NASA JOHNSON SPACE CENTER ORION ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

JAMES P. BRAY
INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is July 13th, 2016. This oral history interview with Jim Bray is being conducted for the NASA Johnson Space Center Orion Oral History Project in Houston, Texas. The interviewer is Sandra Johnson, assisted by Jennifer Ross-Nazzal. I want to thank you for joining us today. We appreciate it.

BRAY: You're welcome.

JOHNSON: I want to start by asking you to briefly describe how you first became involved with the Orion Program here at Lockheed Martin.

BRAY: I've had an amazing career in human spaceflight. I started my career on the External Tank Program back in 1983 and worked through a series of programs. We had just finished up a little project for DARPA [Defense Advanced Research Projects Agency] in 2005 when Lockheed Martin found out that they had won the phase one study for Orion. I was working out of New Orleans [Louisiana] and I started on Orion in August of 2005, and two weeks later [Hurricane] Katrina hit. Orion conducted the first Program Management Review in Houston in early September. It was really important that we win Orion, so we left everything behind to prepare for and attend the Program Management Review at Johnson Spaceflight Center. Since our workplace in New Orleans was rendered inaccessible by the hurricane, my family moved to

Houston for four months so that we could work effectively and drive toward winning the next phase of Orion.

I started the Orion Project as the Site Manager for the Michoud [Assembly Facility, New Orleans, Louisiana], and had primary responsibility for the Crew Module and Service Module primary structures; it was right at the very beginning of Orion. I've worked since then in a variety of roles, as Service Module lead in 2009, the Crew Module and the Service Module lead in 2010. After the EFT-1 [Exploration Flight Test 1] mission, NASA had worked on some international partnerships, and we split off the Service Module so that the Europeans could have a major role on this program, and I'm now responsible for the Crew Module [CM], including the CM structures, all spacecraft thermal protection systems, all spacecraft liquid propulsion systems, the CM landing and recovery system, and environmental control and life support systems, and crew systems. .

JOHNSON: That's pretty interesting that you were in New Orleans and at Michoud when the hurricane hit. I can imagine that affected the work down there, or it affected the workforce significantly. How did that impact what you were doing?

BRAY: It did impact the work and workforce significantly. The interstate was wiped out and there was no way to get to the plant. It was an 800-acre facility but it had a levee around it that protected it from the flood waters. At least the production of the External Tank Program was saved by people who had worked at pumping rain water out and over the levee. The condition was in no shape to be able to work there. We certainly couldn't do what we needed to do. To support our staff, gathering in Houston, we airlifted people by helicopter into the Michoud Assembly Facility to obtain computers and equipment and bring them back.

My kids' schools had been flooded. I had one daughter away at college, but three kids still in New Orleans schools, and we moved them to Houston, enrolled them in schools, and were able to operate out of Houston for four months until things settled back down again in New Orleans. After living in makeshift fashion for four months, all of the staff that had gathered to work out of Houston went back to New Orleans at the earliest opportunity, to rebuild the workforce and the community over there. Our staff was amazing, dealing with personal losses while driving everyday towards a primary goal of winning the next phase of Orion. Our families and our work team were amazing.

JOHNSON: How long were you at Michoud after that?

BRAY: I started off at Michoud in 1983 and I moved to Houston about five years ago, in 2011.

JOHNSON: Talk about some of the work that was going on there for Orion once you won the proposal.

BRAY: We knew that there were going to be several major elements of the next generation Constellation Program. Being on the External Tank Program, we thought that we had a good chance of winning the SLS [Space Launch System], the launch vehicle portion. We bid on the Crew Module portion, and a lot of people thought we didn't have a shot at it, and were extremely pleased when we won the spacecraft portion of Constellation Program.

Our role at the New Orleans facility was to develop all of the primary structures. We had the capability to develop the primary structures and all the thermal protection systems on the vehicle. Those were all the main roles at that location. We got started with a small team and grew the team as the program demanded.

JOHNSON: How much did the team grow?

BRAY: It grew to about 250. We started phase one with about nine people, and accomplished all the proposal work, the performance reviews, and all the initial concept development with that small staff. Then when we needed to start producing drawings and accomplish development work we needed to grow the team a little bit at a time.

JOHNSON: With the external tank work and then with [Space] Shuttle shutting down, I imagine the workforce still shrunk even though you were growing this team, correct?

