires anywhere from eight to ten minutes to reach stabilized high temperature, so have to run it that long to see if the water spray boiler is operating normally or is still malfunctioning.

If it's still not operating correctly of course that APU then is delayed from starting until the very last stage of the flight. That APU is left inoperable until approach and landing phase, which is roughly 70,000 to 80,000 feet before landing. That happened on more than one occasion, that's one that stands out.

ROSS-NAZZAL: When *Challenger* [STS 51-L accident] happened [January 1986], were there any questions about was it the APU system? At that point was there some discussion or study into that?

BARAUSKAS: Yes. When that happened, I was actually at Vandenberg Air Force Base [California]. I was in the midst of demonstrating the APU fuel servicing ground system to the Air Force, and turning over control of that to the Air Force and to Lockheed [Corporation]. Lockheed was going to be the company that operated the Vandenberg site, as well as the Kennedy spacecraft site.

As soon as I learned of the *Challenger* failure, I immediately called my boss at Downey to see what I should be doing and whether there was any indication APU played a role in that. My concern was the APU is a very dangerous component because it operates at such high speed and has such volatile and toxic and highly dangerous fuel. I thought, "Oh my gosh, what if the APU blew up and caused damage to the aft section and destroyed the orbiter?"

I had those visions in my mind. I was not doing flight support or launch support because I was at Vandenberg demonstrating the fuel servicing system. I was not party or privy to the data they were looking at, so when I heard from my counterparts in Downey that the APU data looked normal right up to the point of the explosion, I felt relieved. "This is really good, the APU didn't play a role in that." I was very sad for that whole event to happen and it was quite a setback to the whole Shuttle program, but I'm glad that APU didn't play a role in causing that accident.

ROSS-NAZZAL: During that downtime you were working on the improved APU? Was that your focus?

BARAUSKAS: The improved APU development was well on its way. The development contract was just between NASA and Sundstrand, so I wasn't party to that. That was already in place, it was already going on.

But what happened as a result of that was interesting. All the various engineering personnel were on a downturn at that point in the Shuttle flights, even though we were far away from the 100th mission. The systems were designed to operate for 100 missions, and we were far away from that with STS 51-L. Still the layoffs were actually coming on the horizon. We were actually following something called the "Beggs line." This was a line drawn that showed the total engineering population at a certain point high up on the curve, and a line you draw at a certain angle down like this. Down here you'd see the years [demonstrates].

There was a gradual decline in engineering manpower all the way through to the end of the program. The decline was at a rate of roughly 500 engineers per year, that's how fast there was going to be a decrease in engineering population at Downey. Everybody was very concerned about these upcoming layoffs. Shortly after we learned about that Beggs line, the

*Challenger* explosion happened and right away that whole curve swung the other way. We started adding on people. We went from maybe eight or nine people in the APU group up to 19 in a fairly short amount of time.

The reason for that is that NASA initiated a recovery program where they wanted to reevaluate all the Shuttle systems. Not only the orbiter, but the external tank and the SRBs [solid rocket boosters] and the main engines. All those had to undergo a complete certification review from the bottom up. Meaning everybody had to identify all their Crit 1 areas, the highest criticality, had to identify all the specification requirements, identify all the verification, all the OMRSDs. Every document that had any kind of requirement, we had to show where we satisfied that requirement in writing. Everything that we did had to be redone all over again. All the documentation search was going on, and that took over two years to do. We needed to increase the manpower to accomplish all that. Our failure mode and effects analysis, hazard analysis were all updated, all of that.

NASA was looking for any potential, anyplace else in the whole Shuttle system, that such an incident could once again occur. They wanted to prevent that from happening in the rest of the history of the program. We did a very thorough job in relooking at all the requirements, make sure they were satisfied by some test or analysis or similarity. That was a pretty intense period of time, those two and a half years before we resumed launches with STS 26-R.

ROSS-NAZZAL: For *Discovery* [OV-103], those APUs had been sitting for quite some time. Did you change them out or inspect them for the return to flight?

BARAUSKAS: At that point we knew that the APUs could withstand long term installation within the orbiter. We had an every four year requirement to remove them for inspection and do some maintenance on the APUs, but as far as remaining installed it was acceptable. Much later after *Challenger*, even after *Columbia*, we discovered that there's a time factor with respect to APUs' performance from the valve operation standpoint. The valves, if they're not operated, became sluggish in the opening response. The valve had such critical time associated with it, it had to open—they're completely up to speed within about three seconds. They go from standby up to 72,000 rpm in three seconds. If the APU takes longer than ten seconds to reach that speed then the APUs go to underspeed shutdown. In other words there is a criteria that says that they must meet that level before ten seconds expires.

