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FRANK J. CEPOLLINA
INTERVIEWED BY SANDRA JOHNSON
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The questions in this transcript were asked during an oral history session with Frank J. Cepollina on June 11, 2013. Mr. Cepollina has amended the text for clarification purposes and to add relevant information. As a result, this transcript does not match the audio recording.

JOHNSON: Today is June 11, 2013. This oral history interview is being conducted with Frank Cepollina at Goddard Space Flight Center [GSFC] in Greenbelt, Maryland, for the NASA Headquarters Oral History Project. The interviewer is Sandra Johnson, assisted by Rebecca Wright. I want to thank you again for agreeing to talk to us today.

CEPOLLINA: Always a pleasure.

JOHNSON: We appreciate you taking the time, and we want to talk about your long history with satellite servicing. I thought we'd start by talking about the most recent thing that's happened, the robotic refueling mission, and the success that you've had with that. If you'd like to just walk us through that project and that mission, and why that came about, and what you've been doing with that.

CEPOLLINA: Very briefly, I will, but I'd like to come back to that at the end.

JOHNSON: Okay, that's perfectly fine.

CEPOLLINA: What we're trying to do with the International Space Station [ISS]—which has two beautiful, very nice, robotic arms and one big long 55-foot robotic arm—is robotics to a very high level. It allows us to conduct robotic experiments from the ground, demonstrating that we can do a lot of things that we never thought we could do on orbit. Our robotic commands and instruction sets go all the way up through the Tracking and Data Relay Satellite System [TDRSS], 22,600 miles up, back to Station. You can imagine our excitement, getting the commands, watching all of this activity, moving the arms around, moving the robots around, with hand controllers on the ground at NASA's Johnson Space Center [JSC] in Houston, Texas, and conducting all kinds of activities that never were intended to be done in space. So that's what we're doing now, and have been doing, and it looks like we're going to be doing it for another two to four years, with growing degrees of complexity.

But what it's really all about, all the way back to space servicing, it's about preserving and extending the life of our valuable space assets. I came to NASA in '63, and I was assigned to the Advanced [Orbiting] Solar Observatory Project, which ultimately got cancelled after about two years' worth of work. Then I went on to Orbiting Astronomical Observatory [OAO], and just as I got on the program, the first spacecraft was launched. That was about 1965, '66. It lasted for about 90 minutes in orbit and died because it had a massive generic design problem. My boss at the time was directed to take over the program, the OAO Program, and make heads or tails out of what was wrong, what we needed to do from a Center perspective, and how we needed to fix the other three OAOs that were online to be launched. He was a rather vigorous, very detailed engineer, and we looked at every piece of the pie.

The obvious thing was that there were design mistakes made by the company that put it together. We didn't have the experience or wherewithal to oversee them, and to know what they were doing, and why they were doing it. While I was on that program doing this, two or three other observatories failed. One of them was the most embarrassing—it was an observatory called Orbiting Geophysical Observatory [OGO]. When they got it to orbit and they commanded it to go into operation, it spun backwards because they had hooked up the gyros backwards. All kinds of things like this bit us in the first 10 years that NASA was in space.

At this point in time I was four years into the agency. Lots of pressure was coming on Goddard, why can't you do things right? Historically, I think something in the order of maybe 20 to 25 percent of the spacecraft we launched in this early period from 1960 to 1970 would encounter serious problems within the first six months of operation. So we had to get over this. There were all kinds of activities sanctioned by the Center Director, and sanctioned by George [M.] Low, who was Deputy Administrator for the agency. He was kind of the technical giant for the agency. What basically he told us was, "You guys at Goddard have got to find a way to build spacecraft cheaper and more reliable. Oh, by the way, this thing called Apollo is coming to an end, and we're going to have another vehicle come along that could possibly provide astronauts to fix things for you," just like we had done in 1973 on Skylab. We used an Apollo vehicle to carry astronauts up there and fix the failed Skylab vehicle. Put a shroud (umbrella) in front of it, whatever you want to call it, and made four or five other fixes, and Skylab continued; it wasn't a total loss. That was the message in the late '60s, early '70s. Find a way to do things better. Find a way to take advantage of humans on orbit, to be able to repair, maintain, and prolong the life of valuable space assets. That was our philosophy.

At Goddard we put together an ad hoc team of a bunch of satellite builders, and we came up with a concept that was a modular spacecraft in which all the modules plugged in from the outside, so that everything was externally replaceable (pluggable). Like your battery is externally replaceable on your recorder, same idea; everything was modular. The modules were rectangular and they went around the entire spacecraft system. Smaller modules were also used for electronics, sensors, and instruments. We called that the Multimission Modular Spacecraft [MMS]. That was designed to be easily serviced and repaired by the Shuttle, and could be launched by the Shuttle, or could be launched by conventional vehicle, it didn't really matter. As long as the Shuttle could reach it and grab it, then the astronauts could fix it, and upgrade it, and do whatever else was necessary to do.

That concept folded into the design for what we called then the Large Space Telescope [LST], and was the follow-on astronomy program after OAO. Goddard was assigned the formulation job of coming up with a concept for a Large Space Telescope that today is called the Hubble Space Telescope [HST]. That was a three-meter telescope, 45 feet in length, and designed to do space physics astronomy (what Hubble's doing today). The instruments were modular, so they could be plugged into the telescope from the outside. Components also could be accessed externally. That's what we called the modular concept. We became the ownership of that particular MMS concept.

As time went on, different [NASA] Administrators came along. The Department of Defense [DoD] folks picked up the concept, and they used it on several of their satellites. All told, we used it on the two Landsats, we used it on SolarMax [Solar Maximum], we used it—as I mentioned—on HST. We used it on Upper-Atmospheric Research Satellite [UARS] and Gamma Ray Observatory [GRO]. The big spacecraft and the little spacecraft were able to take advantage of this modular system. That lasted for an era from about 1980 to about 1993, '94, and there were 16 different spacecraft that flew this modular concept.

Modularity had great servicing benefits, but there were cost benefits as well. The need for man rating was marginalized since components were encapsulated in a box (module). EVA [extravehicular activity] hand rails were not necessary because the power tools to unbolt the modules from the spacecraft had EVA handles on them. All the spacecraft did have external robotic grapple fixtures so that the Shuttle robotic arm could reach out and grab the spacecraft. As early as 1972 we began to work with a company called Special Products and Applied Research [SPAR] Aerospace [now MD Robotics, a subsidiary of MacDonald Dettwiler and Associates, MDA] to develop such a robotic system to capture and help service our modular spacecraft. In the spirit of international cooperation, the Canadian Department of Industry, Trade, and Commerce sponsored the robotic effort. We worked with the Canadians to make sure the Shuttle Remote Manipulator System [RMS] arm, which was provided by Canada, would be compatible to capture and service these spacecraft.

