NASA VIPER ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY SANDRA JOHNSON
SAN JOSE, CALIFORNIA – OCTOBER 4, 2022

JOHNSON: Today is October 4th, 2022. This interview with Dan Andrews is being conducted for the VIPER [Volatiles Investigating Polar Exploration Rover] Oral History Project. The interviewer is Sandra Johnson, and Mr. Andrews is in San Jose, California, and talking to me today over Microsoft Teams. I appreciate you agreeing to talk to me and taking time out of your schedule. In our last interview we talked about LCROSS [Lunar Crater Observation and Sensing Satellite]. LCROSS was so important because it showed that water ice was present and detected in the vapor plume and the ejecta with the Centaur impact on the Moon. It's such an important mission and it got a lot of attention and the beginnings of possibly having a VIPER mission. Of course there was about 10 years' worth of work in between. I want to just talk about some of those projects that you worked on in between. I know you've done a lot, but one of them was the Resource Prospector [RP] mission, which was very important for VIPER too. Just talk about that time period after LCROSS and before VIPER.

ANDREWS: Sure. It's very interesting. The way that the Agency puts together missions that stand on each other's shoulder is not usually nearly as efficient as we would like. If you even look at LCROSS, LCROSS took place in 2000, we started in 2006 and ended in 2009. Where did LCROSS come from? LCROSS came from some interesting data that came out of a couple missions in particular about the polar regions on the Moon and this possibility that there was water ice. But did they take place right before LCROSS? No, they took place in the mid '90s.

What was about those 10 years or more that was happening there? The answer is that these things are not beautifully stitched together. Honestly, even between LCROSS and VIPER there was not an easy stitching between there because the Agency's broader goals move all over the place. After LCROSS and during Resource Prospector that you just mentioned, the Agency was decidedly Mars-focused, not Moon. Moon was very much being ignored openly because the focus was all about Mars, and some Asteroid Redirect stuff and things like that.

What happened was as LCROSS finished, made this big splash, other missions came along. One of the missions was LADEE [Lunar Atmosphere and Dust Environment Explorer], which was also an anomalous lunar mission, didn't fit within the broader framework of what the Agency was doing. I and a couple others on the LCROSS team went off and started working other completely unrelated missions. I headed up a multicenter OCT, Office of Chief Technologist, flagship technology demonstrator mission. It was a solar electric propulsion technology demonstrator that was trying to prove technologies that would be useful for deep space travel. Sure, there might be lunar implications, but it wasn't lunar-focused. That ended up becoming so attractive that [NASA] Headquarters started putting a number of different requirements on that mission that just blew up the cost, up, up, up, up, until it became completely unaffordable. It was one of those frustrated, not the best customer arrangements, where they wanted more, more, more, and then they couldn't afford what they asked for. That was unfortunate but it was a really great experience from a leadership point of view, going across multiple centers and having a really good team that we built from that.

It was after that, I'm skipping a couple smaller things, but we started working on this idea of Resource Prospector. Resource Prospector itself as you may have heard from some other interviews grew from some technology work that was being done elsewhere in the Agency. One

of those technology efforts was a project called RESOLVE [Regolith and Environment Science & Oxygen and Lunar Volatiles Extraction]. RESOLVE was an in-situ resource utilization package that would help find water ice and volatiles on the Moon and then even practice with extracting them from the soil. That became interesting to HEO, the Human Exploration and Operations Mission Directorate, and they decided they wanted to wrap it into a real mission. That's where Resource Prospector was born, to take that package and put it into a mission framework.

I was the Project Manager for that in AES, the Advanced Exploration Systems group within HEO. We took those RESOLVE instruments and some other instruments and packaged them and created a whole mission framework. But you got to remember again Moon was out. The Agency was not looking to go to the Moon. It took a very long time to go through that Resource Prospector development not because we needed it but because it wasn't politically in alignment with what the Agency was doing.

What we were told at the time was the only way this is going to fly is if you can get a notable international partnership. Then it's worth it. Even though you're going to the Moon and we're not focused on the Moon. We spent literally years working with Canada as a potential partner, working with Japan as a potential partner, talked a little bit with Europe, but there is not so much clarity there, and ultimately spent a lot of time working with Taiwan, with us traveling back and forth to each of these countries, starting all that partnership. Went pretty far actually, before in the end it being decided international partnership is not going to work.

We were kind of cut off after all that investment. But the good part, the lasting part, of that was through all that time we were really maturing our instruments, our technologies, the approach, how we would navigate on the surface, all that stuff was valuable, even if Resource

Prospector didn't fly. The way that Resource Prospector ended up was right before Administrator [James F.] Bridenstine came in, like literally days before, it was decided that Resource Prospector should be brought to a close. That was very frustrating for those of us on the team because honestly it was the Agency's largest lunar effort at the time. You might recall when Bridenstine came in what did he do? He actually said publicly he was confounded how after the data from LCROSS was revealed, how it is that the Agency did not pivot immediately to the Moon was beyond him. Suddenly we had an Administrator and a political framework that wanted the Moon, and we just terminated Resource Prospector.

What did the new Administrator do? Jim went ahead and immediately called for three different tiger teams to study what Resource Prospector was. I was called back to [Washington] DC to answer the individual teams' questions. Why did you do this? What do you think about that? What was your intention behind this? Those three different teams were looking at one, the instrument suite, two, the rover vehicle itself, and three, the mission idea, the whole construct of a polar region mission. Each of those teams, which were separate teams, concluded Resource Prospector was pretty much the right thing.

What they did was they created a new framework for the mission that included one additional instrument, and then from there we rebuilt Resource Prospector and the team around a multi-lunar-day mission. Resource Prospector was going to be one lunar day. It's a more robust mission with an even better instrument package, and that's the origin of VIPER. You could have never drawn a straight line looking forward out the front windshield on how that would play out. It looked like a doomsday scenario. Now you look backwards and you find it amusing, but here we are.

