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INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is August 17, 2015. This interview is being conducted with Dr. Donald Pettit in Houston, Texas, at the NASA Johnson Space Center for the International Space Station [ISS] Program Oral History Project. Interviewer is Sandra Johnson. I want to thank you again for meeting with us today and agreeing to talk to us.

Dr. Pettit, you became a member of the astronaut corps in 1996, and since that time you've served in a number of capacities for the space agency, including science officer for [ISS] Expedition 6, then in 2008 you flew on STS-126, NASA's 27th Shuttle-Station assembly mission, followed three years later by Expedition 30/31, where you served as the NASA flight engineer. You've been involved in many different areas involving the Space Station Program, even before you started at NASA from what I read. If you want to talk about your early involvement with NASA and the Space Station, through your work at Los Alamos [National Laboratory, New Mexico] as a staff scientist, and then working on the Space Station Freedom redesign team.

PETTIT: Wow. It's a pleasure to be here. You just outlined a whole story in itself. When I was a little kid I've always been interested in space and rockets and going off to places away from Earth, and that aspect stayed with me all through college, where I did chemical engineering, both a bachelor and Ph.D. Then when I went to work for Los Alamos, we could spend a fair amount of our effort developing our own research programs, particularly if we could bring in research money, and so that's when I started to work with NASA.

I was right out of school, and I got some research grants from NASA, where we were flying on the [Boeing] KC-135 [zero-gravity aircraft]. That led to meeting a number of people here at the Johnson Space Center, and that led to my being asked to be part of the Space Station Freedom redesign. I think that was like '91 or '92, around in that era, where Space Station Freedom was torpedoed in its current design, and NASA was asked to change it into something else, which is what we have built today. I was part of that team working back in Washington [DC] for about six months, but as a staff member from Los Alamos.

JOHNSON: What sort of things did you do on that team?

PETTIT: I worked on the underdog project. There were three basic tracks that we were asked to look at. One was to do the minimum amount required to make Space Station Freedom into something that looked almost like Space Station today. Then there was one track that was basically make the least possible modifications that you could do and claim at least political success, and that would basically be our exit ramp to our human space program. Then there was the third program, which was kind of an underdog program, and that was the one that I was assigned to.

That program was to put Station up in a single launch with a huge single-moduled spacecraft sort of like Skylab [space station]. There were a lot of pros and cons associated with that. Obviously the track that was ultimately chosen was the track to rescale Space Station Freedom, and basically it looks like 80 to 90 percent of everything that was planned for Freedom ended up being put on the current Space Station.

JOHNSON: When you were working on the research on the KC-135, did you get to fly at that time?

PETTIT: Oh yeah, I had about 80 hours in the KC-135 before I got selected as an astronaut, and I lost a lot of good lunches—or breakfasts, as it was, because we typically flew in the morning.

JOHNSON: I'm sure that wasn't unusual, either. Talk about your interest in becoming an astronaut and applying to be an astronaut, then eventually being selected.

PETTIT: As I mentioned before, I've always been interested in space and exploration and going there. After I was finishing up my Ph.D. at University of Arizona [Tucson] in chemical engineering, it occurred to me that I was qualified to be an astronaut, particularly what NASA had in their literature, and they were going through a selection. I graduated in 1983, and I put in an application for the 1984 selection. I was fortunate right out of the chocks to actually go in for an interview. Out of maybe 5,000 applicants, about 120 come in for an actual interview. Then I got the "Thank you very much for applying to the space program" letter that started off with, "Due to the large number of highly qualified applicants, dah dah dah."

I got that reject letter in 1984, and then over the course of the next 13 years I kept my application current and I interviewed three more times, and I got rejected a total of three times, and the last time, the fourth time, I somehow managed to get in the program. I tell my friends it was probably due to a clerical error, but anyway, I got into the program.

JOHNSON: That was in 1996.

PETTIT: That was in 1996.

JOHNSON: Then, of course, you went through your training, and your first mission was on Expedition 6 in 2002, and part of what you were doing was helping with the continuing construction of the ISS.

PETTIT: That's right. In the 2002-2003 time interval, when I first flew to Station, I likened it to living in a house when you're still building the house. You have a bucket where the kitchen sink should be and a table saw set up in the dining room, and you're living and constructing at the same time. And then you find out you have to invite the boss over for dinner, and that's the equivalent of doing the scientific utilization on Station, which we were doing at that time.

The facilities weren't built, we had one-fourth the electrical power, we had about half the pressurized volume, and we had half the crew size. Resources were limited in terms of power, volume, crew time. We were learning how to operate the equipment. We were turning on equipment like the CO_2 [carbon dioxide] scrubbers, we were learning that we could run it for about two weeks at a time between major failures, and that would require a whole bunch of spare parts flying up and a couple of days of crew time to get it working again.