The very first mission we launched in 1980 was SolarMax, and it had a Canadian provided RMS grapple fixture attached to it. Four years later, the reaction wheels on SolarMax failed, and we used that grapple fixture to grapple the spacecraft with the Shuttle RMS arm and then proceeded to change out the entire subsystem with astronauts and the robotic arm in just 40 minutes. Bringing the old sub-system back was very important, because we refurbished it and put it on another satellite that was worth three times as much money, called UARS, and operated successfully in orbit for 19 years. While that all was going on, we were building and launching two Landsats [satellites]; one lasted about 15 years, and the other [Landsat 5] operated for 29 years before it was turned off and replaced.

There is a lot to be said about modularity, and the testing approach, and various concepts like that. This is how we got started in the servicing, but interestingly enough, our direction and key driver was to build spacecraft so they would be more reliable and less expensive. Servicing was kind of an "Oh, by the way, if you can make your system compatible for servicing, then do it." It wasn't until 1983 that the new Administrator said, "We need to demonstrate utility for the Shuttle. If you have a satellite that's in trouble, and it can be reached by Shuttle, then let's look at on-orbit repair." SolarMax was ideal for this kind of assignment. We had spare modules to back up Landsat builds. These 4 foot by 4 foot white modules were our spares to back up all our MMS programs. That's how we started with human servicing from Shuttle in 1984, and we went from there to WESTAR [VI]/PALAPA [B2], to SYNCOM IV, to INTELSAT VI, and then finally the five servicing missions on Hubble.

Hubble was the game changer, so to speak. All these other missions did it because the standard sub-systems were the least costly way to build a spacecraft system and launch it. None of them were really, truly interested in servicing, and the modules were so reliable that they didn't break. We made them too good, right? It wasn't until Hubble came along, when there was this huge error—I should've also said that Goddard did not build the HST system. The formula and the concept for servicing Hubble was kept by NASA's Marshall Space Flight Center, in Huntsville, Alabama.

The scientific instruments (5) were modular and built by GSFC through universities and contractors. Goddard had the responsibility for operations, and the HST mission control center. Through this Hubble involvement GSFC's knowledge of Hubble and Hubble science was current, and after launch GSFC was given the responsibility for understanding the nature of the optical problem and repairing and servicing it. As it turned out, the HST primary mirror was incorrectly polished; close, but incorrect, and it was just giving us blurred data all the time. The job was to go figure out how to fix a telescope that had a 2.4-meter primary mirror that produced blurred images. How do you do that in space? The answer was ingenuity, ingenuity, and more ingenuity.

A bunch of really huge, optical experts from all over the world got together in a meeting in Europe. Astronaut Bruce McCandless [II] went to that meeting, and Bruce McCandless—I don't know if any of you know him—but he was a true, creative engineer/astronaut and had been on the HST Program from the early days of development. He would come up with tremendous engineering, out-of-the-box solutions. At the meeting in Europe, where you had all of the global astronomers and scientists yelling and screaming about, why can't NASA do this right or that right? They all got in a room, and they all sat down, and he went through a process by which we would fix it—common sense process.

What he said was, in effect, "We'll put glasses on each one of the instruments, and then all this spherical aberration will be corrected by the glasses." It was really a rather elegant solution to the problem, and yes, it would take some extreme refinements and advances in optics and precision mechanisms, and the EVA astronauts' activity in orbit. They built an instrument that had little arms that came down and accurately placed dime-size reflective lenses right in the optical path of each of the instruments. It did the job. That was the first servicing mission, and the rest is history.

In my opinion, the hard part about the first HST servicing mission wasn't the conduct of the mission. It was the fact that it was the first time that we had tackled something that big. The first time the Shuttle had reached up and grabbed this 25,000-pound telescope and hung on to it, and then berth it; the first time we planned for five days of EVA repairs. Goddard had the responsibility of building the berthing and stowage platforms, the tools (both powered and manual), the EVA trainers, all the replacement instruments and replacement spacecraft hardware, like gyros and solar arrays. So there were these firsts.

The challenge to this was also the development of new technology on a tight three-year schedule. The astronauts going out in EVA five days. Every day with a different pair of astronauts also required us to work very hard with JSC relative to astronaut training. Astronauts on Day 1, 3, and 5 were the same, and Days 2 and 4 were a different set, but each pair had to be cross trained – just in case.

There were all these different kinds of learning exercises and questions. Could the astronauts stay out that long and not get cold, because we're talking about 5 or 6 hours? Really we went through a very rigorous test and development program on the ground. I remember that Story Musgrave, who was the lead EVA astronaut, stayed in the thermal vac [vacuum] chamber at JSC a little too long, and his fingers got a little too cold, and he got frostbite. He had to go see a doctor in Alaska, who had this medication for frostbite, exercise, and prescription for how to get his sensitivity back in his fingers. He stayed with that exercise for about eight months, and when it came time to fly, he was ready. He had all the sensitivity he could ask for. He was a "true astronaut leader." He basically kept the crew in shape; he told the EVA crew what kind of exercises to do.

There was a lot of learning, and there were other degraded and failed pieces of Hubble that made it a lot more difficult to diagnose and repair or replace. For example, the solar arrays produced large spacecraft disturbances every orbit and this required a lot of work with the European Space Agency [ESA] European Space Research and Technology Centre [ESTEC] since the solar arrays on Hubble were provided by ESA. Although there were many questions about the solar array performance, ESA worked very, very hard to understand and solve the problem. We found out when we went to change out the solar arrays in space that one of the stems that hold the arrays extended had broken sometime during the flight of Hubble, so that one solar array was like a broken wing on a duck, thus accounting for many of the solar array anomalies. Once the new solar arrays were installed the problems went away.