JOHNSON: Since it was Resource Prospector, as you said it was not politically in alignment working towards something on the Moon during that time period, what kind of constraints, or how was that working in that kind of environment? I know you were looking at international partners and trying to satisfy what they wanted you to do. But how difficult was that working in that kind of environment when you knew you weren't the favorite child, you weren't Mars?

ANDREWS: It's hard. But it also brings opportunity. Every challenge I really do think has a silver lining if you look at it right. The hard part is probably pretty self-evident. You don't carry station in the importance of big portfolios. You're not taken seriously necessarily when the range is trying to plan launches. When you call up Launch Services Program and go, "Hey, we'd like to talk about this mission. What sort of costs are we talking about?" The stuff that a project manager needs to figure out and get going on, and they're looking at you and saying, "But are you even real?" It's really hard to have those tough technical discussions.

The silver lining though is that you get to work kind of clandestinely, meaning no one is paying attention to you. That means you actually get to progress very quickly because there aren't people saying, "Hey, wait, I need a briefing, hey, you need to come here and get through my gate." Nobody cared, and so you got to just accelerate as fast as you can within NASA and really mature things very quickly. Unfortunately though because of the whole partnering constraint the total duration ended up being a reasonably long amount of time, four or five years. It didn't need it. That isn't what Resource Prospector needed. But you take advantage of that and you get to mature things along that way.

JOHNSON: At the end of Resource Prospector, you were looking at international partners but then for the actual rover I think JSC [Johnson Space Center, Houston, Texas] had been brought in when it was still Resource Prospector. Is that correct?

ANDREWS: That is correct.

JOHNSON: You were starting to work with JSC at that point. Once it was canceled and before VIPER officially started, talk about those changes. With VIPER then you were looking at the CLPS [Commercial Lunar Payload Services] initiative and using commercial launch vehicles instead of launching it by NASA. Then all these different pieces had to come together. I know some of the same team members came from Resource Prospector too. But was there a loss of any people because there was that period of time in between? Talk about that time period and building those teams and starting to work with the CLPS initiative.

ANDREWS: There's so much to say here. One funny anecdote that you may not know to kick it off is that I was actually involved in the early planning for CLPS before it became CLPS. When we were doing RP, the advanced exploration systems started wondering about these companies that they were hearing about, these new companies with names you didn't recognize, who were aspiring to be lunar delivery companies. The question was are they ready to be relied on. The answer was probably not, so a [Lunar] CATALYST [Cargo Transportation and Landing by Soft Touchdown] program was started. You can look this up, but it's a whole separate program outside of Resource Prospector where the Agency actually invested, I think, $10 million or

something per CATALYST member. I think there were three different companies. They invested in them to try to accelerate commercial capabilities.

Coming out of that CATALYST program that had a finite amount of time, one of those companies that was in the CATALYST program was Astrobotic [Technology, Inc.]. Another I believe was Masten [Space Systems, Inc.]. I think another was Moon Express [Inc.]. Masten of course just went bankrupt recently, and Moon Express is in a somewhat unclear state right now at least to me. But Astrobotic is apparently thriving and competing within the CLPS Program. We had written after the CATALYST, me and Victoria [P.] Friedensen, now retired, at Headquarters, we had started putting together some associated language. What if we actually tried to get a clearinghouse of commercial capabilities, big and small, all different sizes? It could have all the usual suspects like the Lockheed Martins and the Boeings, could have some of the smaller new players too. The whole marketplace. Then we compete them with each other in the best interest of the taxpayer for different payloads. Maybe big payloads like VIPER, maybe little, tiny payloads like a mass spectrometer. Full range.

I am a giant supporter of that. I think that's a fantastic idea. The only question is is the marketplace ready for that or not. That's the big bet that the Agency is taking right now. The CLPS Office came along. It's worth reminding that when we were back doing Resource Prospector, the rover was going to be provided by a partner, and the lander was going to be done in-house by NASA. That is not at all how VIPER looks.

Johnson, Ames [Research Center, Moffett Field, California], and Marshall Space Flight Center [Huntsville, Alabama] partnered to build the lander. We were going to go to Canada, CSA [Canadian Space Agency], for the rover. We did that for a year and a half or something like that under Resource Prospector, and Canada had new leadership that came in. No different

than the NASA story. They said they're overextended and they want to cut off all these plans. Away went the rover.

HEO and AES scratched their heads and said, "Well, what if we build the rover in-house NASA?" The idea was let's go ahead and find an alternate source than the usual suspects within NASA who can adopt this low-cost risk-tolerant model that we've been carrying from LCROSS all the way forward. It was decided that Johnson might be a good place to go for that in partnership with Ames, because Ames has all the flight software from LADEE, lots of good heritage there. Johnson knows how to build some surface hardware that hasn't been space-tried yet or isn't flight yet, but a lot of different interesting technologies. Let's marry those two. That's how Ames and Johnson came together to take on the rover.

Then the Marshall component faded away as Headquarters said, "We want to go get a commercial lander." Marshall was participating on the lander side. That's a case just like you're describing where then we had to say goodbye to that part of the team because we could no longer do it in-house. We were edicted that we would go and get that commercially.

All those twists and turns we were navigating through the whole process, with a number of us key individuals and subject matter experts and scientists moving through that, and others coming and going.

JOHNSON: Your core team, some of the core people, like you and Tony [Anthony Colaprete], you kept that group together. I would think that that would make it flow a little bit easier just because you had already built that team experience with each other and built those relationships. But bringing those commercial entities into it and then Johnson has their own teams, how was that? Was Johnson receptive and ready to go with it and put lots of people on it, or were there

growing pains there with another NASA center? NASA centers can sometimes be competitive with each other.

ANDREWS: I think that your observations are correct. Each center has its own culture. Yes, there can also be competitive activities in the nature of things there just because of the way the Agency is organized. When it has proposals, it competes them against each other. The Agency sets that in play. But I don't think that was a strong driver, the competitive side there. I think it was more about just getting to know each other and getting frankly to the point where we could trust each other. Because that's what team members do. They become reliant on each other. I just trust that you're going to not let me down in delivering what you need to give to me and vice versa.