We were learning how to operate these systems that we'd never operated before. Like I say, they were all serial number 001. Between its design and the operation and the multiple failures, we were struggling just to keep the water bailed out from the vessel. At the same time, we were adding new construction and we were trying to entertain the boss, which is the science experiments. So, it was a different era than what we find now, where it's Station complete. Station operation is a well-oiled machine, training is a well-oiled machine, and most of the crew time now goes to doing the utilization or the research.

JOHNSON: You mentioned the training is more streamlined now. The training when you went, I would imagine that most of the training was gauged toward the actual construction and not so much the utilization.

PETTIT: It was both. We were learning how to do the training for Station, and it was an international project, so it wasn't something that NASA had complete control over. Training was sort of a dismal, miserable process for the crew. The training was more arduous than the mission itself, because training could be three to four years, first as a backup crew member with no promise that you'd ever fly as prime crew member. Then as soon as you get done with the three to four years of training, you'd be thrown back in the pool for prime selection, not knowing whether or not you were ever going to get prime selection.

When that happened, you were treated just like you fell off the turnip truck and you didn't know anything about Station. You'd got back into Space Station training 101, where they were saying, "This is a module, and this is a solar panel, and here's how the crew will live on orbit," when you've just, a few months before, gone through the full training where you were basically certified to fly. Then you'd go through another three-to-four-year training period as prime crew.

Meanwhile, the Shuttle people were flying every couple of years. If you wanted to fly to Station as a Station crew member, it was almost the kiss of professional death, because you would be training for eight years for one mission, starting off where you didn't even know whether or not you were going to fly, and you didn't know how long your mission was going to be. It could be anywhere from a few weeks to six months. Meanwhile, you saw all your friends flying two or three times in the course of you going through your training period.

This all changed with the help of primarily one astronaut, Piers [J.] Sellers, he's one of my classmates. He saw this and said, "This is crazy." He knew the Russians really well, and he started negotiation with the Russians and got down to what we call the "single flow to launch," where you train for about two and a half years total, from when you start to when you pop out at the other end ready for launch. The first two years of that is kind of generic training where you are backup crew for the crew that launches six months before yours, and then you get switched to prime crew in the last six months of your training for your specific launch. That way you don't have a separate backup flow with a separate prime flow, and everybody that goes through the training pipeline pops out at the other end with a flight.

JOHNSON: When did that change, that training?

PETTIT: That changed right around, I want to say 2008, 2009. Just about the time when we started to gear up for six-person crews.

JOHNSON: Did you have any input into helping to suggest that and to plan that?

PETTIT: No, as far as I know Piers Sellers was the main force behind that. He was ahead of his time, because I think NASA program management would've come to the same thing. The system would've broken down if the training profile would've been the same eight-year training profile for every crewmember. Now we have six people a year that we're trying to fly, and the system would've imploded under its own weight. Something would've had to have changed in order to crank out trained people. Piers saw that ahead of time, and with program management agreement he was the one that helped negotiate that and get that worked in.

JOHNSON: When you finally flew on Expedition 6, it was actually supposed to be a couple of months, and it ended up being extended because of the [STS-107] *Columbia* [Space Shuttle] accident.

PETTIT: Yes. On Expedition 6 I was only backup crew member. I'd trained for about two and half years as backup crew member, and we were three or four months from launch. I was anticipating getting thrown back in the pool, who knows when or if I'd get a prime launch, and all of that. Meanwhile, I'd spent about half my time living in Russia.

At that point in the training profile we were spending 60 percent of our time in Russia, and then we had time that you needed to spend in Japan and time that you needed to spend in Canada, and that all came out of the U.S. allotment of time. So, Russia took 60 percent, and the 40 percent was, quote, the U.S. time, but then that was divided between Europe, Canada, and Japan. You spent a small amount of time at home, and you do that for three years, and without even having a guaranteed flight assignment after that.

In my case, about four months before launch, I was switched out with Don [Donald A.] Thomas due to medical reasons, and I flew as backup. So, I had a much shorter route to Space Station than most people had at that point in time, and it was only because of this fluke of being switched out. Expedition 6 at that time was going to be one of the shortest missions to date. We were going to launch in October, and we were going to come back in January.

There was STS-113, somebody drove a platform into the Canadarm [Shuttle Remote Manipulator System (SRMS) robotic arm] when it was on the [launch]pad, and they had to reevaluate to see whether the arm was okay. We were bringing the P1 Truss up, and we needed to fly the arm with heavy loading, and it took them a month to figure that out. So, we launched in mid-November, and by that time the Shuttle that was going to pick us up, [STS-]114, had been pushed into February. So we were still going to be the shortest Expedition to date, and then that changed with *Columbia*.