BRAY: The whole time that we were working on Orion, the External Tank Program was starting to phase out. We had access to very good people with years of human spaceflight experience and we taped into that well of knowledge for Orion. We also leveraged years of NASA technology that had been developed around the External Tank Program and capitalized on advanced materials and welding processes for the Orion Program; we really stepped-up off of a very solid platform of human spaceflight technologies and developments.

JOHNSON: Let's talk about that time period when the cancelation of the Constellation Program in 2010 was announced. Then the MPCV [Multi-Purpose Crew Vehicle] wasn't announced until May 2011. At NASA, they were still funded, so they were having to continue to work on a canceled project. I know your teammate Carol [L. Webber], said they were working toward this idea for EFT-1 and let's keep working, even though things are looking bad. Let's try to prove that we can still do this sort of thing and change people's minds. Talk about that time period and what you were doing. I know you moved here at some point. But you were still in New Orleans when all that was going on?

BRAY: The initial part of the cancelation I was in New Orleans, yes.

JOHNSON: Do you want to talk about when you first heard about that and what you were doing immediately after that?

BRAY: As a part of the management team it created a lot more work initially. The Lockheed Program Manager, Cleon Lacefield, was a real advocate for getting the hardware out there to demonstrate progress. He would say over and over again, "This is not a PowerPoint Program, we're going to produce hardware and we're going to demonstrate that the designs that we've produced are able to be backed up by the hardware."

We had some major things that were going on that year. The Crew Module ground test article was being fabricated. That ground test article and photographs of that hardware coming together were the visible sign to the outside world that we were making progress. We made it very clear to our teams that despite all of the turmoil, despite us revising the program plan and having to cut the funding three or four times that year, we were going to keep the Ground Test Article on track.

We supported the Phase One Safety Review Panel during that year. It was very important for us to demonstrate that this spacecraft was one of the safest spacecraft designs ever. They checked for fault tolerance across the entire spacecraft—for every hardware element and every function. Since Orion will travel long durations and very far away and there's not really a depot to pull into, everything has to be fault-tolerant. They checked all of our designs to make sure that we were fault-tolerant, and that for anything that was zero-fault-tolerant there wasn't another viable option for us to be able to design in fault-tolerance. We completed that Phase One Safety Review; it was a very important milestone in the program, and demonstrated very mature designs that complied with stringent requirements for redundancy.

During that time, the management team first generated the idea that we needed to accelerate our flight tests, and do so with reduced funding. We did that. We proposed accelerating the flight tests by two years, and we cut our costs by 50 percent. The OFT-1 [Orion Flight Test 1] was the original name for EFT-1, and we conceived of the idea. We presented the idea to NASA and included a proposal to buy the launch vehicle so we could get this early flight demonstration off and enable everyone to focus on the developing quality hardware.

We developed a flight configuration for the mission that would support a list of flight test objectives, tests we could get out of a flight mission that would confirm our design and develop data we could not get from ground based testing. When NASA committed to proceed with the mission, it gave the entire team a focused goal, despite the political turmoil surrounding the program.

During the same time we were canceled, right around early February, there was a major program event being prepared for May, and that was Pad Abort-1. We conducted a test out at the White Sands Test Facility [New Mexico] and it was an outstanding demonstration of our launch abort system. There were 40 critical events that had to happen and the prevailing opinion was that if anything happened to the flight test, it was game over for the program – a visible problem that would make it easier for those supporting cancellation to prevail.

The team that had fielded that hardware—Roger [P.] McNamara was the lead for that area—invited us all out to watch that launch, and we knew that the success of the mission was vital to continuing this human spaceflight program. It was a hugely successful mission. We had 40 of 40 events that went perfectly – flawlessly. The precision timing required on those 40 events and the pyrotechnics that had to work with split-second timing to achieve mission success was just incredible. But we engineer to meet these demanding missions and with that flight success, we all walked away knowing that we did what we needed to do.

JOHNSON: You proved a point, didn't you?

BRAY: We did.

JOHNSON: That was an interesting time. You talked about the technology. You mentioned long duration. Let's talk about some of the technological advancements in the spacecraft and the differences from some of the previous programs. The glass cockpit, the improvements in the heat shield, the redundancies that are there for long duration flights that are going to be farther from Earth, and the redundancies in the engineering and the way things are done with Pathfinder. If you want to talk about some of those changes and some of those things that have been done.