We had some early meetings and we were chatting. The nice thing was that this group that we went to at Johnson was very motivated to do actual spaceflight, which they hadn't had that experience with before, and VIPER and Resource Prospector before it would offer the opportunity for them to get to space, as opposed to doing very interesting development that just stayed as a terrestrial demonstrator.

We had their motivation. But as you can imagine, Johnson has a lot of activities, a lot of irons in the fire. This activity was not going to rank as important as Orion [spacecraft], as Artemis [program], as a number of other very multibillion-dollar costly missions. So I have had to, throughout both Resource Prospector and VIPER, stay engaged with middle management, because that's where the culture lives. Center directors come and go but the culture stays in middle management, I don't care where you are, in commercial, government, it's the same. I

had to work with them to win them over. This is worth you putting your excellent resources on. This is worth you investing some of your people into.

Look at some of the benefits. We're going to turn this around much quicker than you're used to at big decadal human ventures. You definitely have a part of your workplace where people want to turn things around a little quicker. Sometimes that's younger in their career people or just people who are tired of taking 10 or 12 years or more to get something done, so they're excited to come on over too.

JOHNSON: Let's talk about the purpose of VIPER. VIPER is going to benefit humans on the Moon. Was that part of what you did, is to convince people that this is going to help? Especially at Johnson, because that's human spaceflight. This is going to help human spaceflight, because you have to know these things that VIPER is going to find.

ANDREWS: My position on that is a little different. I think when you're at the policy level folks, so the Headquarters folks, the reason RP made sense is the exact same reason that VIPER makes sense. There's no difference between the two. The two do look a little different but they're scratching the same itch. That itch is the following. Six, seven, eight years ago, I lose track when it was, there were a number of studies that were conducted by MIT [Massachusetts Institute of Technology, Cambridge] and some other parties, independent of NASA, that were taking a look at so-called in situ resources on the Moon.

The studies were trying to figure out look, yes, LCROSS found that there was water there, great, very interesting, kind of surprising, but what does that really mean? Is that just interesting or scientifically interesting? Or is that actually practical? Is that actually something

that could matter for the exploration, not just for scientific endeavors? All these studies kicked off. They were fascinating.

I was staying very close to them during RP because as you can imagine without RP having a lunar support system, these studies could potentially show just how very important RP was. I was watching them closely, and sure enough, what the studies showed in various levels, because there was different levels of speculation required, but in these detailed studies they found that the amount of water or other supplies, volatile type supplies, that would have to be brought from Earth to sustain humans, to sustain manufacturing, maybe growing, making, mixing regolith with water and superheating it and creating bricks and just all the potential uses, not to mention propellant, oxygen to breathe, hydrogen, oxidizer for rocket fuel, on and on, if you could get it right there out of the soil, the amount of rockets that you could reduce from Earth was notable. We're talking over a decadal period of time when humans are there hundreds of billions of dollars potentially saved by just taking it out of the soil.

That was very moving to the policy folks. But they didn't know if it's real. "Okay, I get it," say the policy makers. If this analysis is right this could be huge. But all we have so far is LCROSS that says, "Yes, water is there." It's at roughly this concentration. But we have no idea specifically where it is. How deep is it? Where is it X-Y? Horizontally. Where are the terrains where it tends to be located? With how deep it is, that's going to define how hard it is to get. LCROSS can't answer those questions. It was just answering the big binary question. Water ice or not. You need a VIPER.

You need a VIPER to determine if it's worth trying to live off the land on the Moon or forget it, it's too hard, so you're going to have to bring everything to the Moon. VIPER with its maps, with its ability to look down as deep as a meter, which is probably the most functional

depth you could probably get to. If the water ice is 2 meters, 3 meters, 4 meters, the amount of effort required to get it may make it completely impractical. VIPER is going to be answering those questions.

Whenever I go on international travel—I just came back from the IAC [International Astronautical Congress]—I always get swarmed after my talk by people and companies internationally that are saying, "When are you going to have your data? Because I've got this great approach for taking water ice out of regolith but it only works if it's in the first 50 centimeters. If the ice is all below that my idea is a poor idea." They all need this information from VIPER. That's why VIPER is critically important.

The part that's a little less easy for some people to understand is to get humans on the Moon you do not need VIPER. You do not need VIPER at all. Because VIPER is not about bringing humans there. VIPER is about that sustainment part of the story. Jim Bridenstine, Administrator at the time VIPER was green-lit, that was always his point. If you're going to keep humans there you got to have the most practical way to do it. In the same way that when settlers moved west in the United States you can't keep expecting the east coast to bring food and water and everything for them. They had to figure out how to live off the land in the West. That opportunity gold came along, which I fully expect that metaphor to happen on the Moon too, may not be gold, it might be platinum, it might be helium, it might be any number of different things. But once that incentive comes into play everything else is going to take care of itself. Again, you need VIPER there to have the basic framework to understand how you go forward.

Back to your Johnson thing. All that I just said there, I don't think that that was an especially powerful motivator for Johnson, because that's out in the forward years. As centers

know, they're having to deal with what's right in front of them. What do I have right now? What do I have to commit to right now? Where are my resources? As the Director of Engineering working VIPER right now, I get it. I can't worry about even three years ahead of me, much less 10. I don't think that story motivated Johnson because Johnson tends to be a human spaceflight center. I think it was more about the fact that when you hire engineers and scientists and even procurement specialists and schedulers and technicians, the whole group of people that you need to do one of these, there are people that have very high long view aspirations and are moved by working on human-based stuff for large projects, and then you have people who are a little more scrappy, want to see more turnaround and get some experience. I think VIPER and Resource Prospector before it scratched that itch for that part of the workforce within the engineering and science orgs at Johnson.

JOHNSON: It is different. It's an interesting project. Like you said it's relatively quick by NASA time.

ANDREWS: In NASA time.