JOHNSON: How did that affect what you were doing on Station? As you said, there was the construction part of it that you were going to be doing, and then the science. How did that extension for another four months affect your stay?

PETTIT: The extension allowed us to get a whole lot more work done. And [Kenneth D.] "Sox" [Bowersox], Nikolai [M.] Budarin, and I, we worked really well together. I was the rookie, and both of them were very experienced people. We ended up doing two EVAs [Extravehicular Activities]. These were staged EVAs, EVAs done without a Shuttle docked, and that had only been done one other time before on the U.S. side.

A staged EVA is in a different regime than when the Shuttle is there, because if you make a mistake and drift off, the Shuttle, in concept, can undock and go get you. If you drift off at Station when there's no Shuttle there, it's game over. So they're in a little different regime of seriousness. We did the second and third staged EVA during that time.

We had quite a few science experiments onboard. There was no time to do them during our planned mission, but now there was time to do them. There was lots of construction, lots of things that were broken that we now had time to fix. So we were busy. I don't think there's ever an opportunity to be not busy when you're in space, there's always something to do.

JOHNSON: You devoted some of your time to the Saturday Morning Science [videos] during that time. Was that your idea, to come up with that and to start making those videos?

PETTIT: Saturday Morning Science. Sox actually came up with that term, but it was my invention, and it really wasn't an invention. What it is is, what do you do in your off-duty time? On a Shuttle mission, there's such an intense short phase of flight. You're working 14 to 16 hours a day, and you're sleeping most of the time outside of that.

On a Station flight, you can't work at that intensity for months and months and months on end, so you have off-duty time. It may only be a few hours a day, but you have some time off. You can't work 12 to 14 hours and then just float into bed and go to sleep, you have to have some unwinding time. We're adults, nobody works like that at home. You have to have some unwinding time, and that's your off-duty time. What do you do in your off-duty time?

I like to use the term off-duty, not free time. There's a difference. Off-duty time is like you would have on a military vessel, where you are off-duty but you're still there and could get called up to work any time. Free time is the idea of, I'm outta here, I'm gone, I'm not gonna answer the phone. And, you have no free time on Space Station, it's always off-duty.

Anyway, what do you do in a few hours a day of off-duty time? There's a number of things. One of my colleagues read 40 books during his mission in his off-duty time. Some colleagues watch DVD movies, one watched over 100 DVD movies. Some like to do e-mail. We have an internet phone, and with certain kinds of K_u band coverage we can call anywhere we want.

Some people like to call their friends and talk on the phone, some people like to send e-mails to their friends. There will be uplinked football and baseball games, and some crewmembers like to watch baseball games and football games.

So, you have a whole gamut of what do you want to do during your off-duty time to develocitize, recharge your batteries, and get ready so you can attack another day. Any and all of these activities are things that can and should be done at the crewmember's discretion and are worthwhile to do.

What I chose to do was to utilize the Space Station environment and do little techno [technology]-vignettes, scientific demonstrations that show what this environment is like. So, that's what happened with the Saturday Morning Science. It spawned from my personality of I didn't want to watch a movie. I don't watch movies on Earth, why should I watch a movie in space? I don't like to watch baseball, football, basketball games. I'm not a big spectator sport person, so why would I want to watch them on orbit? I read maybe two novels a year. I'm not going to spend time on Space Station reading a novel, I could do that on Earth. So, what I'm going to do in my off-duty time on Station are things that I can't do on Earth. I decided to do extensive photography and to do these scientific investigations of my own design for no more reason than I was there and I could.

JOHNSON: And you continued that. You flew next on [STS-]126, which was another assembly mission, and then again on [Expedition] 30/31 when you were on ISS again. You continued those Saturday Morning Science—I think the name got changed to Science off the Sphere.

PETTIT: Yes, I continued. I changed the name to Science of Opportunity. There's a website developed by the APS, the American Physical Society. It's a physics educational group and they also publish peer-reviewed magazines. They orchestrate a lot of things dealing with hardcore science and education. They, through a memorandum [of understanding] with NASA, would take my raw downlinks, and then they would edit them and put them on their website. They came up with the name Science off the Sphere.

When I talk about it in my own presentations, I like to call it Science of Opportunity. The reason is, what I did on Station has parallels to what scientists do in any laboratory on Earth. You have your programmatic work in your laboratory that just supplies your salary and all your facilities and supplies and whatever you're doing. But, because you are there, and because you come up with other ideas while you're working on the programmatic work, and for no more reason than because you can, you develop little side projects, and that becomes Science of Opportunity.