There were all these kinds of brand-new servicing ventures, which led us to doing a much more thorough investigation along with a testing and training operation. Up until that point in time, the degree of EVA training was not nearly as rigorous as it was from the Hubble days forward. There were many more water tank tests [Neutral Buoyancy Laboratory]. We used the water tank at Johnson, and the old water tank at Marshall Space Flight Center. We would double up so that everybody (astronauts and trainers) would have lots of runs. We'd have hardware in both places, and it was a huge, "how to get it right" kind of thing. There was a lot of pressure on the agency to make sure that we would be successful with that mission.

As a result of this test, test, and retest, train, train, and retrain philosophy, things went well. Everything on HST that was broken and/or malfunctioned got repaired. The most significant lesson in the bigger picture was that you could change out the scientific instruments with completely new upgraded science capabilities. We changed one instrument out and put a brand-new technology instrument in place of it (Wide Field Planetary Camera #2). When we did that, we could extend astronomy observation distances in space never before possible. That was the miracle of Hubble repair; new technology meant new discoveries. From that point forward, there was a significant breakout of new discoveries. Then we went to the second mission. For the second mission we brought two new instruments up to orbit, took two older instruments out, and brought them home. Then we achieved yet again a new super-sophisticated telescope with a new infrared capability on HST that did not exist when Hubble was first launched.

Components wore out, and components failed. On the third mission we put new gyroscopes and new tape recorders on. And we installed a new super sophisticated 486 computer, which by today's technology advancements would be considered obsolete. The idea was to pick up on the capabilities of today's computers, as opposed to the 1990s' capability of the computer. There was this constant evolution of improving pointing accuracy and stability, computational capability, and new scientific detectors and optics for the instruments.

The most important driver and investment was always new and more powerful scientific instruments. Because Hubble servicing represented a completely different way of doing science, it provided an evolution to science discovery through periodic upgrades to the technologies without having to change the observatory. New science and scientific instruments brought to Hubble were designed to answer the questions that the previous science brought to the table. For example: why is the universe accelerating? Where is the missing matter? Are there black holes in every galaxy? Etc., etc. There was this constant evolution of scientific discovery coupled with improved instrumentation capability. I think that was the most economic way to run a major scientific observatory. Keep augmenting it with new technology and expand its return on investment.

The last servicing mission on Hubble was performed in 2009. We put two new instruments on, but then, most importantly, we fixed two of the existing instruments as well. We didn't even bring them home for rework/repair. We avoided having to spend $160 million for each one. For about $20 or $30 million, we brought new electronics up with us, had the astronauts open them up—in one case, they actually had to cut a hole in the instrument. Yes, left it in place, cut a hole in the instrument, pulled the bad electronics off, and put a new set of electronics in, and then closed the hole with a cover. They did that for two different instruments. In one case (Space Telescope Imaging Spectrograph, STIS), they had to disassemble 110 very teeny, teeny screws, just to get at the electronic cards, and then replace the failed four cards. They did a very excellent job; the instrument is working fine today and is key to Hubble spectroscopy.

Of all the missions that were most demanding, the most difficult, but had the greatest degree of scientific payoff, it was that last mission. That last mission—nobody believed that we or the astronauts could do the entire mission in five days. We always had this hidden wish, "In case you have a little extra time, do this. In case you have this amount of time leftover in this particular day, we'd like you to take the insulation blanket off of this particular box." Well, they did it all.

Now, where are we today? From 2009 to today is almost five years later, and HST is producing all kinds of new discoveries, and it probably will keep on operating till, I would say, 2020 to 2023 timeframe. It'll eventually fail, because hardware wears out, and without the Shuttle there is no apparent way to repair failed items. Think about launching in 1990 and working till 2020. That's 30 years; that would be a record. That's extremely good. There's where cost and return on investment end up showing a tremendous payoff for servicing. With the decision to close down the Shuttle Program, our servicing project was left with quite a dilemma.

But in preparing for the last servicing mission, the *Columbia* Shuttle suffered a tragic accident and for almost two years we were asked to look at a robotic way to repair Hubble. The only way we could do this last HST repair mission was to figure out a way to do it robotically.

No orbiter, no astronauts, just launch a vehicle to go to it, capture it, and use robots to repair and service. We studied that robotic mission and built hardware for it for about a year and a half. Then another Administrator came on, and directed that we go find a safe way to repair Hubble using the Shuttle and astronauts.

They found another way by basically putting two Shuttles—one on each launch pad—getting both of them ready to fly. One would fly with all the new equipment; the other would be prepared to fly in case the first orbiter got into trouble. Then the second orbiter would be prepared to fly to save the stranded crew and bring the crew home. Fortunately, we never had to use that, but that was the strategy. If one were to look at the photos of STS-125 two days before launch, one would see two orbiters, one on each launch pad.

During the one and a half years we were working robotic Hubble servicing, we did get very involved in robotics. We went onto that robotic approach long enough to pick up a pretty good feeling that we could repair Hubble with robotics, and that we could repair other satellites with robotics as well, even if they were never designed for in orbit servicing. Once that last Hubble mission was done, our whole project turned around to start focusing on robotic servicing, robotic repair. For two reasons. One is all our scientific payloads were moving far away from Earth, much further out than humans had the capability of going. Therefore, the only way you could service systems is to do it robotically. That's why we made this transition shift. The transition shift started off gradually, but began to build some momentum as commercial satellite failures continued and NASA-NOAA [National Oceanic and Atmospheric Administration] satellites began to run out of fuel in geosynchronous [GEO] orbit.

Then we had a workshop and we invited the commercial communications satellite community to come to that workshop. Basically what they did was straighten us out and headed us in the right direction. Their interest was clearly in GEO servicing because of the sheer number of satellites in GEO orbit. "If we're going to do any productive good to our satellites, we want them repaired robotically in GEO orbit." That's what basically shifted us to focusing on robotic repair in GEO orbit. These commercial, as well as some government customers like NOAA, also expressed interest. We found that most of the government customers, and even a majority of the commercial customers, had investments in those assets well over several billion dollars. You knew there was an economic necessity, reality, whatever you want to call it, to repair those birds.

We basically worked with the commercial communications community to the point where we were able to focus with them as, "What do you all want done for your satellites?" The number one item was, "We want to be refueled, because some of our satellites are going to run out of fuel and we won't have enough energy left to dispose of them." The other one was, "We have appendages that did not deploy correctly, or did not deploy at all. We want your satellite to be able to grab those appendages and deploy them, and cut off whatever's in the way, so we can put both antennas into operation, or we can put both solar arrays down." Then they said, "Oh by the way,"—other groups would say—"about 10 to 15 percent of our satellites never quite make the right orbit. Something goes wrong with the engines on them; something goes wrong with the tank—usually the fuel lines get contaminated. What we want you to do is to be prepared to grab us and relocated us to the right orbit." *Relocation* was one of the five Rs. Some of them said, "There are certain boxes, like batteries, that fail, and they fail prematurely. They may fail after six or eight years. We want you to have the capability of replacing those components." *Replacement* was the last R. That's where we are today.