There was an APU that were left standing installed in the vehicle longer than a year, and that APU was started. It took about seven seconds to reach normal speed, where normally it takes about three and a half. So it doubled the amount of time that it took to reach that point. We were very concerned and we imposed a time limit, that if the APU stood unoperated for nine months it would have to undergo a hot fire test on the pad before it would be allowed to fly on the mission. That requirement was imposed on all the APUs just a relatively short time ago, maybe five, six years ago. That was the only concern we had about downtime for the APUs. I think there was some need to drop the tank pressures, that kind of thing, to avoid leakage. But the APUs didn't have to be removed and changed out after a long wait time.

ROSS-NAZZAL: You went back to the Cape to support some of the activities following return to flight. Any of those missions stand out?

BARAUSKAS: I was back there again for at least three flights—STS-26, 27 and 29. 28 was later, they changed them around. Those three missions I returned to the Cape to do launch support to make sure everything was okay. Those APUs worked fine, they had no difficulty at all. So back to normal again, until of course STS-107, *Columbia*.

ROSS-NAZZAL: Did you have any concerns about the APU with that accident?

BARAUSKAS: Well, *Columbia* was totally different. Once again I was not at my station looking at data for that particular flight, I was actually on vacation. That happened on a Saturday morning [February 1, 2003] when entry was taking place, and I was at a ski resort in Mammoth Mountain [California]. I heard about it on the TV, and I called in to work to see if there's anything I could do, maybe cut my vacation short, to come back. Actually, Saturday was the first day of my vacation, but I'd be glad to come back if I could be of any help.

It turns out that they immediately concluded that the APUs were working fine. There was no problem with the APUs, it's all a matter of hydraulic system, actually the wing section, that was responsible for all the entry failures at that point. Ultimately they found that it was that foam material that impacted the wing that caused the gap, allowed the temperatures of the wing to exceed its normal limits. I think someone mentioned it could have been above melting point of steel. So it destroyed all the aluminum structure in the wing, and the vehicle broke apart. The APU, again, played no role in that particular accident.

We did go back again and once again review all the data. The one thing that was astonishing to many people, including myself, is that come to find out in all the failure analysis, the foam impact was a routine event that took place over many many missions, and it was actually recorded and reported over time. There were numerous dings in the tile material underneath the wing and on the surface of the wing. All of this was thought of as being incidental and not critical and just a maintenance problem rather than a serious design defect.

They actually fired a piece of foam that's estimated to be the size of the one that impacted the [*Columbia*] at a test wing, and it created a gap about one foot in diameter. They were astonished at how such a light piece of foam like that could do such damage to that strong wing. But it's a matter of the velocity, the speed at which that foam was traveling, combined with the fact that the foam maybe had internally in it some ice from the condensation from the cold surface of the external tank. That could have been part of the cause, that it was actually heavier than they previously estimated. It astonished everybody, especially I think Ron [Ronald D.] Dittemore, who was the program manager of the Shuttle program at that time. He couldn't believe it.

That foam was captured on film, and people recognized that the foam looked like it had flown off the external tank and potentially was in the vicinity of the wing, but not much was done with that information. I don't know how much they really could have done, because probably there was no potential for rescue. It was a shame that it actually did happen. There was a lot done of course to prevent that from reoccurring, with new design foam installation and heater systems in that pod where the foam actually came off and inspection techniques that they now use. Also some preparations for repair in case that was needed in orbit, started bringing repair kits into orbit with them each time they go. They got that problem under control. Hopefully that's true for the rest of the two, three flights we have coming up.

ROSS-NAZZAL: Hope so. What impact did the President's [George W. Bush's] Vision for Space Exploration have on any improvements you might have had planned for the APU?

BARAUSKAS: Major impact, yes. Before the President's announcement [in] January 2004, we were actually well on our way towards recommending to NASA significant improvements to the APU system. We thought because of the toxic fuels and highly flammable and critical fuels that it would be a great idea to have some protection against leakage, some with detection techniques. We had none at the time. Other safety features for our fuel tank that we could have introduced would be much greater protection for the fuel tank, other features in the electrical circuitry. A single short would cause a total failure, a Criticality 1 short in the system that could be prevented by redesign.