Oftentimes these side projects will gather enough data so you could write a proposal and then that will become future programmatic science that has funding, and can be fully developed. The Science of Opportunity is how a lot of new, innovative science gets ultimately funded and done here on Earth, and I'm just extending that model to Space Station.

JOHNSON: Between your ISS missions, there were some changes as far as the way the Station was looked at. In 2005 it became a National Lab, and in 2011 NASA chose CASIS [Center for the Advancement of Science in Space] to be the nonprofit to help coordinate the science on Station. There were some changes as far as the science itself and what was being done. As you mentioned, your second flight, then you were in a utilization phase. You were starting to, as a member, devote more time to the science and some time, of course, to maintenance and things that you have to do on ISS.

If you want to talk about maybe the differences between the science you were able to do from your first mission, and how those relationships NASA had now developed, including commercial entities such as NanoRacks [LLC], some of those different relationships on that second flight and maybe some of the differences there.

PETTIT: I'd be happy to comment on that. It's all, I think, a step in the right direction. First off, let me take the National Laboratory thing, and CASIS as the nonprofit to run that. Let me first start off with an analogy, realizing that NASA's primarily an engineering organization. They build hardware and operate the hardware, and NASA is really, really good at that.

Take the Hubble Space Telescope as an example. NASA doesn't dictate what that Hubble Space Telescope looks at. The Space Telescope [Science] Institute does, which is a nonprofit, NASA-funded, but outside-of-NASA program that figures out, through academics and other inputs, what the Hubble Space Telescope should be looking at. If you look at the Apollo lunar missions, they had the Lunar [and] Planetary Institute. They helped define what NASA should do in terms of the science and the geology that was going to be postulated to be done on the Moon. Again, NASA's really good with the engineering, really good with the operations, but they have classically relied on outside entities to define the scientific investigations.

Now you look at Space Station. Up to the point of it being declared a National Laboratory, NASA itself was the one that was in charge of the science on Station. They got to a point where they decided that it would be good to use an outside model to help propagate and best utilize the resources of Station. I think that's a step in the right direction, and it's a model that's been used in the Apollo program, it's a model that was used through the Space Telescope Institute.

It's a tried-and-true model where you use an ensemble of industry and academics in an outside organization to review and propose and get the target science done for an expansive, complex, publicly-funded engineering project. I think that's really, really a step in the right direction for the utilization of Space Station.

JOHNSON: As far as how much science you were able to do, as you said, on that first mission it was like inviting the boss over and your house was half-built. And now you're on Station again and you're in a utilization phase. How much time did you actually get to devote to the different projects? And maybe interestingly, the Human Research Program on the NASA side, and then some of the other more commercial research on the National Lab side.

PETTIT: About the science, I could talk about this at length in terms of how well thought out and orchestrated the science is, and the hardware. Let me back up a little bit and talk about utilization. I like to use the word research, because you go out to the public and you say, "Oh, we're doing utilization of Station," and a lot of people don't know, "Well, what do you mean by utilization?" And you have to sit there and talk for five minutes and explain what the utilization is. If you say research, most people in the public have an idea what research is. I differentiate two flavors of research: there's scientific research, and there's engineering research. They're different. They're different animals, but they're both research.

If you look at anybody that has a graduate degree in engineering, whether it's a master's degree or a Ph.D., you've done engineering research in order to get that degree, and that's different than scientific research. You're working in an engineering department, and you're working on the nuts and bolts of advancing typically known technology into some useful and productive way that hadn't been used like that before. As opposed to scientific research, where maybe you're actually discovering something new, whether or not it has any practical applications. The engineering part of the research has some kind of practical spin on it.

Now you get the Station and the utilization. The utilization only includes the scientific research. Under the utilization number, they don't throw in engineering research. I've had discussions with people in the program about this, because I think that we should be, as NASA, getting credit for the engineering research that we're doing on Station. Just as an example, the regenerative life support system on Station, which starts off at the toilet and ends at the galley. I like to call this the coffee machine, because it takes literally yesterday's coffee and turns it into today's coffee.

That's engineering research. There's no place on Earth where we have compact machines that do this. You can be in the middle of a desert, you could be in the middle of the ocean, you could be in the Arctic regions or Antarctic regions, and nowhere on Earth do we do this. We basically toss our urine and figure out some way to make new potable water. If we do recycle our urine here on Earth, we call it a sewage treatment plant and it covers five-acres with huge pieces of equipment. Nowhere do you have a couple of pieces of equipment the size of a refrigerator that you literally pee in one end and you make your dinner out the other end. That's engineering research.