JOHNSON: In NASA time. Definitely. Let's talk about being the project manager for VIPER. In the last interview we talked about managing from the middle and how important that was, and managing the middle, and the difference. But communication in something like VIPER I think would be important because like you said you're traveling. You're talking not only to NASA people but you're also talking to the public. I was looking at the mission management updates online on the VIPER website. Talk about that for a minute, and how important this

communication is when you have a project like VIPER that you want it to keep moving forward no matter who's in charge.

ANDREWS: I have given whole presentations just on this topic to aspiring project manager groups in the Agency and even to outside parties. I've given a lecture at Stanford [University, California] to engineers there who are very used to thinking about engineering but not yet used to thinking about leadership and leading teams and so forth. I always enjoy giving that talk. I'll try to keep this short.

But communication is important for all the reasons and other good reasons that we all know. The dimension you didn't mention at all though is how does that communications angle get tweaked or become even more important in the middle of a global pandemic, when people are being told, "No, you have to stay home now. You're going to be given a bunch of very poor tools to try to do your job." Because Teams wasn't what it has since become, very capable, as you and I are chatting now. It was very irregular, very shoddy. No one was on any uniform system. You have to stay home even if you're feeling fine. You have real work to do, it's all about collaboration, but stay home.

Communications, if it was important before, it's five times more important now. I was one of the early embracers of how do we get the most we can out of this. Certainly not the only person, everyone was trying to figure their way through this. I started finding that there were some silver linings there too with the communications. I had to stay close of course to the stakeholders. I manage up and I manage down. You come to know when you're working across multiple centers—we have Kennedy [Space Center, Florida], Johnson, and Ames as three principal centers, and then you have some other parties too, we have a good working relationship

for testing with Glenn [Research Center, Cleveland, Ohio], we have commercial partnerships like with Honeybee Robotics for a drill and some of our other instruments. You got to worry about all of that.

But I was most worried about the team. In that case, one of the things that I tried to immediately think about is how do I make up for the fact of our loss of community? You're used to going to the meetings with each other regularly and then maybe you'll go grab lunch together, or you'll have an argument in the office, or whatever it is. But it's a very communal thing, and from there sometimes comes really great ideas or innovation. One of the things that I had started up—there was a number of ventures I started up—but one of them I created was an ask me anything session where through Zoom and with upvoting tools that we could have online; people could put up questions to me, literally anything they wanted. I would only screen them if they were somehow inappropriate or duplicative. But otherwise ask away.

People would upvote them, and then I would get together for a session and just start at the top of the list, which by definition is the most important thing to the most people, and walk my way down, and answer very candidly with them. I got huge appreciation for that because you forget sometimes with everyday work and with other leaders on VIPER's everyday work. You take for granted your domain. You don't realize that there's also people who are technicians or engineers who are focusing on their subsystem and that's their whole world. They don't ever get to see that. It's really important to be able to pull them up and give them that sense of ownership, their part in the whole puzzle of VIPER, and that sense of pride.

I also started up a number of seminars, and we're now up to something like 13, where we pick a topic, something about VIPER. We put that up for vote too. People could pick whatever topics they wanted and upvote them. Then I would go get an expert and we would brief the

whole team on that. That's another way to engender a sense of ownership and a sense of participation and education. We like to get smarter. What's better than if you work in this little corner of VIPER to be able to talk about all the other corners of VIPER? That's fun. That's one of the benefits of our blessed position that we're in to be able to work on these things.

We did a number of those things. I also made a fundamental change on communications with how I ran my staff meetings. Continues to this day. Because now most of the centers are back in some level or another, back to in person, at least part-time, full-time, whatever. Varies based on your position. I always held staff meetings the way everyone does, at my home Center. We all met around a boardroom table. We had a Polycom audio device in the middle of the table. We would sometimes project things up on the screen that of course were always easy for us to see in the room, but other people, even if you had some sort of Zoom or Teams or Skype thing, it was always crappy. They're looking on a tiny little screen, and the sound was terrible for them, and they couldn't read nonverbal cues, it was awful for them. But that's how everyone did it. That's just how it is.

Along comes the pandemic and we're all forced to be individuals in our homes. No one has a leg up on anyone else. Even the people who always sat to my left and always sat to my right, they're now just as distant or close as someone who's working in Florida on the project. As the pandemic constraints started easing, I never went back. I do not to this day hold my staff meetings in person. I choose to not do that because I want everybody to have equal footing. I want people in Florida to be just as able to see me. I always turn on my camera. I want them to be able to read my face. I'm scrunching my forehead. I'm not buying it. I'm falling asleep. That's just what's fair. They should be able to read me. I encourage them to do the same back to me although I don't require it. That's a whole other thing that I brought into it as well.

But on the broader communications, we now have importance. It wasn't like the old Resource Prospector days. Just like I said in the Resource Prospector days, the double-edged sword is now flipped. Now we get the attention we need. We can ask for things. We can demand priorities to some level. But now we have all the obligations too. Now people get to say, "I want a briefing on this. You're now going to get a GAO [Government Accountability Office] audit. You're now going to get an Inspector General's Office audit." You can't brush them off. Now you have all that burden. Everything in life may flip around but that's in place. Your communication skills there are essential. If you are not conveying knowledge and comfort with that knowledge and the ability to give a clear narrative in answering your questions or in telling your story and making your case, you instill nervousness or at least questions.

Conversely if you can give a clear picture, a clear story, this is what we're doing, this is why we're choosing not to do that, which may look risky to you, but this is the context in which we made that decision. On the other side of a videoconference just like you and I are having, I can see them go, "Ah." That aha moment where they say, "I get it. Yes. You're accepting risk. But to go any other way would be worse, got it, thank you." That's huge. That just put to bed all sorts of hesitation, questions, actions you'd have to address. It's through this medium of just being able to tell a clear narrative, and listen for their questions, because you may not have addressed it, and then be prepared to give your best answer back. Very powerful.