There were a number of items that could improve the safety and reliability, and in some cases the performance. The performance was the least significant factor in our proposal. It's always oriented primarily at safety and reliability. We proposed all of these to NASA as a way to improve the system to allow it to operate up to 2020 or even beyond that. NASA was really looking for inputs like that, and they were going to introduce those into various subsystems across the orbiter.

We were looking forward to incorporating those changes, and all of a sudden we had this vision for spaceflight from President Bush that really canceled all of these proposals, because many of them were of a kind that would be very costly and would take quite a good deal of time to introduce. With the short period of time remaining in the flights, up to 2010, NASA considered it ineffective—cost-effective—to introduce that into the APU system.

They did go along with some other minor changes that were introduced. One of them being a heater system we introduced into the QDs where there was some indication of leakage from the fuel tank, which was a critical concern to us because if gas had leaked out of the fuel tank it would make that system inoperable. We had heaters on the fuel because that could freeze, but the gas obviously would not freeze so we didn't need heaters there. Come to find out that the QD itself would allow some small leakage of the gas from the fuel tank because of the seals. They would harden under very cold conditions so we introduced heaters there to prevent that leak from happening. There was another heater concern that we had in the gas generator valve module where there was a heater introduced.

Those were all fixes that were roughly $1 million, a few months type of impact to the program. So NASA welcomed that and they introduced that into the design. They were fairly easy to implement and very quick and very low cost, but all the others that were $5 million and greater and took about a year, two years to introduce, they were just discarded and not considered. It dampened our activity quite a bit and we didn't have an opportunity to deal with the safety features anymore after that.

ROSS-NAZZAL: Was part of that plan the Advanced Hydraulic Power System?

BARAUSKAS: The electric APU system?

ROSS-NAZZAL: Yes.

BARAUSKAS: Yes, that was a proposal that was made some years back. In 1973 when I first started working on the APU system, I was introduced to a project that just had begun a few months before, the introduction of the electrical mechanical system as a replacement for the hydraulics APU system. I said, "What did I get into?" Here's this brand-new APU system, and the second week I'm in the group I'm already talking about replacing it with a completely different battery mechanical system, eliminating all the hydraulics and all the fuel.

I said, "My career is going to be very short in the Shuttle program." Then, that new system they wanted to introduce was much heavier in weight and somewhat more complex than the fuel system, and there was very little aircraft experience with that kind of system. On the other hand, hydraulics in aircraft they had tons of experience, thousands of hours. A variety of aircraft had experienced the use of the hydraulic system.

The hydrazine-powered APU had very limited use. It was used in the supersonic transport (SST) and the Concorde [aircraft], so there was some experience in airplanes with the hydrazine APU, but really zero with the electromechanical battery-operated systems at that point in time. It was considered not something that NASA wanted to pursue even after it was proposed, and the studies determined that it was going to be much heavier in weight and more complex so they set it aside. That was 1973. It came back again in the 1980s and reintroduced and reevaluated once again. Again it was considered to be too heavy and not able to be introduced.

The last time, the most recent time, was in the year 2000. This time the hydraulic system was left intact. Only the power behind the hydraulics, the APU, was considered as a good potential for replacement with the battery-powered system. The battery now operates completely electronic APU that would not depend on any of the hydrazine fuels, which are very very, extremely toxic. Personnel have to take special care—it was very volatile and extremely dangerous, explosive, a lot of factors against it. NASA wanted to do away with it so they initiated this study of the electric APU.

We consulted with a company in Japan, Mitsubishi [Heavy Industries, Ltd.]. It had created a battery that had sufficient power for our needs, but the question was always about the weight. The weight of the battery was just something that could not be reduced enough to satisfy NASA's needs. Matter of fact, NASA went to the extent that they would accept a weight penalty of 2,000 pounds, the weight in excess of the APU system's weight to be able to incorporate the electric APU. The electric APU could not reduce its weight down below 2,500 pounds. That was one major factor.

The other factor of course was the cost. The initial cost estimated for the introduction of the electric APU in all the orbiters was roughly $350 million to $375 million. By the time development had progressed so many years downstream, the cost zoomed up to in excess of $650 million. NASA were looking towards maybe seeing that number even escalate up to $1 billion level, and they decided to cut it off before they reached that level and not continue with development of the electrical system. So two things knocked it down, the excessive cost and the really heavy weight. They didn't want to pay a 2,500-pound weight penalty to introduce the electrical system.

My role in that primarily was to produce once again the certification plan for electric APU. I was looking forward to actually implementing the plan with great anticipation, but the plan is collecting dust someplace. It never got implemented, but I was ready for it.