Where does Station come along? In doing all of this, the first question for all of these satellite owners is, "What are you going to be able to do to reach us, to grab us? We have no grapple fixtures. We've never designed a satellite for robotic repair. How are you going to do it?" There were these very, very good questions that started about three years ago that they brought up to us that said, "How do you know for sure that you can do these kinds of tasks?" Our answer was, we will build a simulator that looks like the back end of a spacecraft, or several spacecraft, and we will take it to Station. We'll put it on Station, and then we'll get the Station robots—with these special tools that we'll build for them—to go through this operation of demonstrating that we can cut tiny wires, unscrew valves, put liquid lines, and then pump fluid through the lines.

Over the last two and one half years, that's exactly what we have done to demonstrate robotic servicing in space. This demonstration hardware, along with special robotic tools, are all on Station There we are conducting a set of demonstration tests. We call this effort the robotic refueling mission [RRM]. Although refueling demonstration is part of the mission, it also demonstrates the repair aspects as well. All the RRM hardware is now on ISS and we are conducting operations from the ground. All of these activities, including pumping fuel through valves, to receiving tanks are now being done in orbit. That's where we're using Station, and more importantly the ISS robotic arms. That's a big Station payoff for us because it proves to the user community—the Intelsats, the SES Americoms, the Eutelsats—all of these big-time, satellite owner-operators that robotic repair is feasible and it gives them confidence that yes, we can fix them robotically. Our project uses the Station as an in space demonstration base.

Through our experience and expertise on ISS, we are pioneering robotic tools that can be used to improve ISS health and operations as well. For example, if you have ammonia leak, we're developing a tool for Station now that can sense where the leak is coming from very accurately. If it's not ammonia, it can tell you what kind of gas is leaking. Is it leaking hydrogen, or helium, or whatever, or nitrogen? It's a very sensitive sensor and it sits on Station. It brings about the capability of being able to—without sending an astronaut outside—find leaks that occur, and then, with an astronaut, at some convenient point in time, plug the leak. Or perhaps use some form of robotics to plug the leak. It gives you all of the inspection capability, without ever having to send an astronaut out there. There's beginning to be this kind of learning experience. This is the experience factor that gives the satellite owners the confidence that they can do some of these inspection jobs, assembly jobs, with robots.

Through all this robotic work, we've learned some things that could help use robots on this asteroid mission. The robots that we're designing are on spacecraft, free-flying spacecraft. They have technology on board that can find other spacecraft, that they can know which spacecraft is the one they want to repair. They don't even have to have any kind of grapple fixture on the spacecraft, as long as it was launched with a conventional launch vehicle, and it has a launch-ring adaptor. We can grab that launch-ring adaptor.

We're pioneering this whole area now, and we call this Approach Rendezvous and Dock. We call that piece of it, the sensor piece, Argon. Argon is a set of instruments—one is optical, one is infrared, and one's a laser. What the function of these sensors are is to image spacecraft up to two thousand kilometers away. They look to the sky for where a particular spacecraft that they're going to try to rescue or repair. They send out signals and receive images, and they compare the signals against pictures that are embedded inside of the computer. They keep comparing the pictures, and the computer keeps making position adjustments until it gets the picture just where it wants. As the chase vehicle gets closer and closer, the Argon sensors are continuously updating the computer, which in turn guides the chase vehicle closer and closer to target the spacecraft. It's a very sophisticated, fast computer. We've got two on orbit, on Station, where we're space testing them to see how good and how reliable they are. So far, they're very good, and one has been operating for two years, and the other has been on for just six months, but they're doing their thing.

In the process of all our robotic work on ISS, we've discovered that the Station is a great test platform. The other things that we're starting to look at are physical demonstrations that have a more direct public spinoff and benefit other than the more conventional science research, or medical research, perhaps something that can result in a direct product that the public could benefit from quickly. Recently there was this big global community meeting in Washington on food scarcity, and where we're going with food production around the planet. Several folks here at GSFC looked at a lot of the statistics and said, "What we need to fly on Station is an instrument that will focus on farmland, and do crop evaluation." That's kind of a tricky thing, because, it means very focused sensing. You look for disease in the crops, you look for stress in the crops, you look for nutrients that are missing, or crops have too much of. There are many areas of interest for improving crop production but the technology can be very complex, and has to take into account seasonal dependence, solar illumination, etc. Furthermore, the data is very time dependent.

The Farmland and Agriculture Remote Measurement Sensor [FARMS] instrument focuses on farmland, and it's a concept we're trying to develop to put on Station. The idea of flying it on Station is that the U.S. will have something practical that the agency can show the worth of ISS to agricultural product consumers. With such an instrument, it would be possible to assess what crops are doing around the world, on a local farm by farm basis. It's not the same thing as Landsat. It does not look at the entire canopy of the planet. It looks at specific locations that you tell the instrument to look at, in Global Positioning System [GPS] coordinates on the ground. It looks at them in very small pictures, 15 kilometer by 15 kilometer pictures. Within those pictures, you will see crops on specific farms, and you will see plots of frequencies that only mean something to the agricultural agents and farmers. What those plots do is they give you the signature of nitrogen, of sugars, of potash, etc. They give you the kinds of signatures for crop disease of a local farm as well as plant growth status.

We're working very, very hard with the Station people to get that instrument manifested and partially funded. The technology is very difficult because it relies on many different disciplines that have never before been lumped together. It relies on very high-speed computing, ground referenced GPS, fast steering optics, precision pointing ISS jetter illumination, ISS cooling, ISS/TDRSS high rate data transfer, etc. As an example, a key feature for the FARMS is that it needs a GPS coordinate system on-board, along with a star tracker that tells you where you are in space and then the GPS coordinate system computer tells you where to point your mirror on the ground so that one is looking at the requested farm. The imaging detectors are very sensitive, and visible on infrared cameras. Now, again, these optical elements represent brand-new optical technology. The beauty of those optics is that it makes possible picture taking in these 15-kilometer wide fields. The nutrients from these farm fields emit very low reflectance and low-light level signals.