That is considered a system on Space Station, therefore it's not utilization. We're always working on this system. It's always breaking down, because it's number 001, and we're learning how to do this. From my perspective, that should be considered engineering research, because we're learning how to do this for the first time. That's an example of we don't get any credit for utilization for fixing the toilet, but we should, because it's part of this life support system. It's engineering research just as much as doing research on salmonella bacteria or protein crystal growth or any of the combustion experiments. We get credit for that; we don't get credit for fixing the toilet. Anyway, I think they should all be classified as research and everybody get the credit for that.

Now, remind me what the second part of the question was.

JOHNSON: Well, I was just talking about the difference between the amount of time and how that was split out as far as dealing with the Human Research Program, the NASA side, and then you have the National Lab, and you have maybe even some commercial research going on, on your second visit.

PETTIT: By decree, 50 percent of the Space Station resources are for the National Laboratory, and all the commercial stuff comes from that. The National Laboratory, some of it can be non-commercial, because it could be academic, that kind of thing. Some of it could be commercial. That's how the split goes.

A lot of times things are chosen by what hardware happens to be on orbit, and if we have a resupply vehicle that ends up blowing up. Out of about 32 or 33 vehicles, we've had 4 failures since 2010, so about a 10 percent failure rate for unmanned resupply vehicles going to Station, which is about normal. That's in-family for rockets. You have a resupply vehicle failure, and there could be a whole series of experiments that don't get on orbit. So, what you do is, you open up your closet and you pull out experiments that are already there, and you work on those.

The particular orchestration of experiments on orbit may hinge on what your logistic resupply chain is like, and maybe one mission you might do mostly National Laboratory experiments simply because a resupply vehicle didn't show up. Maybe another mission you might mostly work on Station systems or spacesuits—we've been having issues with our spacesuits falling apart. That's sort of figurative, not real, but they've been breaking down, which has required a lot of effort from crewmembers. Many, many hours of rework on the spacesuits on orbit in a way that they were never intended to be worked on, with few spare parts.

These things can come up and take away time, and this is life in a frontier research environment. You go to Antarctica to do research—and I've had an opportunity to do that—things don't necessarily work out per the plan, and you regroup and reassess how you're going to spend your time on a weekly basis, based on the resources you have and what things happen to be broken that need to be repaired.

JOHNSON: You mentioned the resupply vehicles, and of course while you were there on the second flight, the SpaceX [Space Exploration Technologies Corp.] Dragon [cargo spacecraft] arrived and was berthed, and that was the first time that commercial vehicle came. Do you want to talk about that for a moment, and that experience?

PETTIT: Yes. I wasn't supposed to capture the first Dragon spacecraft. My crewmate Dan [Daniel C.] Burbank was supposed to capture it, so he was all trained up for it, and then Dragon got delayed, and then Burbank went back to Earth. So, it was Oleg [D.] Kononenko, myself, André Kuipers, Joe [Joseph M.] Acaba, Gennady [I.] Padalka, and Sergei [N.] Revin were the crewmembers on orbit. The only ones that really trained for the Dragon were Dan and I, and he wasn't there, so I was prime for the Dragon and André was going to be my backup. Then Joe Acaba, who hadn't trained with it at all, was going to be the visiting vehicle guru, and he had a different checklist to use.

I wasn't slated to capture Dragon, and when I knew that I was going to be the one that was going to capture Dragon—we had a little Dragon trainer, a computer-generated Dragon trainer, and I spent a lot of time practicing lassoing Dragon with the robotic arm. It was supposed to have wider deadbands in its stability for yaw, pitch, and roll, so it was thought to be a bucking bronco compared to [Japan Aerospace Exploration Agency (JAXA)] HTV [H-II Transfer Vehicle] in terms of being able to grab this thing with the robotic arm and bring it in to berthing.

I was training to possibly catch something that was not going to be behaving in the way that we were used to having things behave. I wasn't going to let the future of commercial space get muffed up because of some mistake on my part, so I spent a lot of time practicing. I didn't want to see commercial space go down in flames. The way it turned out, it was a creampuff. It behaved very politely, and I was able to snag it with the arm without any undue complications, and then the rest is history.

JOHNSON: You mentioned the photography—and I know we could talk a long time about the photography, and maybe we can do that at another time—but one of the things I just wanted to touch on is, there were a lot of differences in photography in 10 years. Were you still using film on that first ISS flight?

PETTIT: Yes.

JOHNSON: Since it was extended, were you resupplied with more film, or did you have enough? And then, of course, the last one it's all digital.

PETTIT: *Columbia* basically killed film in space. On Expedition 6, we had some of the state-of-the-art digital cameras at the time. This was a hybrid camera made by Kodak and Nikon, and it said "Kodak" and it was a [Digital Camera System (DCS)] 760, but it was built on a Nikon F—I think it was an F3 frame—so it was a Nikon film camera that had a Kodak digital chip put in, but the controls basically ran like a Nikon camera. It was the state-of-the-art chip for that time. We had that, and we had film.