ROSS-NAZZAL: One of your colleagues asked me to ask you about how the APU development advanced state-of-the-art hydrazine turbine.

BARAUSKAS: Quite a bit. Early in the development program it was recognized that the APU turbine wheel, which was really a very very critical design, had experienced some blade tip cracks. At the very tip there were some incipient cracks, and also at the root where the blade emanated from the central hub there were some slight cracks. There was some concern about that turbine, particularly because it's accelerating at such high speed that in case the blade may be partially fractured it could release very fast flying particulate that could cause damage to the housing and maybe penetrate the housing and cause damage to the vehicle internally, and maybe destroy the aft section.

There was a design requirement within the procurement spec [specification] that the turbine wheel should be totally contained in case of its complete breakup. In other words if it separated and maybe tips or the entire blade broke off that all that damage would be self-contained within the APU, not cause damage to the surrounding hardware. Sundstrand promised, "Cross my heart, yes I'll do that."

When it came to demonstrate they'd actually succeeded, they could not. A couple of times it accidentally occurred and one time there was actually a planned tri-hub burst. They created cracks intentionally within the turbine to make sure that it failed at high speed, like 150 percent speed. Normally operates at roughly 102 percent speed, but at 150 percent speed it would let loose. When the wheel came apart it caused so much damage. It destroyed the housing and the pieces flew apart and caused some damage to the test cell. They were astonished. Their containment never contained anything, it didn't work.

There was at least one other event where the speed control system malfunctioned, allowed the APU to spin at too high a speed, and the wheel broke apart. Once again it destroyed the housing, it didn't contain the wheel at all. So NASA got very concerned. Instead of providing for a stronger containment, they decided to introduce more and more redundancies in their speed control device to prevent that from happening. They had like quadruple redundancies in the controller to prevent that from overspeeding. That was a good thing to do.

They looked at the turbine wheel itself and found these initial cracks happening at the tip and also at the root, and they went into a massive redesign of that wheel. They beefed up the root area and made it a different shape turbine wheel blade such that it wouldn't experience these cracks, and put it to the test. Put 75 hours on a number of these turbine wheels. Spun them up in different APUs, inspected them at intervals, and did what they call a wheel mapping where they have identified exactly any imperfections in every blade of the wheel. They had like 180 blades. They'd map every one of them, make sure they knew exactly what these blades looked like. After like 25 hours, they'd take it out of the APU, inspect it again, map it all over again, see if any cracks had developed. They did that about three times after every 25-hour period on about three different wheels.

They found out that their design now would not create any cracks that were excessive. On occasion, whenever there was cause for the APU to be disassembled when it's removed from the vehicle, they would do a wheel mapping again. But that was not introduced as a regular part of the maintenance plan. Only if the housing of the wheel had to be disassembled for another reason they'd have a chance to look at the wheel. They never took it apart just to inspect the wheel because it's considered to be such a good redesign. So yes, that wheel was a breakthrough in design for turbine wheels for any hydrazine systems of the future.

ROSS-NAZZAL: Looking back over the development and design phase of the APU, do you think there's anything that NASA or Rockwell or Sundstrand should have done differently, or could have done?

BARAUSKAS: In the early phases of the program, they could have identified the problem much earlier and maybe would not have had this explosion that took place in STS-9. But they didn't know that downtime played a role. That's something that was recognized much later in the program, and they paid the penalty for that because of the downtime and damage that was caused and the lingering problem with the injector tube even today.

Hindsight is 20/20. We didn't know that downtime had even played a role in there. But it did. Matter of fact, most people say the best kind of operation for that APU would be if you connected it up to a huge fuel tank and turned on the APU and let it run for 75 hours without stopping. That would be the most benign condition for that APU.

The problem, it has to stop and start again on a regular basis. The stopping and the starting is what deteriorates the APU much faster than normal operation. They recognized that later in the program. That aspect also was recognized late because of the heat transfer I mentioned before. The heat soakback coming back from the gas generator caused excessive temperatures in the fuel pump and the valve. At one point actually the valve did blow up because they had excessive temperatures. That's something they didn't know.

The function of development is exactly that, it's to find out these problems so you don't have them in an operational APU. The only time we did have an operational APU go bad is when that injector tube cracked and caused the two APUs to explode post-landing. Those problems were recognized much later in the program, and we paid the penalty for that but we recovered from it.

ROSS-NAZZAL: Do you think the APU should be considered for use in future spacecraft?