Most soil nutrients do not radiate very strongly, but because we can take repeated pictures of the field, it is possible to build up the signal to discernible levels. This is done very much like we take pictures of galaxies 10 billion light years away whereby we count just a few photons an hour. You take picture, after picture, after picture, but you take these pictures very quickly. Because you take them very quickly, you can build up the signal level so you can see the desired characteristics of the crop. That crop may have a disease, the crop doesn't have enough fertilizer, the crop needs water, or it's got too much water. All these different kinds of things are what we're trying to focus on.

We're doing this because it is important for humanity as it relates to world hunger. It is something Station can do in the near time frame and it shows a more direct/human payoff of ISS investment. It is a more practical and direct application of all of ISS capabilities and answers some of the questions like, "Why are you investing all of this money year, after year, after year, in space? Where's the return?"

I feel that we have to show our stakeholders (the public) the return, and I think the easiest way to show them is to say, "See this crop in Kansas? Last week it had a disease; it had orange blight, growing on the wheat. That farmer got alerted, he went out with his spray trucks, and three days later the blight was starting to disappear." That's what you have to do.

I pulled this example after our visit to Purdue University in West Lafayette, Indiana several weeks ago, and we were going through the question of, "What is the economic value of FARMS?" That's the kind of thing that we're trying to focus on. It's a spinoff to all of our knowledge and practice on Station. So these are the things of things we're working on today.

JOHNSON: If you don't mind, for a minute, I'd like to go back to some of the earlier projects. When you first started here, one of the missions—Gemini 9 with Gene [Eugene A.] Cernan—during his spacewalk he ran into some difficulties. Tools were developed because of that, and because of what was learned, every time an astronaut went out on EVA. It seems to me that these tools were the early precursors to moving into robotics, to moving into all that. If you want to just talk about some of those early tools, and how your team developed that, or any of the processes that you used for that.

CEPOLLINA: Yes. I can't go as far back as Gemini with respect to EVA tools, but I can tell you that Bruce McCandless was our first astronaut over viewer on Hubble and participated with us on tool design for SolarMax as early as 1978. Bruce would instruct us with the words, "You know, the problem with us astronauts trying to fix anything or capture anything in space is that we're pretty weak up there, and we tire easily, because we're in these spacesuits and we're constantly fighting 4 ½ pounds per square inch of pressure. You need to give us power tools." He then advised us, "I've invented this little tool to unscrew bolts and screws." He said, "I can't get my Center to invest in it. You guys are doing SolarMax, and you guys are doing Hubble. Would you guys be interested in helping me develop this power tool?"

Of course, we said yes, because we didn't put handrails on our spacecraft. We put the handrails on the tools that went up and locked onto the individual modules of the spacecraft. That's how we got EVA capability without major man rating investment. We danced into this development. It was called the Power Ratchet Tool [PRT], and it was something that Bruce McCandless had done and applied for patent. The PRT had been developed to breadboard state, and we worked with him to complete flight development. One of our engineers who worked here, and helped develop that tool—and that meant batteries, motors, gear trains—was Paul [W.] Richards. Paul Richards later on became an astronaut. That's how we progressed in power tool development.

Initially the astronauts didn't want to use power tools, "Oh, don't bother us with that. We'll just go use a regular wrench like we work on our cars." Most of the astronauts who were on EVA were mechanics at heart. They had racecars in the garage in Houston, they had airplanes, and they would do their own maintenance on cars and airplanes. They liked the regular feel of a regular ratchet wrench. Then they discovered that when they took that ratchet wrench to orbit, things would happen. They couldn't see bolts quite as well because they had the visor on. They couldn't have the full degree of motion because their suit joints ran up against the stops. Pretty soon, they said, "Try this one. All that one has to do is put it on the bolt and squeeze your finger. If you want to go counterclockwise, flip the switch this way. Clockwise, flip it that way. Squeeze the trigger, and it'll be done for you." They liked the idea.

Many other power tools have come along. Today, the pistol grip tool [PGT] is the tool of choice on ISS. The PGT was the follow-on to the PRT and was really very, very sophisticated, because when you ask a clever mechanical engineering astronaut to do it, it will never come out simple. Never. This tool has a microprocessor. It can count the turns, it can measure the torque, and it can control the speed. All you had to do was remember how to flip all the switches. There's a permanent set of four of these power tools on ISS.

In all there were over 210 tools developed for all the Hubble EVA repair missions flown to date. Of these, four were designed to be multifunctional power tools with sophisticated capabilities. These capabilities included the capability to count turns, measure torque, and control speed. There are automatic features that will stop the tools when the tools hit the prescribed limits of torque and turns. The tools are illuminated so you can find the screw at night. But they are not really derivatives or evolution of the Gemini tools. The Gemini represented the beginning of astronaut manual tools for EVA.

JOHNSON: Speaking of the tools, I was just thinking while you were talking about some of the things that you're doing on ISS now for practice, for these other satellites that are further out and are built by different companies. Are those tools somewhat generic, if you're going to repair different types of satellites, or are they specific for each satellite?

CEPOLLINA: Somewhat. It's sort of like your power screwdrivers, you have a regular flat screw blade and you have a Phillips screw blade. You have an attachment for various sized sockets and Allen head drives. We have to have storage locations in space on the tool boards, where you can store different front-end pieces. They are more universal today because we've made the sockets removable. We're learning how to do that, and it's always on a case-by-case basis. Part of the complexity is that tools are matter of choice for the EVA crews. We have a lot of great tools but for simple tasks new tools are not necessarily wanted.

As maintenance tasks become more complex, new tools are needed. For example, because of various ammonia leaks on the external surfaces of ISS, we had an idea that an ammonia sniffer would be a good tool to have. The crew would be able to sense leaks on the outside of Station with a robot. So we went out, and began ground test with a commercial until called a residual gas analyzer. We use them in thermal vacuum chambers at GSFC all the time to sense whether our thermal vac chambers have any leaks or whether a spacecraft inside the chamber is leaking gas in a vacuum.

We proposed to build one of these sniffer tools for ISS. But there was very little interest. ISS just did not have a need. Then all of a sudden they had an ammonia leak, and then we got the call. We just finished an engineering model test in the thermal vac—with the Johnson folks here at GSFC—demonstrating to them that you could detect a leak as small as one pound a year of ammonia coming out of a Station pipe, and it would tell you where it was. This would be done robotically, all with a robotic arm moving over and looking at the failed ammonia pipes. We're hopeful now to get turned on to go build a flight version of this tool.