BRAY: To anybody on the outside this looks like Apollo. To those on the inside though it is a wonder of a spacecraft. The level of redundancy is unparalleled with anything that's ever been done. The Apollo for example had one engine that had to fire when leaving the Moon. If it didn't ignite, the astronauts were not coming home. Orion has two sets of engines. If one engine does not ignite, we have backup and redundancy in another set of engines that could be ignited to accomplish the return mission. This level of redundancy and zero fault tolerance is without peer.

The computing systems that are on our spacecraft are more advanced than what's in your home. We have a time-triggered gigabit Ethernet that is processing at a speed that allows it to self-detect any faults and fix them without the intervention of an astronaut.

Apollo had a single computer that had an eight-digit display that was numerical-only, no alpha characters. We have three screens that are full alpha-numeric and visual representations so that any schematic that needs to be brought up, the astronauts can be able to see and assess any actions needed. Apollo's computer at the time was cutting edge, and included one of the first integrated circuits, a fixed read-only memory capability 69 kilobytes. Orion's flight software is stored in 64,000 kilobytes of ROM. For relative comparisons, Orion's computer is 2.6 times smaller than Apollo's with a flight software read-only memory capacity 925 times larger. Orion also possesses 192GB of data storage capability, used to store information from cameras, sensors, and science instruments. Orion's computing capacity and redundancy improves mission reliability and crew safety and will enable longer missions that reach further from Earth.

The Orion Crew Module improves overall system reliability by incorporating computing redundancy. The extent of redundancy and the benefits to the mission could easily be lost to the casual observer. Redundancy begins with twin processors on a single computer called a Flight Control Module [FCM] running in parallel, constantly checking against each other for differences. These self-checking pairs ensure that output streams are 100 percent consistent within that computer or actions are immediately taken to self-correct. This provides continuous checking of a single computer and a great level of redundancy, but Orion adds an additional measure of redundancy by having three identical FCMs running in parallel, each with twin processors running the identical code, and using its own self checking pairs to ensure output streams are 100 percent consistent within that computer or actions are immediately taken to self-correct. By operating in this manner, control can be switched to any of the redundant computers while the faulty FCM resets without any mission interruption. This greatly improves system reliability, yet Orion adds another measure of back-up capability with the addition of another completely different computer, capable of running different code should it ever be needed. This dissimilar computer and software provide streamlined functionality with a focus on crew survival and return functions, in the highly unlikely scenario where anything renders all of the FCMs ineffective.

When we look at wanting to go further and for longer durations, you have to carry more supplies. Apollo was designed only to do one thing. It was designed to go to the Moon and come back. Our set of requirements put us on a 21-day mission to anywhere, and if you add other services, fluids, gases, water, we can be a 1,000-day spacecraft. We're good to go. The processing capability is there for NASA to go beyond the Moon and to different destinations.

The thing that's amazing is the mass optimization that has been accomplished so that we are able to launch from the ground and carry all those supplies for those longer duration missions. All the advances in technology that we've implemented has made things lighter in weight so that we can do these extended missions.

A very interesting example: we designed and fabricated a ground test article and the structures came in at about 3,800 pounds for just the crew module structures. By the time we had designed and fabricated the Exploration Flight Test-1 vehicle, we had reduced the mass by 600 pounds; it weighed 3,200 pounds. What we have designed since flying the EFT-1 mission, we've taken another 500 pounds out of that crew module structure. That is because of advancements in material and advancements in the processing the material, along with ground and flight test measurements, that let us get that much mass out.

JOHNSON: You mentioned advancements. There were so many things that happened over the life of the Shuttle as far as technology upgrades. Orion is more upgradable? Is that true?

BRAY: Orion is very upgradable. Yes, it's meant to be plug-and-play in replacement. We've got a computing system that is based on a [Boeing] 747, which is very upgradable. It's meant to be in service for a long time, so our software is based on that. We've got a lot of elements that were preplanned to be plug-and-play and upgradable if new technologies come along.

JOHNSON: When everything was being designed, did you look back at some of the previous programs such as Apollo, Shuttle to, instead of reinventing the wheel, go back and look at the technologies that had already been done and apply those?

BRAY: Absolutely. We're looking for the best technologies. We've got to be as lightweight as possible. We've got to be able to have the level of redundancy that will assure mission success. Carrying two sets of engines, Apollo didn't have to do that. We've made accommodations even for that.