BARAUSKAS: Absolutely. I don't think there are any more major problems remaining in the APU. All of those were sorted out in all these different test phases and flight phases, we've covered every aspect of APU operation. Just to tell you how good the APU is, the APU is now certified for 75 hours, but demonstrated operation well over 100 hours. There was some thought that maybe we could certify the APU to 100 hours or more, but we decided against it. We decided to call the additional 25 hours of operation as margin over the certified number. We don't want to exceed the 75 hours because it's a procurement specification requirement of the supplier, the vendor.

If you increase that, that means that we have to document their ability to demonstrate the 75 hours, and they could not do that contractually speaking. It's a major contract change. They don't mind demonstrating the APU can operate above 75 hours, but they're not contractually liable for that. All these extra hours that we have demonstrated—just like you carry in your hip pocket kind of thing for emergencies. For example, if you approach 75 hours' operating time on an APU, and there's a potential for adding on another three or four hours or replace the APU with a spare, we'd have no problem allowing that APU to continue and operate for one [or two more] additional flights without any concern. That was the way that additional hours were used.

ROSS-NAZZAL: Did the Marshall [SRB] HPU [hydraulic power unit] have any impact on the APU program?

BARAUSKAS: The opposite I think is more true. On occasion when the HPU had its problems in acceptance test and operationally, the orbiter APU would learn about that and see if it had any kind of comparable problems to contend with. Typically we did not. The HPU mission is substantially different from the orbiter APU mission. The HPU, operating time is much shorter. It starts pre-launch, 15 to 20 seconds. It operates throughout the ascent flight through SRB burn, which is two minutes and six seconds or so.

It has an oil system, but it doesn't have any heat exchanger to cool the oil because it never gets hot enough. It has to operate ten minutes to get hot, so in two minutes of operation it doesn't need any heat exchanger. Doesn't need any heaters because it never reaches orbit. All its requirements are much much less. Its controller is much simpler because it doesn't have all the operation requirements the orbiter APU has.

The HPU guys were invited to participate in all the program review meetings of the orbiter APU, because they would learn about problems that the orbiter has to see if it has any bearing on their operation. It's more like they would learn from the orbiter APU, and we would provide inputs to them. For example the turbine wheel, they were the beneficiary of that. Because their operating time is so much shorter they wouldn't really have a problem with their turbine wheel. They wouldn't experience the high temperatures and the high speed long enough to create these cracks that we had in the orbiter APU. Some fuel pump design changes that we had incorporated earlier, they incorporated in their HPU.

The one thing that we didn't have to contend with that they did is the orbiter APU never saw the ocean, but the SRB HPU got dumped in the ocean every flight. It comes back to Sundstrand and has to be completely refurbished, completely torn down, a lot of new seals put in. Anything that had been exposed to seawater had to be renovated, refurbished, recleaned. [The HPUs were not] tossed away. They were reused over and over many times. After a while the seawater impact would have some corrosive effect and the HPU no longer would be usable, but they did a lot of refurbishment that the orbiter APU never had to do. They came back for maintenance every flight, whereas the APU came back for maintenance once every four years.

ROSS-NAZZAL: In order for the APU to be successful you had to have a successful partnership with North American Rockwell, Boeing, JSC and Sundstrand. Would you talk about that a little bit?

BARAUSKAS: Yes, that partnership worked out really very well. There were some minor hiccups along the way which we took care of to some degree, never completely. We came very close, and that was a relationship among all these factions when it came time for testing. Specifically the certification or qualification testing that I was involved in. In development testing the responsibility was solely Sundstrand's for the APU because they had total control and they were responsible for the development.

Once it came time to do certification, the certification test [often] had to be done in a facility outside of Sundstrand because of the vacuum capability that JSC had at the Thermochemical Test Area, TTA. Also White Sands Test Facility had the vacuum chambers that were needed to demonstrate high altitude operation and thermal control, low temperature environment and high temperature environment. Sundstrand did not have that, so we had to make a great deal of use of those facilities.

The question became who's in charge. Rockwell is responsible for the ultimate certification. But Sundstrand was responsible for the unit as well, so they had to direct technicians as to what to do. The technicians were actually employees of NASA TTA, NASA had its own managers and supervisors operating the test facility. So Rockwell was here directing Sundstrand, Sundstrand was here directing technicians and NASA guys were boss over the technician. Do we pay attention to the NASA guy, the Rockwell guy or the Sundstrand guy?