It's never an easy mission, and maybe that's one reason why I stayed so long. I just hit my 50th year last March, at NASA. I'm saying, "Why on Earth am I doing this?" Well, because it's both a challenging technological battle, and a psychological battle. At times the psychological (motivational) battle is more challenging than the technical battle. We can prove that we can do something, and build it, and deliver it, but can we convince somebody that they should pay for it? That's a lot harder. A lot harder.

JOHNSON: That's what I was thinking about when you were talking about the modular components and coming up with those ideas at the beginning. Was that a hard sell?

CEPOLLINA: Yes. We did have one thing going for us; we had the Deputy Administrator, who said, "You've got to find a better way. You've got to find a way to take advantage of humans in space to fix your problems in space. Don't bring them back to ground, don't throw them away." That was a hard sell, but you know what? Today it's a harder sell, because along the way, from 1980 to 1995 funding was tight. There was a great desire to do more with less. Then the agency got an inrush of funds and managers would say, "Oh no, we're not going to do it that way. That's old fashioned. We're going to just go develop new spacecraft for our mission and fly. Let us start with a clean sheet of paper for each new mission."

From 1996 on, all these programs started with a clean sheet of paper. They started from scratch. No serviceability, no commonality, no modularity, no replacement. What happened?

What happened is what you saw with James Webb Space Telescope [JWST]. The companies got a hold of NASA and started dictating the degree of difficulty, the desire to descope was lost, and that just drove up the price. There was little sense of necessity for the companies to hold the price tag down. We lost the wherewithal to be able to step in and take control.

We should have, but it got to be a very politically difficult, and we were afraid. We were afraid to take the work away from the company that's overrunning, and bring it in-house, and finish it off ourselves or find another supplier. Maybe we were afraid of doing that, because we lacked the technical courage to take charge and use our own capability in-house. Maybe we were afraid of doing that because of all the political ramifications. Earlier on we tried to cancel a program that was overrun. It was on an airplane, Stratospheric Observatory for Infrared Astronomy [SOFIA]. We tried to cancel SOFIA, and there was so many repercussions that it was reinstated.

My perspective is, yesterday was easier than today. Today we have 11 NASA Centers to keep healthy. That is very difficult to do. One reason is that the watcher/doer ratio is way too high. We need to start by drastically changing this ratio (this is my very naive idea). We need to get the watchers to become doers on each Center. All true engineers at NASA Centers need to go back to engineering (analyze, design, build, and/or test). Their work can be for technical development, flight development, and/or operations, but they all must have a direct hardware function as opposed to a management function.

JOHNSON: Also in the modular design and working at Goddard, and the work between engineers and scientists, and having to communicate between different groups of different types of people. Scientists think differently than engineers.

CEPOLLINA: The benefits of modularity is that you specify right up front all the mechanical, thermal, and electrical interfaces, whether it be for a subsystem or scientific instruments. There is significantly less design iteration between spacecraft and the science instruments (if they are modular), since scientists don't have to become spacecraft experts and engineers don't have to become would-be scientists.

JOHNSON: With the modular components, was that something that was a hard sell for the people that wanted the scientific data from these satellites?

CEPOLLINA: Yes and no. They didn't have as much freedom as they do today because the budget was capped up front between science instruments and spacecraft. In those days, you want a program, this is the dollar box. Go figure out how to take advantage of Multimission Modular Spacecraft with well-defined interfaces. If you don't take advantage of it and you get into the dollar box, then descope. For programs like Landsat 4 and 5, UARS, and GRO, it was black and white. You want a program? Better use these standard sub-systems, and pick up on the commonality across the board.

Then the agency got rich. The desire to save disappeared. It became a lot more difficult to tell a project manager that he had to do this, or he had to do that because of cost constraints. We're in that stage today. Every new project wants to start all over again with a clean sheet of paper. The argument being that we can innovate more by starting with a clean sheet of paper. How expensive and wasteful can that be?

The following are examples of how NASA can do more for less.

Servicing is doing more for less. Extending the useful life of Hubble to 30 years when it was only designed for 10 is doing more with less. We can make that analogy in a lot of different ways. Being able to change out a scientific instrument—robotically or with humans—is doing more for less because you extend the life and the discovery capability of the observatory. That's the concept. That's really the concept of Shuttle. The beauty of Shuttle wasn't that it could go up there; the beauty of Shuttle was that they could come back with valuable, reusable hardware and repair tools. At least 30 percent of the returned instrument hardware on HST was refurbished, tested, and reflown, thereby saving additional funds and schedule.

We took all the instruments that we brought home, removed reusable electronic hardware, optics, and structure. We then put these elements into the new instruments, completely retested the new instruments, then reflew them on HST three or four years later. The most notable instrument was Wide Field Camera III, which we flew on HST in 2009.

That's the instrument of favoritism. That's the one many of the scientists want to use, because it takes great images of distant galaxies, both in the visible and the infrared, and they can make great discoveries with it. My perspective on the beauty of Shuttle is that it could bring the hardware back. When you got it back, you could see how it degraded and learn from it.

There's a lot to be said about going up and coming home. A lot to be said. Now, like FARMS, what do we send home? We send data. We don't send apples. We send pictures of the apple crop in distress, being attacked by larvae or whatever. There is a difference, but the farmer doesn't care. He just wants to know within a very quick period of time that he's got a problem with his crop and he can do something—if he knows what it is, chances are, if he knows he can do something about it. What I'm really trying to say is, there's nothing wrong with just getting data back, but it's educationally beneficial to get your instrument back too. Maybe someday we will see another orbiter flying.

The problem is, the companies that build those satellites want to see another billion dollars laid on the table. They want to see new ones; they don't want to see the old ones fixed and their life extended. But, there's not going to be that kind of money available, so some way, somehow, everyone will lose out. A great consolidation will hit the industry. Yet, maybe we have the wherewithal to fix them, to do something about extending scientific value, maybe. You can see where I'm coming from.

JOHNSON: That brings up when you were working on what was to become the Hubble, the Large Space Telescope. Shuttle was being developed at the same time. How much input did your area have into the design of the Shuttle or the capabilities the Shuttle would have for servicing?