Let me give you a couple of examples. We reached back to Apollo. The best heat shield material that's out there, for these very high re-entry temperatures, is still what they had developed for Apollo. So we've got Avcoat™; it was made by Textron. It was developed for Apollo, but they had to reconstitute it for Orion. We found that in conjunction with our Orion design, there were things that needed to change. It's very difficult to keep all those processes in play for 20 or 30 years, and we spent a lot in trying to reconstitute this thermal protection system. Turns out right at the end of the acceptance process for the EFT-1, we found hairline cracks that needed to be repaired.

We worked through a fix for that, which was sufficient for the EFT-1 mission, but that set a course to make some changes needed more stressing missions. We use the same basic formulation that they had for Apollo but switched to a block architecture to allow stresses to be relieved over this larger surface area. Apollo had about a 10-foot-diameter capsule and Orion has a 16.5-foot-diameter capsule. There's much more area that you need to allow for thermal growth and thermal expansion. We leveraged Apollo by using the Avcoat™ formulation, but we've switched to a new block and seam technology which now meets all of the requirements for the most stressing missions.

JOHNSON: Can you just explain a little more about that? I was reading about it. There was that honeycomb structure, and then it was filled. What I was reading said it switched from the honeycomb design to a monolithic heat shield. If you don't mind just explaining that a little bit more.

BRAY: Process control is extremely critical. I'll give you the setup process for the Avcoat™ and the heat shield installation. There's a composite surface that forms the outside of heat shield structure. To that surface the honeycomb is bonded, and then there are 380,000 honeycomb cells that are hand-filled with a caulk gun. It takes six months to complete that whole set of assembly operations for a monolithic heat shield.

The process controlling how the material is injected into each one of those cells is very important. The injection duration as technicians are backing the injector tip out of the cell governs the final strength of the materials. We had about 14 technicians filling those 380,000 cells over six months and after it was finished, we checked the material strengths on witness panels made using the same people and same processes, and we did not get the strength in the materials that we expected.

So we sought a process that was less sensitive to processing parameters. We looked at switching to a block architecture, the blocks require the same Avcoat™ material, but the injection process is automated. The thermal material is injected into a mold up to 18 inches square and there is no honeycomb required. After material is injected into the mold and cured as a single block, we can check the block strength before we put install it on the heat shield. We gain certainty of material strengths before we install it in the vehicle – very different from fabricating an entire monolithic heat shield and finding problems after it is complete. For the

EFT-1 mission, because we were very close to the flight, we found that we could fly and meet mission requirements for that mission, but it would not be suitable for continued use. The Avcoat™ blocks give Orion a more certain product, that meets the most stressing mission requirements.

JOHNSON: Back in 2012 after a pressure test, there were some cracks that were found in the spacecraft too. You want to talk about that and what caused that and how that affected the timeline getting ready for EFT-1?

BRAY: There's a lot that goes on in the development of a spacecraft. We test everything on the ground in a relevant environment to make sure when we get into space, we have a safe spacecraft that is absolutely proven capable of surviving all mission environments. We must test for qualification and most environments are achieved though ground-based tests, however, some require flight tests like the EFT-1 mission. Qualification test prove the design worthy. Acceptance tests prove each individual part has been fabricated to meet the requirements.

We found hairline cracks in the EFT-1 heat shield during acceptance testing at the most stressing temperature. Our processes worked to discover the issue before shipping and before installation into the EFT-1 vehicle. It can be traced to manufacturing process controls. We developed a patch and a work-around for the EFT-1 mission, but it was something that you learn as part of development. It's the reason why we have test articles. We fixed that issue and changed to a different and more robust design. This design saved about 500 pounds on the heat shield structure since EFT-1. We took into account all the learning from the first build and test experience and incorporated changes into the design to achieve the final, long term, design for the spacecraft. We finished the EM-1 [Exploration Mission 1] heat shield design and we're done; this is the spacecraft for the next generation.

JOHNSON: Speaking of those kinds of things, were there any other things that happened or you recall working toward EFT-1 that you'd like to mention? Any other events or memorable moments?

BRAY: Yes. There's a lot of things that go into the design. You can get wrapped up in a lot of the different details. As management, problems show up on our desk all day long. What we're looking to do is find a solution that fits the schedule and is technically what we need for the spacecraft and to keep our astronauts safe.

We have a variety of memorable moments that I could talk about and one for sure was the EFT-1 mission. We had every one of our certified principal engineers down at the launch for the EFT-1 mission; I thought it was very fitting. These are the people that are technically responsible for every element of the spacecraft. For every component there's somebody that's technically responsible. They were all there for the launch and able to say that their hardware was good, that we were good to go for the launch. We all got to share that moment together.