JOHNSON: It's definitely changed the way everyone works. I think it does. I know some people that don't like interacting on Teams. With oral histories we normally would travel a lot to get to someplace like San Jose to interview people out there. Now we can do it this way. To me, we're not in the same room, but we can see each other. Knowing like you said that context and having

the expressions on their face and whether they understand what you're talking about is very important.

COVID has definitely changed NASA. It's caused some delays for some projects. I know it's caused delays because of delivery delays. Now later on in the pandemic people started having problems getting things delivered. Were any of the delays that VIPER experienced due to the pandemic? How did you work around those?

ANDREWS: Ninety-five percent of our delays are pandemic-based. It's the vast majority of the issues. You said, "And how did you work around them?" like it's the past tense. We are still actively working them. It's insane. I have a list that I've been sharing with the stakeholders that is a ranked order list of the degree of lateness off of the original contract commitment date. This list is filled with 25 items, and that's just the top 25, some as late as a year.

What that does to the team is awful. I just had this conversation with the stakeholders this morning in my weekly phone call with them. The team is left in this position of saying, "Well, yes, I know those vendors aren't doing this intentionally. They're doing their best. Their own suppliers are holding them up." It's not just supply chain. It's also that people have retired, that people have said, "I'm out of here," and left the workforce. New people coming in, they're not nearly as experienced or trained.

We've found vendors where they were manufacturing a flight part for us, a machined flight part. Then after they machined it and went through inspections, they Alodine it, which is this process of coating it so that it's good for flight, prevents whiskering and some other things, for people who know what that is.

They left it in a tank over the weekend. They just forgot about it. They pulled out the part on Monday. It was ruined because it just was all gunked up with this Alodining part. Humans make mistakes all the time, but we're seeing this all the time. It's because the smart experienced people have bailed, new people have come in, and they're learning on the job. I'm not even talking about internal matters where things are slowed up internally because we were being kept at home early in the pandemic. Or the flight from government of staff.

I lost somebody six months ago who went to a start-up here in Silicon Valley where I live for triple his salary, and that's common in Silicon Valley, two and three times your salary, because we're competing with the tech industry. But now even in Houston there's a lot of start-ups there that are spacey kind of start-ups, and they are just cannibalizing the skills that are at NASA because good people are being given very attractive options, and they're working very hard, but they're saying, "I could work at NASA very hard or I could work at this company very hard and get twice the compensation."

It makes it even more challenging to hold together a project team and to focus on an end goal and everything is coming in late, which then compresses the amount of time that you have as a team to get them in place, test them, build them, and get them ready for flight. It's not your fault, which is perhaps the most frustrating thing for the team. All these things are coming in late, but your launch date has to stay the same, so the burden falls on you.

When the launch date changed recently for VIPER because the Agency requested more testing of this new lander coming from CLPS, from Astrobotic, that was good for VIPER, because now they had to go through a replan and lay things out a little differently and go check where we're going to want to land and redesign the mission plan. But it breathed a little bit of

air into the schedule that was just being squeezed so very hard by the global pandemic, supply chain, and all the other issues.

JOHNSON: This is more asking your opinion, but do you think because so many of these commercial companies, these companies like you said that are attracting people that NASA can't compete with the salary range as a government entity, do you think that's going to change more so the face of NASA? Today we had another launch that went up to the [International] Space Station, and those get a lot of attention. NASA has been in the news more in the past week than we have in a long time. But I would imagine those companies are more attractive because they can pay more money. We're moving that way with CLPS, but do you think it's going to move even more so? Or is just the catalog that NASA chooses from going to be okay, we're going to get a lander, a launch vehicle, everything we want is going to come from a catalog, and we just oversee it?

ANDREWS: A lot to unpack there. First of all in the Bay Area, Silicon Valley, we're used to this. Because the people who are hiring away from us are not space people, they're technology people. What that means is as Silicon Valley is growing, the pay disparity between what we can offer at NASA Ames Research Center and industry goes disfavorable. It's hard for us to compete. But what traditionally happened is the economy goes through these natural ebbs and flows. When the economy turns sour outside, you'll find a lot of those people clamoring to come back for the stability and the fun of working at NASA and the salary is not the point anymore. That cycle goes back and forth. At Ames we've gotten used to that.

What's different about what's happening now is it isn't just Silicon Valley booming, but now it's this whole commercial space arena. I don't think any of us know whether that's going to have a correction and go back down again or if it's just going to keep climbing like airlines. At first it was a bumpy road and was unreliable and people were dying and now we just take it for granted, it's highly reliable. Is that the track that space is on right now? I think it's a little early to speculate.

But if it is going to more or less, even with bumps and bruises along the way, go up, NASA does have an existential question to ask itself. I know how I would like it to answer. But in general if you look across the government, like the DARPA [Defense Advanced Research Projects Agency] type entities, many places within the military, have hollowed out their technical capabilities and chosen to just acquire what they need. They become smart buyers and go out and acquire from commercial entities, all the usual military suspects, and other companies that are coming up.

NASA has chosen historically to not do that. We have a great deal of technical competence in-house, and that has served the government and the U.S. interest even beyond space. When there's some issue that comes up, they know there's some NASA experts who know this little strange thing here, have a mass spectrometry background here, have this, have this, and they can go apply it to even things that aren't space related. If the government continues along that line where they want to keep that expertise in-house, then NASA is going to have an existential problem of how do you keep talent in-house when good hardworking technical people can work at the same level and double the salary. I can't blame any of them for taking themselves up on that.

Does NASA find a way to separate itself from the constraints of government pay and look different? Or is something else done? This is something that the Agency and of course Congress and the broader government are going to have to think really hard about as they look to is the Agency going to fall away and become just a buyer of technologies like DARPA and lose its internal expertise. Okay, well, then maybe you don't need to be competitive, you just need contract monitors. But if you actually want to keep that expertise, you've got to have an incentive for people to want to work in the government and not just go to the commercial side. The next five years are going to be very interesting to see.

JOHNSON: Yes, I think so. You used the term that it's a big bet. VIPER is a big bet for NASA. Using the CLPS program and working it that way is somewhat different than what NASA is used to. It should be interesting to see how much changes, and if things just keep going that direction.