We had two kinds of film. We had Nikon F3 cameras, which were film-based, and then we had the Hasselblad cameras, and they use 70-millimeter film. They were the paragon example of Earth photography. If you wanted to get good Earth photography, you used the Hasselblad cameras and put it on 70-millimeter film. So we had a mix. We could downlink the digital files, but the film files had to stay on orbit. They would go down, and there were Shuttles coming up every couple of months, and so you would have film come up and then film go down, and that was fine. That was the logistics.

Then *Columbia* happened, and we didn't fly Shuttles for two and a half years. Film gets fogged by galactic cosmic rays, and so if the film stays on orbit more than a few months, its usefulness as film deteriorates. So, that killed film. We could barely get enough food and water up to keep the crew going, and had to drop the crew down to two crew from three crew in the post-*Columbia*, and there was not room for film going either up or down. At that time we switched completely to digital cameras.

The film that we had taken for the first half of our Expedition 6 mission, Sox and I buried in the wall of water. Water does an amazing job of protecting things from the galactic cosmic rays, and it stayed there for two and a half years, and it came down on [STS-]114. The folks here in the photo lab developed the film one roll at a time, changed the chemistry, changed the temperatures and development times, and finally figured out a way to develop the film to minimize the cosmic ray fogging damage. We were actually able to recover the first half of our mission photography two and a half years later, after the film came down.

JOHNSON: That's really interesting. I didn't realize that. There were a lot of changes, as we've talked about, and you mentioned the difference in the training, the single flow to launch, but there were some other decisions and things that impacted ISS and some lessons learned. Can you think of anything that you'd like to mention as far as lessons learned with your experience with ISS?

PETTIT: Yes, here's an example: fixing things on orbit that you'd never think possible to be fixed. Because in the Shuttle era and then the Space Station design, it was designed with the idea that four to six Shuttles would service Space Station every year. If something broke, it was in a box, you'd pull the box out and you'd put in a replacement box and you'd fly the broken box home. It would be fixed on Earth, and then you would always have a supply of spare boxes coming up. You didn't need to have a whole lot of spare boxes staying on Station because you were flying four to six Shuttles a year. There's enough redundancy on Station that if a major thing broke, you could put in your spare box. You may not have any spare boxes now, but in a couple of months a Shuttle would fly up and you'd have a new spare box.

That's the design operation that Station was designed for, and now we're operating it under a regime that's completely different than what it was designed for, which is not atypical for any kind of complex machine. Stuff breaks, and there's no spare parts, and there's no way to get the box down, because it might be too big to bring down to Earth, or it might be too big to bring a new one up. What do you do? You have to take the boxes apart on orbit, and you have to be able to figure out how to fix things at the subcomponent level, and these are things that were never intended to be fixed at the subcomponent level.

The method of changing Mission Control [Center] into this was something that Sox and I worked on on Expedition 6. We would have failures, no spare parts because Shuttles weren't flying, and we would suggest, "Well, we could take the box apart."

It was like, "No, no, the box wasn't designed to take apart. The screws are loose, they're not captive." Up to that point, if you took something apart, the screw had to be captive. If the screw would actually come out as a separate piece, which almost everything is down here, that was considered impossible to repair on orbit because you might have a lid that was fastened down with 27 screws, and how could you handle 27 loose screws in a weightless environment. The idea that we were bulls in the china closet, and we couldn't do anything that involved dealing with lots of pieces and any kind of dexterity.

So, what happened was my Omega [SA] Speedmaster watch broke, and it turned out it was a common failure at that time. We had three Omega Speedmasters break with the same thing. The buttons that control it fell off, and then it had the crown, which is a little stem that you can control it. It fell off, and it was basically useless. I decided to take my Omega Speedmaster apart and fix it.

I've had a fair amount of experience doing watch repair here on Earth, and I figured, well, I can do this on orbit. So, I took my watch apart and I filmed the whole thing, and then I put it back together, and it worked. I downlinked that video with the idea of just demonstrating to people that we could do the epitome of fine dexterous work involving dozens of little tiny parts, and we could do this in a weightless environment. After that video was downlinked, then we started to see repair requests come up, taking boxes apart with the 27 loose non-captive screws, and opening things up and taking them apart at the subcomponent level.

One example of that was fixing a freezer we had. We had a freezer on orbit, it was called ARCTIC. It was a thermal-electric based freezer, so there were no moving parts in its refrigeration cycle, and it broke. It failed hard after only a few months on orbit, and it was this big box. It was slated to fly home and be fixed on the ground, and a new one was going to come up, and there was no way to do that. So, we got permission to take it apart, and it had never been designed to be taken apart on orbit.