I think after having seen the issues come across your desk every day, because that's what management does, there's no one thing you can point to and say, "Boy, that was the one." It's the sum total of 250 components that have to be delivered, that have to work, that have to go through their acceptance tests, their qualification tests, the design certification reviews, the flight readiness reviews, and the acceptance reviews to say that yes, today we are ready for launch and we're going to have a good mission.

For me the most memorable moment of my career was the EFT-1 mission. I had worked in the human spaceflight program since 1983 in a variety of programs. I was pretty much always working on let's get the replacement for the Shuttle going. We worked on a lot of NASA advanced programs: Shuttle-C and the X-33 Program. I worked two-stage-to-orbit and single-stage-to-orbit. We were always really trying to get our design to flight.

EFT-1 was that mission where is all came together and resulted in a successful flight. I think it's really interesting if you take a look at the [Space Shuttle] Program – it accomplished its Phase A study in 1969 when we first walked on the Moon. It flew for 42 years. I always look at it and say we got started in 2005 with the Phase A study where we defined what Orion was going to be, and I think about 2047, and believe we have a pretty good chance of still flying that long, because it's once in a generation you get to design a spacecraft that is as complex as this, that can do these extraordinary missions.

JOHNSON: Talk about the launch and getting to see that.

BRAY: The launch was an amazing weekend, an amazing day. I was one of three Lockheed people that were in the Delta Operations Center when we launched. It was the closest building to the launch pad, and that was where the orders were given to launch. I got to watch the Delta [IV Heavy rocket] take off and I saw its engines disappear up the windows in the building.

To me it seemed like the moment I lost visual contact with the Delta it moved right over the top of our building and it just was pushing all of its thrust down on us, because the building floor started to pulse. Yes, it was an incredible moment to be that close to a spacecraft that went.

I was responsible for all the Crew and Service Module for that mission, all the pyrotechnic events, and most of the separation events, and we had all the liquid propulsion. Studying spacecraft and working on so many advanced programs during the years, the number one and the number two sources of failures are propulsion systems and separation events. This mission we did a lot of testing on all the mechanisms that we had to separate. The first key test of that was when the Service Module fairings had to separate.

I can tell you that watching that on the screen and seeing that event take place was just an awesome moment. But even more awesome than that, it was a four-hour mission, and there was a lull in the mission, and I saw Mark [S.] Geyer do an interview with some of the reporters during that lull. When he described how he felt when he saw those fairings go off, I could just see him smiling. To me, making a program manager's day like that—it's what we work for, to make sure events like that go right.

The rest of the four-hour mission was pretty incredible. A lot of people were breathing easy because we were in space, but my responsibility was for entry, descent, and landing as well. We still had a separation event and had to make sure that the Service Module separated from the Crew Module. That went well. But that wasn't it. We were responsible for the heat shield, and the heat shield had to come in and do its job. The heat shield came in and did its job, but that wasn't good enough. Then we had to have the parachutes come out and land it.

That whole series of events, there are so many eventualities that we plan for, that we talk about, that we engineer solutions for. Watching that go as flawlessly as it did, there's just nothing like it. It was a dance among a lot of perils, and it was emerging with America's spacecraft landing like it did very gently in the ocean. It was a very good landing and recovery. You couldn't have asked for a better mission.

I'll never forget that I felt a little isolated from my team. My whole team was down there for the launch. We had a big screen showing the mission in one of the hotels that was down there just off site. I really wanted to be with my team but we had responsibilities for the launch. As soon as the mission was complete, I joined them. We had the whole team that just stood up and they were having a really good time. It was a day to remember. It was fun.

JOHNSON: Well, there was a slight problem with the uprighting system after the landing.

BRAY: There was. We learn things on every mission. I'll never forget that before the mission a lot of people had tempered expectations for the mission. It's a test flight. So many things have to come together for a mission like this. The software, the hardware, the Mission Control, the ground systems, all the flight systems, all the tracking and data, all the recovery systems. So many things have to come together that you expect that you might have to be explaining a few things.

For us there was very little to explain. On the uprighting bags, we did have an issue. Only two of them actually deployed and stayed fully inflated. Resolving this issue was work ahead of us. We're two years, now, from that mission, and just about to make the final call on the best engineering solution. We've put design options through their paces. We've completed an incident investigation, assessed what could go wrong and identified proximate causes. We've designed a solution to fix that for the next time around.