CEPOLLINA: Believe it or not, it was great. We made them love us. Here's why, because early on in the game when they were trying to sell Shuttle, they made the point that Shuttle could fix spacecraft in orbit. Shuttle could be cost effective. North American Aviation (the Shuttle prime contractor) built at Downey, California, a full-scale plywood Shuttle mockup. We at GSFC built a full-scale mockup of an LST and the Canadians (SPAR) built a servicer for our mockup. We brought everything to Downey and placed the LST mockup and servicer inside the Shuttle full-scale mockup. North American then conducted a full-scale servicing demonstration in front of the press. "We've showed cargo being serviced by the Space Shuttle" This was in the 1974 timeframe. The message was delivered by this demonstration.

The press took all kinds of pictures. Rocco [A.] Petrone, the NASA Administrator at the time, saw it when they invited him out for the monthly meeting. They took him through the demonstration. He immediately got on the phone and called all his Associate Administrators to come out and see it. After that, getting technical accommodations considered became much easier, much easier. They realized that we were part of their ability to sell the use of Shuttle, the two-way capability. Those are the kinds of ways we broke through, and after that it was a lot easier. They would listen to us.

Nowadays, the problem that we've run into is that Orion developers, and to some degree with SLSs [Space Launch Systems] too, have put blinders on. They feel like the marketing piece of it will interfere with their program's ability to stay on track and stay on schedule. They fear that they're going to get off-course, and to some degree, I'd say, I'd have to agree with them. By the same token, you have to marry both the marketing and the development cycle together. These are the real world kinds of problems. It's like trying to develop an automobile without any customer considerations. You may have a great car, but no one wants to buy or use it!

Today we're looking at all different kinds of programs that will take advantage of heavy lift and humans in Orion. We're looking at assembly of a 20-meter telescope in the gateway orbit. Taking that 20-meter unassembled telescope, with an SLS, 8.6 meter faring, and then going to the gateway orbit, attaching to some kind of habitat module, and then having the astronauts come up with Orion and do the assembly of this telescope in the gateway orbit, check it all out, and then let the telescope push itself out to some operational orbit, L2 or whatever.

I view that as the epitome of the huge investment we are making today on SLS and Orion. Now the one beauty about a 20-meter telescope is that you can see something about two or three thousand planets around the entire Milky Way galaxy. Our own Milky Way. We can observe that many planets, and in many cases, you can tell where the water stops—if there is water—and where the land is. And the land formations, and the cloud formations if there are any, around these other planets. That's tremendous. Of course, 20 meters is a big telescope, especially when one says you're going to put it in space. But, we have the lift capability with SLS. It's a 70 metric ton kind of mission, but SLS has that capability. You certainly have that capability with Orion, so let's go put the two together and use them to drastically improve our scientific knowledge of the universe.

My belief is the agency goes to hell in a hand basket when individual groups focus in on only their own objectives. The human group goes that way, the launch services group goes this way, and the science group goes that way. It just breaks apart. If you pull those people back together, get them to focus on a mission that has common purpose, common scientific goal, I think the American public will love it. Believe me, it's hard to do. We're starting to discuss getting the groups together at Marshall, Kennedy, Johnson, and Goddard, and start thinking about a 20-meter telescope feasibility study. Gradually, maybe.

JOHNSON: You have a history of working with a lot of diverse groups and different Centers. Has it always been difficult, as far as communicating with all the different Centers? In the Hubble repair missions of course, they were multi-Centered projects.

CEPOLLINA: Yes. It is not always easy and it is usually accompanied with an element of distrust, until they see results. SolarMax repair and HST repair were good examples of this. It was because it was multi-Center. It was because if you didn't pull all those groups together, you could've never pulled off the mission. Now there's future missions just like that, and this 20-

meter telescope is an example of one. In order to pull all together one needs Headquarters program sponsorship from all Associate Administrators involved. Otherwise nothing really happens. Even then, there is no certainty.

You know, some of this is nostalgia, but I keep trying to figure out where's the winning pull-together formula? Where's the winning formula? I don't know, and I don't have a good answer. I think the answer may be an agency unifying mission – the 20-meter telescope. The reason I say that is because, when you sit on an airplane, and you have a NASA emblem or a Hubble emblem, people want to know you right away. "Oh, you work on Hubble. You must be with NASA." And you say, "You must be in the space business." They don't have anything to do with space, but they've seen the pictures of Hubble. They've seen them in the papers, they've seen them in the magazines. They connect with the true goodness of the agency, the ultimate quest for knowledge, and the predominance of the scientific discovery results.

That's what we have to do, we have to reawaken the general public that NASA's about discovery. The discovery is about science, and science is about transportation, and human and robotic assembly, and launch vehicles, and launches – all put together to uncover the mystery of the universe. It's a tough proposition to deal with, because everybody says, "Oh, yes, but go away, we are on full-cost accounting." You've really got to stay in front of key folks to get this over. One really needs to be persistent.

The challenge today is that the public want to dive in a lot more. If they see a picture of a galaxy, they're not just interested in the picture and the colors; they want to know what it means in terms of our collective destiny. Today the U.S. public is much more into wanting to know what the facts are. I think there are scientific and space application challenges like that. There's probably three, four, five others. I like FARMS on Station, because I think it proves the value of

Station, and it proves the value of Station as to being able to check things out and understand their true value before you ever spend five, six, seven hundred million dollars in putting them on a free flying spacecraft in orbit. That's the beauty of Station.

JOHNSON: The Argon technology and the autonomous rendezvous and docking system that you've been testing. I was thinking about the SolarMax satellite, and issues that the astronauts had with it.

CEPOLLINA: Capturing it, yes.

JOHNSON: Capturing it, because of a problem with the docking. Then trying to grapple it with the arm. With the work that you're doing with the autonomous system, would those kind of things still be an issue, or how would you work through those?

CEPOLLINA: Yes, you learn from these experiences. When we had that first OAO failure, the one lesson was, never put all your eggs in one power control basket. That basket may have a manufacturing or generic design problem, so always have a backup system. When we worked with SolarMax, we had the same philosophy. Never put your eggs in one basket, especially with respect to something you haven't done before, like capture of a spacecraft. We put a grapple fixture on SolarMax before launch for the backup situation, where if an astronaut was unable to physically capture SolarMax, the Shuttle RMS arm would reach out and grasp the grapple fixture on SolarMax. As fate would have it, it was the backup system (Shuttle RMS) that did the job. The RMS was able to capture SolarMax even though it was still rotating at 1/3 RPM.