ANDREWS: On that point I am kind of bullish though. Because you know what has been in the government and NASA for more than a decade is the Launch Services Program. I really see CLPS being an extension of that. Even though they're not affiliated; they're two separate programs. But remember, when the Launch Services Program first started, the idea was crazy. There's going to be this program whose whole job is to go buy commercial rides for NASA needs. They're always going to be commercial. It probably had a rocky start. I wasn't paying attention. I was doing something else during those early years. But now it's grown to be this service that the Agency relies on. We buy our ULA [United Launch Alliance] vehicles, our SpaceX vehicles. More companies come into play. We'll buy those too. We get to be the buyer of commercial services, compete them against each other, get the best dollar value for the U.S.

taxpayer, and it's working. Okay, great. Now CLPS comes along and says, "Yes, that, but also not just getting off of Earth but being able to land on the Moon." Okay, well, that could work. Why can't that work? But we got to go through that early development phase where I guarantee we already have a company that went bankrupt. There's going to be other failures. I really hope it doesn't happen on VIPER. But that's part of the marketplace maturation, to try to get to the state that we say the Launch Services Program is where we have a fair number of commercial launch vehicles that are very reliable. But it took a while to get there.

I'm pretty bullish on that but I do see that as different than should NASA become a DARPA. Because remember, these commercial ventures are just in areas where it's commercially viable. The marketplace thinks that there's money to be made on launching things. If CLPS is successful, and if these upstart companies are successful, they will be profitable delivering stuff to the Moon. That's great. Is that profitable to bring stuff to Venus yet? No. Mars? No. How about deep space? Jupiter? Pluto flyby? No. Not commercially viable.

That's the world NASA should be living in. NASA just will always need to be adjusting its domain based on what the current commercial marketplace is. That's fine.

JOHNSON: Let's go back to VIPER. I want to talk about the team that VIPER has right now. VIPER is project management-led, not PI [principal investigator]-led like some of the other SMD programs. You've also brought in a science team and the outside scientist community. I think Tony said there were around eight people that have been brought in to be part of that team, and to be integrated, and not just someone to use what comes back from VIPER but to actually be integrated into the team. That's a little different. Part of that is that real-time scientist is

going to be sitting next to the rover driver. Everything's going to be real-time as that information comes back, which you started on LCROSS for that mission. But there's just some differences with this and with some other teams I've looked at. You also have a sociologist on your team to help with that team building. Maybe talk about that team and the differences of this VIPER team compared to other programs or projects you've worked on, and why it's different.

ANDREWS: This idea of a principal investigator or PI-led mission versus a project manager or PM-led is not a new one. The Agency has these type differentiations in place. It may not surprise you that I much more favor the project manager-led mission. But it's not just for self-serving purposes. A PI-led mission, the idea there is that the principal investigator is the person who's in the best place to understand whatever it is they're trying to investigate, explore, prove a hypothesis, learn, it's very science-oriented.

That PI, however, that's their first focus, and that can make for difficulties when it comes to issues of schedule performance, cost performance, understanding risk, and so forth. That isn't to say it can't be successful. But my view has always been that since we're accountable to the taxpayer and the Congress and so forth, you need to come up with a mission construct, any mission construct, lunar, Mars, doesn't matter, that answers questions you want answered, does it against a budget that has been granted by the stakeholders, does it in a timeline that also has been granted by the stakeholders, and the fourth leg on that stool is does it with a risk position that everyone agrees to. Are you especially risky? Are you very risk-intolerant? Whatever it is, there's no right answer. But everyone needs to be on the same page. That is the venue of a PM to walk that balance all the way across. Tony Colaprete is the project scientist on VIPER as you know. He contributes his science-oriented view to the team. He expresses why this instrument

is more important than that instrument, why we need to behave on the surface the way we do, because it's the best way to get the science. I need that. I am not the expert in that.

But at the same time, I have a rover team who's saying, "Yes, but to go get that science that that scientist wants is going to drive my mass through the roof because I need to have all these capabilities on the rover to go do what the project scientist wants to do." Then I have an assurance person who's saying, "Yes, do you realize the complexity of that rover to go do that?"

There's this tension that's built in across all the systems. In my view a project management-led mission is in the best place to survey all of those. I ultimately have to answer to a set of Level I requirements, which are very sciency. But they're against the backdrop of a budget that I have to live within, a schedule in which I have to perform, and a risk position that has to match our behavior. That's my view of PI versus PM.

There are definitely pros and cons to each. But I prefer the PM arrangement because I think it's the best managed cost and schedule basis for an excellent science mission.

JOHNSON: Is it unusual to have a sociologist brought into a team for a project like this? What is the purpose of that? Is that to help with team building, or is it because there's so many different aspects for VIPER?

ANDREWS: We haven't brought in a sociologist at the team level. That has been done, I know of, on a number of different projects. In fact one I learned of just this morning, which I won't name. But there is a project there where the team just suffered a big delay because they were not able to be ready for the launch timeframe, and because of the nature of the mission it's being delayed a certain number of years. That's hard on a team who've been gearing up to get

something done. Now you got all these extra years. Maybe you were going to retire. Maybe you planned to move to another project. Maybe you're tired of this one. Whatever it is. I've learned this morning that they have brought someone in to just help with the team dynamics, team vibe. Try to help make sure that the leadership on the team is aware of where the team's head is if you will.

In our case I think in different places, subteams, like you could have an instrument team, you could have a rover team, you could have an avionics team, all these different levels within the bigger construct, there are differing motivations for why you might bring in some atypical talent based on what you might want to do there.

The other thing is sometimes you bring them in not because of anything team-related but because you're trying to get your data of what you're doing with your mission to be as relevant as possible for other things. For example, if you were to bring in some talent who was going to understand how the findings of VIPER might affect future human missions, the VIPER team may not have any position on that, or might be completely unqualified to answer that, even as we're telling them you find the hydrogen here, you find the oxygen there, here's the water, here's the methane, here's all that stuff. Yes, but what might that mean to human inhabitants? What's it like? There's lots of different dimensions on why you might go to atypical experts to help you out.