I think if you look at the EFT-1 mission, and what it accomplished for the engineering team, you see learning from the CMUS [Command Module Uprighting System] bag changes; you see an ability to take mass out of the structure; you see an ability to change the major elements of the architecture to take mass out. We know everything is contributing to mission capability and ultimately mission safety. It's the reason why we test.

There are some things that you really can test on the ground, like we can test the heat shield thermal protection system in small batches on the ground in the Arc Jet Test Facility. But we can't test it in the Arc Jet Facility with the air pressure applied, and that air pressure could rip off the heat shield, so you know that you're good thermally, but for thermal and mechanical load it's only a flight test where you can learn those things.

The EFT-1 mission was good for that. We listed the test objectives, things that we could not get on the ground, and we used the flight demonstration to be able to collect that flight information. If you look at the reconstruction of the data after the mission, we tracked predictions. The engineering ability to predict what the acoustic signature is going to be, what the landing conditions are going to be, what the pinpoint accuracy is going to be for getting to the destination after you've traveled thousands and thousands of miles, it's really an engineering marvel.

In America, the space program helps the STEM [science, technology, engineering, and mathematics] education and inspires people to go into these careers. Having had the benefit of seeing a complex engineered spacecraft come together, it is amazing! We have amazing talent and an ability to understand our systems before we leave the ground.

JOHNSON: You mentioned the thermal protection, but other things that testing on the ground gives you so much information, but of course the flight test is going to give you more. Are there other things beside that?

BRAY: There are. Let me go back to the fairings separating for that. We had originally proposed a test case on the fairings that was about seven different tests that tested in a lot of different ways for a lot of different variables that you've got. We eventually only tested two on the ground. What you can get on the ground and what you can't get on the ground is what you really asked. What we got on the ground was the split-second timing that has to happen from the time a pyrotechnic sends the signal to zip open the structure to the time the pin pushers push the fairing out and making sure that all of that timing happens correctly.

There are variables like the load from the Crew Module is sitting above it. This is the first time that we've had a fairing separate anywhere in the world with load applied to the top of it. Most fairings separate and they're free bodies, there's no load on top of them, they just separate out and they move away. We had a Crew Module sitting on top of these fairings applying load on the top. In that ground test setup we were able to test the timing. We were able to test the mechanisms pushing them away under this applied load, and that was all very good.

What we didn't get were any of the aerodynamic forces that you might get in flight. You can predict what that is, but you can't necessarily test that kind of thing on the ground. So we were able to get that that from the test flight.

JOHNSON: You mentioned before that you were in charge of the Service Module too until of course now that we're going with ESA [European Space Agency] and they're going to be doing that. How did that affect Lockheed Martin having that and then having that go to ESA instead? Did that have any effect on the work that was being done? Obviously you still had that portion for EFT-1, but talk about that transition.

BRAY: If you take the long view, it is a very good thing. These space missions are expensive and it'll probably take many years of investments to make some of these long missions go off. The only way to really sustain that are these international partnerships. I look at the model of [International] Space Station, and Space Station is a model for international collaboration technically on projects that advance science for all of humankind. That model has been able to sustain itself; it's been continuously operated by astronauts for over 15 years. It survived this long duration through the sustained vision of many governments in a spirit of collaboration and cooperation. It's hard to pull out of an arrangement like that.

When we take the long view, yes, Lockheed was supplying the Launch Abort System and the Crew Module and the Service Module and now has less scope. For the long view we need to encourage international collaboration. The Europeans are very qualified to be able to do this work and we're glad to have them as partners. My focus has turned to the Crew Module and supplying all the elements for the Crew Module.

Lockheed is still responsible for the integration of the entire spacecraft. Our responsibility is to integrate all elements no matter where they come from. We are working together to make sure that all of our suppliers are successful on their designs and in the hardware they provide. ESA is eminently qualified to do that. They've proven that on many missions.

The Service Module is very much like the ATV [Automated Transfer Vehicle] that the Europeans designed and flew to send supplies to the Space Station. They had a responsibility to do that as part of their collaboration efforts on Space Station. They're taking a lot of the elements that they had already for the ATV and they're integrating those into this spacecraft.

They've taken a lot of elements of our design, so we're still providing the fairings and the spacecraft adapter. They're doing the elements that are down below the crew module adapter and providing the propulsion systems and the solar arrays and most of the propellant that we're going to need for the mission.