The screws were put in with Loctite, which is basically a polymethyl methacrylate glue that you put on a screw if you never intend to ever remove that screw again. There are several grades of Loctite. There's a kind to just hold the screws in and you can take them out, and then there's the kind that is meant to never allow you to take that screw out again. That's the kind that they had put this box together with, and there were some thoughts that you'll never be able to get this apart on orbit. There were lots of screws. There were probably 30 screws like that that needed to come out.

Then, once you got the cover off, everything had been sort of squirted with this urethane foam insulation that you squirt all over the parts that get cold. Then the urethane foam expands and just fills the void. In order to get to the parts, you have to take a knife and cut into the urethane foam. It makes all kinds of crumbs, and you've got to pull it apart, and everything's just a mess. I was dealing with all of that with the ARCTIC, and I was able to get down into the brains of the thing, and I got it fixed and put back together.

It was one of these things where it had, I think, eight thermal-electric coolers, and there had been some corrosion, and four of them had gone bad and were not able to be fixed. So, I jumper-wired around those and made it so it ran off of four of the coolers instead of eight of the coolers, and then put it all back together and stuck the chunks of urethane foam in as good as you could, even though you'd butchered it by carving it up with a knife. It wasn't repaired to absolute best, but at least it was working. It's exactly what you would do if you were in the middle of Antarctica or you were someplace else where you can't get spare parts and you want to get your equipment working.

Ever since then, the whole repair philosophy of Station has been vectored towards taking things apart that were never meant to be taken apart, and fix things on a subcomponent level. Now new-era boxes, experiments and things that are coming up to Station, are being designed in the first place to be repaired on the subcomponent level. So that's a long story, sorry about that.

JOHNSON: No, that's great. That's quite a contribution, to allow that. Would you consider that your most significant contribution to Space Station?

PETTIT: It depends. There are things that people see from the outside of NASA, and there are things that people see on the inside of NASA. That's one contribution on the inside of NASA. Most people on the outside don't even know. They probably think that we could repair everything on Station, and they don't realize that Station was designed, basically, not to be repaired on the subcomponent level. So, most people on the outside, if you were to tell this story, they'd probably go, "Huh? It doesn't make sense." It's like making a car where, if something goes wrong with the engine, instead of fixing it, you pull the whole engine out and put in a new engine. I mean, we don't do that with things here.

JOHNSON: As far as challenges, fixing things on that level and having to be in space that extra four months, were there some other challenges or anything that you would think of as being the most significant that you faced?

PETTIT: On Expedition 6—there's always challenges in terms of being extended and its effect on your family. I don't consider that a challenge, just the way that I deal with my family and the communication. As my commander Ken Bowersox said, "When you launch for a six-month mission, you need to be prepared for being gone for at least twice that amount." In this case he was half right. We were prepared to be gone for a couple of months, and we ended up being gone almost six months.

The possibility of an extension should not come as a surprise to anyone. It's not by design, but it's not surprising if it does happen, and I had already prepared my family for that. The fact that happened, I don't think, was that big a deal. You should talk to my wife and get her perspective on that, if you really want to see whether or not I know what I'm talking about. The family aspect of being extended was not, I don't think, a challenge. The crew working together, that was not a challenge. We were such a tight crew, and we were working so well on Station, that there was no issue. There was no issue with that.

Supplies—we were sitting on a mountain of supplies: clothing, food, everything. However, we didn't know when Shuttles were going to be flying, we didn't know how long these supplies were going to have to last, so we immediately went into conservation mode. It's like you're sitting on a mountain of food and clothing and you're starting to ration these things out, not because you need to for your mission, but you're doing that to extend other people's missions.

We started to see how long we could push our clothing, and on Station, as bright as the NASA engineers are, nobody's figured out how to wash clothes on orbit. The model is, you use your clothes for X number of days, and then you use them for rags to clean up messes, and then you basically give them a de-orbit cremation in one of the unmanned vehicles that burns up in the atmosphere. Station crews were allocated a change of clothes every two to three days, and these were the clothes that are in contact with your skin, like your shirt and your skivvies and your socks.

We were stretching that out to about every 8 to 10 days, and the indicator that it was time to change your underwear would be when you started to get a rash around your waist, and then it was time to change that pair of underwear. Then you would down-mode it. You'd wear your underwear for prime daytime underwear, then you'd down-mode it to exercise underwear. We'd exercise for two, two and a half hours a day, and you'd use a different set of clothes for exercising. So, your day clothes would be down-moded to exercise clothes, and then from there you'd down-mode them to rags for cleaning up messes.

We were seeing how much could we extend the supplies on Station, and we found 8 to 10 days for a set of clothes was an adequate kind of number.