JOHNSON: I don't think most people think about anyone in the humanities belonging to NASA or working with NASA. It's always good to hear those stories where the atypical people that you wouldn't think would lend any value to a project will lend that value.

ANDREWS: I totally agree. When I speak to schools, when I speak especially to kids, and some of them are immediately in their mind just going, "I will never work for NASA because I don't like math," and I really try to make sure they understand no, that's not how it works. You don't all need to love math. But you need to have a skill set that is relevant if you want to go for human spaceflight to the human experience. Psychologists, psychiatrists, medical, on and on, that may not be your traditional hard science candidates. You could argue that we need those even more because they're atypical. It's not usually difficult for NASA to pull in the usual suspects. Mechanical engineers, electrical engineers, astrophysicists. Yes. This is where you go for that. But some of those other ones might actually be strangely enough of greater importance to the Agency because it's just not expert there.

JOHNSON: Let's talk about some of the testing. I know that it wasn't that long ago. What was it, a couple months ago, that you were out at Glenn doing some testing with the lander and the egress of the VIPER? Talk about that, and maybe other testing that comes to mind. What you learned, and any testing that's coming up.

ANDREWS: I'm of the view and a lot of people on the project are of the view that test test test test test test test. Because no matter how smart your tools are, no matter how much you have conversations, which are all good and necessary, until you put metal to metal, especially when you have party A developing part A and party B developing part B, until you see those two things interact and all the unexpected things get revealed, you should not feel very comfortable with your design.

Sure enough, this Glenn test you were just referring to which took place last month was a scheduled test. We had planned it in with Astrobotic as part of the contract arrangement, which is a whole other topic we could talk about if you want, about how when it's all in your team you just do it, it just makes sense, but when you're on the other side of a contract, you don't just do anything. Everything has to be contended with. That's another challenge that we're navigating in this relatively first of its kind type of mission.

But yes, in that testing the structural test model lander from Astrobotic was brought to Glenn because Ohio is pretty close to Pittsburgh. Then we flew our VIPER rover and team members from Ames, software guys and so forth, and mission operations guys from Ames, and some Johnson rover experts and so forth, we brought them all to Ohio to NASA Glenn.

What we did was we actually had a crane take the rover, plop it on top of the lander, and then drive down the ramps. Sure enough as we were going down, we found that some of the rivet heads or bolt heads of the rampways as they're called, the ramps that go down, like back out of your pickup, would get caught on the edges of the VIPER rover wheels. How much head size can you tolerate for that not to be an issue?

You could design that in, and you could try to make your best estimates. Oh, it can't be more than a quarter inch tall or an eighth inch tall or whatever. But until you actually try driving it will you learn what's involved. We found that the VIPER rover can actually climb up and over the edges of the rampways. Like it would get caught and could lift itself right up over. Like the rampways are not providing any value. You could drive right off of them and fall off the side.

Now we didn't of course, but we were looking for that. That was a mild surprise. Is that the end of the world? No. You thank yourself for giving yourself the opportunity to see it. Then

you both go off. Is there anything we should be doing with the wheel that's different? Is there anything we should be doing with the rampway that's different? Then you plan to get back together a few months later after you've effected whatever changes you're going to effect. Try it again.

I look at it as there's this pile of pebbles of risks that are in front of us. Every one of these tests, you're grabbing a couple of those pebbles and putting them in the no longer an issue pile. When you fly that pebble list in front of you will not be zero. But you want it to be as small as you can afford and that you have time for, another PM-managed type topic, so that your residual risk on the surface is as low as you can get it. But it's not zero. This is going to be a risky mission. It's going to be risky in a number of different ways. That's okay, we all understand that. But we don't want to be reckless. We want to get that risk as low as we can possibly get it so that we can have a successful mission. We can get all these science questions answered for everything that comes after it.

JOHNSON: Talk about what you mentioned at first, working with contracts on that side. Like you said, if you're doing it all in-house, you just make a plan, you do the testing, and you move on. But now you have to deal with these other entities. Talk about managing through that.

ANDREWS: One of the challenges with any contract, this isn't picking on CLPS, but I'll get to CLPS in particular in a moment, is that on a fixed-price contract the provider, the vendor, has said, "I agree to do all these things in your contract that you've enumerated, and maybe things I put in my proposal to you that might be beyond that. Additional things that made you want to pick me. It's for this amount of dollars on this timeframe." That's the agreement. No different

than having a remodel done of your bathroom at home. You're going to get these capabilities. It's going to take this much time and cost this much money.

When you're doing something though that isn't a bathroom remodel, that's pretty clear and well done, but doing something that is one of a kind and these two parties have never brought these two things together, as you can imagine there'll be a lot of discovery. How do you manage discovery across a contract that was fixed price with the government doing its best job enumerating the requirements but guess what, there might be additional requirements that you didn't know? Or the contractor who's saying, "I signed up to do these things, but now you're saying I've got to do these things for it to be successful. I didn't price those in."

It's hard. Because what it means is the CLPS Office has to be very dynamic and responsive as both or either of these parties make discoveries. Because if in the end CLPS wants Astrobotic and VIPER to successfully go to the Moon and go do their thing and everyone's happy, wonderful, you got to navigate all these little details that if you don't, they could be mission-ending potentially. Then all this is for nothing. It requires agility. It requires a pot of money, which I think is one of the lessons learned, that somebody is keeping, not necessarily VIPER, but somebody's keeping, to address the joint needs.

I'll give you a great example of this that I thought was really smart. Back to LCROSS. LCROSS did not fly by itself. LCROSS flew with the Lunar Reconnaissance Orbiter mission, LRO. We were comanifested. LCROSS was here. LRO was on our backs. We were both sitting on top of the Centaur rocket. You can imagine how much interaction is going on there between the project teams. LRO wants to make sure LCROSS is not going to screw them up. Vice versa. The rocket wants to make sure both of them are good.