JOHNSON: Let's talk about significant challenges. I know you mentioned some things you've worked through. Is there anything that you consider the most challenging thing that you had to work on moving toward EFT-1?

BRAY: Challenges come every day. I'll say technically we've got people that are unbelievably qualified to be able to solve the technical problems that arise. Programmatically I've never seen a management team do what they've done for this program. At every turn if a challenge came, if the budgets got cut, if the schedules needed to be changed, if we needed to revamp the program, we have found a way to do that.

We found a way to do that in a way that I believe has helped NASA, our customer, achieve their mission goals, and in a way that has laid the foundation for a long term program. I think that it's probably underappreciated how much it takes to reconfigure an entire DDT&E [Design, Development, Test, and Evaluation] program, if the budget changes. To find a way to be able to still produce a spacecraft that you'll put your name on and you'll stand behind and every American will be proud when it flies, despite the budget cuts is really tough. We'd often like to do more analysis or more testing. But, doing enough and making sure that it's adequate is where our battle line is drawn, and we have found a way to be very successful at reshaping the program to meet the challenges that we've had programmatically.

JOHNSON: What about your most significant contribution? What do you feel that was to EFT-1?

BRAY: Being responsible for the Crew and Service Module, that was a huge portion of that mission and that spacecraft. My proudest technical achievement in my entire career was the EFT-1 mission, delivering the Crew Module and the Service Module. We released over 4,000 drawings. We conducted over 400 tests for that mission. We verified that our design met over 11,000 requirements. It was a huge undertaking. At times we've had up to 600 people working on doing that.

As the quarterback, if you will, to make sure that everything happened, that we made the right calls at the right times, I'm extremely proud of the EFT-1 Crew Module and Service Module performance.

JOHNSON: I know Mark Geyer was quoted in an article as saying the Orion Program learned to persevere. And from listening to you and to Carol both, it seems like Lockheed learned to persevere through all the changes and through the budget and through the cancelation of the project.

BRAY: It's true, but I think there's a human spaceflight culture that believes so strongly in the mission of exploration that through setbacks over the last 30 years when they came, the will to go on, the drive to get back to flight has always been a hallmark of the human spaceflight exploration program.

I know that there's really only one customer for these big missions, the U.S. government is the only one that can mount a campaign like this. I've been to international conferences where I have seen when the NASA Administrator or any of the NASA deputy administrators speak, the rest of the world lines up to go where America wants to go and wants to take part in the space program. So, the world will follow if America leads. They are the only customer for all of the human spaceflight missions that are out there.

We, in the business, know that what we do matters for the perception of America. We believe that the space program benefits the economy with the technologies that we spin off, so we feel compelled to apply those technologies and bring them to a mission rather than leave them in the labs. We know that our achievements in space will inspire our youth into science and engineering careers. We believe very strongly in that mission and support education and people coming into careers like this. We believe that the international collaboration benefits the world, as a community that realizes it's bound together in something as big as space exploration, and we really support that.

For all of these reasons, we feel a sense that we have to persevere. The Shuttle Program has gone away. A lot of us feel very much a responsibility to see this thing through no matter what setbacks come, because it matters. We've been the beneficiary of people who have invented a lot of things, and we want to leave a legacy for our kids and for generations to come on the things that we explore.

You never know really how much impact you have. Last weekend I was with my son. He's a fellow for retina [Vitreoretinal Surgery Fellowship]. He had just started in this new place, and he was in the surgery room for the first time. The Juno mission had inserted over the weekend into Jupiter [orbit]. He said that the only thing they talked about in that surgery room the entire day was that mission. They're in the middle of Alabama, and the surgeons in Alabama care about NASA's missions. They stayed up all night to watch the engines burn. They stayed up to watch the engines stop burning. They couldn't stand any separation from achieving something that great.

I think that the space program is a common bond. It's something we can be proud of. It's something that we realize is hard, and yet we're able to do these missions. It's fun to be a part of that. I think we bear a big responsibility to deliver the spacecraft so that we can fly the missions that we really want to fly, get out of the development phase and the programmatic struggles, and get on with exploring.

JOHNSON: Do the mission.

BRAY: Yes, do the mission.

JOHNSON: We appreciate you spending time with us today.

BRAY: Thank you for having us. Glad to be with you.

JOHNSON: Thank you very much.

[End of interview]