We had to write what's called a memorandum of understanding in a number of instances. We tried to follow that, but it was really difficult. It was rarely followed to the tee, because oftentimes Rockwell, the contractor, had to bow to the customer. Customer is always right, whatever NASA wants we must do. So we had to compromise all the time. If you were to do some testing and you want to maybe apply an instrument in a certain location, and NASA said, "No, we'd rather have it here."

"Well, no, we'd rather have it here."

"No."

"Okay, you win NASA, you'll have it over there." We have to pacify the customer at the same time we are responsible for the APU for its ultimate certification. We have to direct the supplier to make sure they do their job, and the supplier has to have some control over technicians who actually report to the test agency, NASA. How does a supplier control the technicians? He doesn't really, he has to depend on the NASA supervisor.

The way it worked is that Rockwell gave the requirements to Sundstrand, and the Sundstrand engineering supervisor had to negotiate with the NASA supervisors who were in charge of the test facility, and the NASA guy would direct the technicians as to what to do. It was cumbersome. It was really difficult to work sometimes because we all had to be consulted. Rockwell can't independently tell the technician, "Hey Joe, make that temperature different." We have to clear it with the NASA guy in charge, and the NASA guy has to have an okay from the Sundstrand guy who also has the same responsibility. The responsibilities were everyone's, so it was really difficult sometimes to work closely together because we all had different ideas as to what had to be done. But I think in most cases NASA won out, because the customer is always right.

ROSS-NAZZAL: I just had two more questions for you. What do you think was your most significant accomplishment while working on the APU?

BARAUSKAS: Wow, that's 37 years. It could be a comprehensive one actually. I think the word I would use is certification. I've been involved in many different aspects of the APU activity, including working on the failure mode and effects analysis, the hazard analysis, launch commit criteria, the flight rules, working on the vehicle end item specification. Many different documents—creating the subsystem certification plan, the development plan, working all aspects of it. Being in testing, being in mission support, flight support. But the thing that stands out in my mind was the actual certification of the unit for whatever mission it was required to do.

Initially the Approach and Landing Test program, the APU had to demonstrate that it could support all the missions: the captive inactive and active, the free flight program. The APU [had to] perform its function completely and safely and reliably each time. Then it came time for the APU to demonstrate ability to perform all the orbital operations, beginning with ascent, through orbit, and all the way through landing. All that had to be certified and identified to NASA, the customer, that we could actually perform all the specification requirements fully, to all the extremes of the spec requirements. I think all of those things stand out in my mind as my biggest contribution, certification of that system we call the orbiter APU subsystem that is flying today.

ROSS-NAZZAL: What do you think was your biggest challenge?

BARAUSKAS: I think the biggest challenge occurred after the aftermath of the STS-9 where the two APUs exploded. That was a major major catastrophe from the viewpoint of the APU supplier and NASA and everyone. We thought that we were at the end of our rope. The fact that these APUs could explode caused a lot of people great concern, because if this could happen on the ground this could also potentially happen in flight. That would be a disaster that would not only destroy the vehicle but kill all the astronauts participating in that mission.

We had to make sure that we understood the problem and resolved it completely satisfactorily, because if we didn't we could have another major disaster on our hands. We certainly didn't want to be responsible for creating such a catastrophe that occurred in *Challenger* and also *Columbia*. We didn't want to be a party to that, and we devoted a lot of time and effort to prevent that from happening. So far I think we've succeeded very well. We're continuing to operate the APUs very safely and reliably for the remaining missions.

ROSS-NAZZAL: Anything that we haven't covered about the APU?

BARAUSKAS: One last thing. The last stages of my career in APU, working as I do now short term part-time, my assignment currently is to go through all the documentation that was ever created in the entire APU program and pick and choose what documents are the most important to leave to posterity. That's a pretty heavy-duty decision to make as I go through all the documents that we've collected over 37 years of the program. I'm glad to do it, but sometimes it's sad that I have to dispose of some documentation, some notes that my friends had made over the years. I've gotten to know so many people that worked on the program that were experts in their field, and the tendency is to keep everything that they ever created.

I have to make a decision what's important to retain for posterity, and that's something that I enjoy doing. I think we'll succeed in keeping a great deal of the documentation which identifies all the problems we had and lessons we learned so that the future generation doesn't have to repeat the problems that we had and can create a much safer and more reliable and much better spacecraft for humankind in the far future. So I'm glad to be doing that job in the last stages of my career.

ROSS-NAZZAL: That's important. As a historian I can tell you that's the most important thing. Thank you very much for your time today.

BARAUSKAS: Enjoyed it.

[End of interview]