JOHNSON: Since we're just about at the time we need to close, I was wondering if you could tell me, what do you believe is going to be the legacy of ISS?

PETTIT: This is a question that'll be a longer answer than you probably want. The legacy of Space Station is going to be immense. It's criticized as, "All we're doing is going in circles around Earth, why don't we get back to doing something real like the Apollo days." I like to compare the Apollo Program and the Space Station Program from an historic perspective. We can't quite do that yet with Station because it's still an active program, but we can certainly look historically what Apollo did and sort of see where the vector is pointing on Space Station.

Let me start off with Apollo, and you look at the technology that it pushed. In the '60s it pushed a different set of technology than what Space Station pushed in the '80s when it was designed, and in the '90s when it was built. But, let's say, for the sake of this discussion, that the technology development of Apollo and the technology development benefits of Space Station are a wash, they're the same. They're different categories of technology, but let's just say that they're the same. I could go through the details of what specific technologies Station pushed and are out there now in industry, but from a technical spin-off, let's say Apollo and Space Station Program, their effects are equal.

Then you look at what did the Apollo Program do? Well, we went to the Moon and we learned a lot about the Moon. We learned that things on the Moon directly impact the geology and the geologic evolution of planet Earth. We learned a lot about impact processes. After we brought Moon rocks back, we learned that we already had multiple kilograms of Moon rocks on Earth. Nobody had ever thought it was possible for an asteroid to blast off pieces of the Moon at escape velocity, and then those pieces would find their way as meteorites on Earth. But, we found that we already had a large collection of Moon rocks in the meteorite collections on Earth. We had no idea that that was the case until we brought pieces back from Apollo.

Then we found, because we sent Viking [missions] to Mars and we looked at some specific isotopic compositions of the Martian atmosphere, we found meteorites that matched that. Now we were able to ascertain that we have pieces of Mars on Earth as well. None of that would have been possible without Apollo. I just use it that that's some of the paradigm-changing thinking that came because we went to the Moon.

In spite of that, in spite of all of this wonderful knowledge, it doesn't really affect the way people go about their business of living their lives on Earth. To know that the bright spots on the Moon are anorthositic in composition, the highlands, and the mares are basalt, and now that we know that rocks can get exchanged between planets, and you talk about that to people on Earth going about their business, and some of them will say, "Wow, that's interesting." Some of them will say, "Well, so what? How does that help me live my life on Earth?" Well, like any exploration program, these things tickle your imagination and enrich your mind, but they don't necessarily improve your daily living.

Now you look at Space Station. We're doing scientific and engineering research. Already we're starting to find things that can affect people's lives on Earth in a direct way, through the life sciences experiments, through the technology. The technology of doing telemedicine and telemedicine with robots first started on Space Station, where the doctors were on the ground and we were sort of fancy technicians on Station using telemetry and real-time video to do complex medical operations, diagnostics, on Space Station. Now this technology is starting to be used on Earth, where you can have doctors in New York City and somebody in the middle of Africa, and they're doing diagnosis via satellite communication from ultrasound.

We're working with salmonella bacteria and looking at virulent strains which are grown on Space Station that are different than strains that are grown on Earth. Cold combustion—the idea that you can have combustion processes involving hydrocarbons that are occurring at less than half the normal combustion temperature. Things that are baffling people. Why does this even happen? How can it happen? What can we possibly use this for on Earth?

There's a myriad of little discoveries that are coming out on Space Station, and these discoveries are not teaching us about what's happening on the Moon, they're not teaching us about human expansion to Mars, they're not teaching us about these things. They're teaching us about advances that can be directly applied to life on Earth. I predict that in 20 years from now people will look back at what Space Station has done for people on Earth, and they will see that it has, in addition to the technical spin-offs, had a huge impact in the everyday life of people on Earth.

Whereas the Apollo Program, which people will say "NASA in its golden days" and "It's been downhill since." I say this kind of in quotes, the Apollo program really had little impact to the daily lives of people on Earth. Wow, we know the anorthositic composition for the lunar highlands, and we've got lunar meteorites on Earth, and we learned all kinds of other things that can enrich our minds and tickle our imagination, but it doesn't necessarily affect the daily lives of people on Earth.

I think that in hindsight, people will look at Space Station and look at what NASA and the other international partners have done, and they will historically say, "Wow, look at that." Even though these are the same people that are quick to criticize the program in that all we're doing is, "Going in circles around Earth. When are we going to do something that has real vision?"

JOHNSON: Well, thank you very much for adding that, I appreciate it. And I appreciate you coming in today, and I hope that we can speak again.

PETTIT: Keep calling me back, because I can talk about this stuff for hours, like I've just done. Anyway, it's all fun.

JOHNSON: Thank you very much.

PETTIT: Thank you.

[End of interview]