That philosophy of having a backup system when you deal with these very first time unknowns, is key. On HST this backup concept was always maintained. Whatever we do in the future, we'll always have a backup system of some sort: backup computer system, backup grappling, backup tool. I didn't tell you about that, but we also carried the manual tools as backup to the power tools and, yes, backup manual tools for some primary tasks were manual tools. Once in a while, a battery on a power tool would become discharged. The astronauts would finish the job up with a manual tool, and then change the battery inside the Shuttle at night. My perspective is, you're right, and we learned all kinds of lessons.

One of those lessons we learned, which slays me all the time, is the importance of metrology. You have to dimensionally get everything right. Besides the tools and sockets having to be dimensionally accurate, you have to dimensionally record where things are on these satellites. On WESTAR, PALAPA, and SYNCOM IV, we didn't do that, because they weren't ever going to go back and rescue these birds. So, repair hardware or tools did not always fit. During many of these repair missions, the drawings did not show the accurate antenna mount location, so the astronauts had to second-think a problem through and find a fix.

On every mission we flew, we learned something that we didn't know about beforehand. SolarMax was that way, WESTAR, PALAPA, SYNCOM IV, and INTELSAT VI. On the INTELSAT VI mission, the astronauts had to go out with three astronauts to grab the spacecraft because the tooling they had did not fit the spacecraft. Metrology knowledge avoids embarrassing results. That's a good question.

JOHNSON: I was reading that a lot of the things your team developed, and things that happened along the way, led to technology spinoffs for different areas, including the medical world. One of them was the Hubble Space Telescope instrument Charge Couple Device.

CEPOLLINA: Yes, CCDs.

JOHNSON: It's actually for breast cancer detection. Of course you were talking about the programmable handheld power tools and that sort of thing. Do you have any other examples, or if you want to talk about some of those?

CEPOLLINA: Yes, the very, very sensitive CCD detectors we developed for the Hubble Spectrometer Instrument [STIS] ultimately became the detector for stereoscopic breast imaging equipment. Since 1997 the technology has continued to advance and today there are much more sensitive detectors in the medical field, not for just breast cancer detection, but for many other medical fields.

I would like to think that FARMS could also be one of those spinoffs one day. It uses the spinoffs from three or four areas—one of the areas is Hubble, one of the areas is the FPGA [field-programmable gate array] computer technology, another of the areas is the GPS, which we don't take credit for. The reason I like FARMS is because there's 22,500 people a day that die of malnutrition on this planet. Half of them are children under 12. The statistic is absolutely staggering. There are many reasons for this: wars, genocide, food distribution, floods, draughts, etc. But with the ability to improve agriculture production, we can make a dent in reducing these numbers. As our world population grows, we can at least stabilize these numbers.

Now, there are other examples. I don't want to make it sound like they're our ideas; they're really technologies that have come along, and what we've tried to do is put them together so they can do some good. Then there are also medical technologies that are very good and can benefit from space processing on Station. I'm just peripherally knowledgeable of them, but one of them is this ability to separate very critical hormones in the blood with electrophoresis in zero gravity. Hormones in the blood stream vary by molecular weight. Because of this, on the ground processing can result in poorer separation levels than in the zero gravity of space. The process for this separation is called electrophoresis. Experiments with such equipment and fluid samples on Space Shuttle have demonstrated separation purity levels of 98 percent in zero gravity.

I've got to believe that in the pharmaceutical world there are some significant benefits that can be achieved. We have had discussions with Johns Hopkins Medical School on this topic. But the value of this process in space is directly coupled to our ability to transport the processed product back to Earth in a routine, reliable manner. We are not there yet, but it could happen in the next two to three years.

JOHNSON: You've described yourself as someone who never worked a day in your life.

CEPOLLINA: Absolutely, yes, yes, except for working on my grandfather's farm.

JOHNSON: You feel that way, and you've said that you just passed your 50-year anniversary. That's amazing that you still feel that way.

CEPOLLINA: I feel now and then like I do work, when I go home at night ready to collapse. But new ideas, new concepts, new research opportunities have a reinvigorating effect on me.

JOHNSON: No plans to quit anytime soon, though?

CEPOLLINA: I don't know. I'm certainly thinking of it more and more. The older I get, the more I hurt, and I just had rotator cuff surgery. That's physical therapy. Surgery was nothing. Take a pill, give you a shot, fall asleep, next thing you know they slap you on the face and say, "Go home. Come back in a week and I'll pull the stitches." Then you go to the physical therapy and you hurt. They never tell you about that. But in the end, everything works out okay.

What I am worried about is that as an agency we need to focus more on practical near-term outcomes. We have some great opportunities, but a lot of times these opportunities are not under the purview of NASA. They belong to other agencies like U.S. Department of Agriculture (like FARMS). Other agencies don't even want to think about space, "We've got all we can do to take care of food stamps, or crop insurance, etc." The government is so compartmentalized; it's hard to get departments to work together. It's difficult. Here we are right next door to Beltsville. We're sitting on U.S. Department of Agriculture land. I have a team of four of their agricultural scientists working with us on FARMS, but they won't spend any money.

JOHNSON: Rebecca, do you have anything?

WRIGHT: I have one question for you, because you brought it up, about the commercial side, or the new public partnerships with commercial ventures. Do you see at some point science experiments or science instruments being put on these rockets that are being developed by these new companies?

CEPOLLINA: Yes, eventually this will happen. But it will only happen if it's good for commerce and industry can see a near-term return on investment. The best working example today is the commercial communication satellites. There's over 400 of them in orbit. They're all in GEO orbit. I see this commercial market growing. Although this commercial business was started in the early 1960s by AT&T, today the top U.S. company in terms of satellite ownership ranks 26th in the world of commercial satellite ownership. What on Earth went wrong over the last 50 years? Through a satellite GEO repair mission called Restore, we (NASA) are trying to kick start a new U.S. commercial industry for the repair, refueling, and upgrade of commercial and government satellites at GEO. From a national perspective it is critical that the U.S. maintains its leadership in satellite servicing. This is a potential $1 billion per year market – commercial satellite servicing for commercial communication satellites is huge.

JOHNSON: Is there anything we haven't talked about that you wanted to mention before we close?

CEPOLLINA: Good question. No, I think we've covered it all, yes.

JOHNSON: Okay, that's good. I appreciate it.

CEPOLLINA: I think we did.

[End of interview]