As LRO and LCROSS were talking about our interfaces, we came to places where we had an incongruity, an incompatibility. Is that LRO's fault? No. Is that LCROSS's fault? No. There's no fault. It just has to be worked out. We got to go work it out.

Should LRO pay for that? It's not LRO's problem. Should LCROSS? It's not LCROSS's problem. You need a program office or somebody to have a kitty of money to go, "Yes, I need both of you successful. I'm going to write the check to whomever, to LRO, to LCROSS, to some other party, to make sure that we work that out." There needs to be a kitty of money over there to address those needs. It's just inevitable. I think there's a lot of learning going on in the CLPS Office about that right now, about how do you manage that.

In the future, fast-forward 5 years, 10 years, when let's say the marketplace is filled with commercial parties who all have multiple missions under their belts. They have these products that are available. That's going to be much easier because think about then. Let's say VIPER launched 10 years from now. Instead of us working with a partner who's developing a lander, we would go through a catalog somewhere and say, "Hey, this one says it can carry our weight. They're claiming they have the ability to land on the Moon." We just order it like it's an a la carte menu or something. Then that company says, "Here's your lander. This is what we can do. This is all that we can do." Then we can design around that just like the Launch Services Program. There's a Falcon 9 rocket I could get. A Falcon 9 is a Falcon 9. If I can go on a Falcon 9 good for me. If I have to go to a Falcon Heavy, okay, I hope I have extra money.

When the marketplace on the CLPS domain 10 years from now is more like that, I think it'll be easier. But these early missions are really going to be doing a lot of pathfinding as the marketplace finds its way, I guess I would say.

JOHNSON: I was listening to something that you did for APPEL [Academy of Program/Project & Engineering Leadership]. I think you used the term an Uber to the Moon. I thought that was interesting. It's like calling up an Uber.

ANDREWS: Yes. Play that one out. Because I think that's a funny metaphor but it's also really pretty accurate. I've got to go to the airport, and I call up an Uber. When that individual rolls up, what do I know about him or her? Their driver's license, their experience, their anything? All I know is the number of stars they have. I don't know if they get tickets all the time. I don't know. Somehow, I'm okay with them driving me.

I also don't know the condition of their car. Uber is supposed to inspect them on some basis. Lyft, all those parties are supposed to. But honestly as that individual is rolling up, all I can do is when I walk in, I can look around, see if it's an awful place or it's clean and tidy and all this. That doesn't tell me anything that's going on under the hood, and I don't really know what the driver is capable of. And yet I'm going to go buy that service. It's really remarkable when you think about it. That's the equivalent here. We don't know. Astrobotic doesn't even know their capabilities yet because we're going to be one of their first missions. Certainly their first on this particular lander. But we're trusting that we're going to have a successful mission by good interactions and things like what the Agency did asking for more testing of their lander. Which is what caused the one-year delay. But that's an extension of trust, not unlike the Uber scenario, with the difference being that this is a company called Uber with only one or two drivers instead of thousands and thousands. It's an interesting metaphor but it carries pretty true. You only have so much influence over the driver and his vehicle. That's exactly the case with CLPS.

JOHNSON: Exactly. It is interesting. When I heard that I thought wow, that's an interesting way of putting it, because we've all had various experiences with Uber or Lyft, I'm sure. Some good, some not.

ANDREWS: We're hoping to have a five-star experience.

JOHNSON: Yes. If you could get some guarantee it's going to be at least a five-star that would be great. You mentioned that Inspector General audit. I did read some of the things that they wanted NASA to do. One of them is of course to keep track of VIPER's lessons learned. Is that something that was happening anyway? Or have you done anything special to make that happen the way they wanted it?

ANDREWS: The Agency already requires that every mission capture lessons learned across the project, across all things. I would say how the Agency goes about organizing them really could use an AI [artificial intelligence] algorithm, because the problem is all these missions capture all these really great pieces of learning, but they're very particular to the circumstance of that stakeholder base, of that mission, of that contractor. Some deep learning by AI going through all the Agency's learning to be able to synthesize well, for a mission that's smaller that has this type of customer that's going to the Moon, these are relevant. We got a ways to go on that. But yes, I didn't need the IG to tell us to keep lessons learned. We actually have on our own SharePoint system here a way that all of the team can go over there. If they just spontaneously get off the phone, go, "Oh my God, I wish we had," they could literally right then throw it up onto a document that's already there waiting for them 24-7 and capture it while it's fresh in their mind.

Then the question will be at the end of the mission when these get gathered and entered into the lessons learning system by the Agency, that's always a nightmare to get them in because how do you organize them? But that's someone else's problem. Our obligation is to catch that learning.

JOHNSON: It made me wonder, did your team or you go back and look at any previous programs or projects such as Apollo? Because Apollo had rovers. Or any of the Mars rovers, any of those programs. Did you go back and look at those historical programs at any point to get from help their lessons learned?

ANDREWS: Absolutely. But we haven't done it so much through the Lessons Learned system for the reasons that I just mentioned. You could comb and comb and comb through them. You're still not—the system isn't good enough and sortable enough yet to assure relevance to you. But what's nice is there are still humans you can talk to. With humans we have an ability to quickly filter and sort down to oh yes, that's not going to matter for you, is it, or ooh, something you're really going to need to worry about is. You would have never found that in lessons learned, because this person just on their own, this expert, this experienced person, just said, "There's this thing that was a real nightmare for us. I bet it'll be a nightmare for you too."

We have spoken literally to many different Apollo era folks, all the way to Jack [Harrison H.] Schmitt down to people who were rover designers who learned about static electricity issues on the regolith and traction issues, and understand the south pole might be different, because all that learning was around the equator, which always gets lots of sun. But still, that doesn't mean we shouldn't talk to them. We should understand what that looks like, and then understand we

might have that and, an additional dimension, when we go in the shadowed regions. We have spoken to various rover experts from JPL [Jet Propulsion Laboratory, Pasadena, California] on the Mars missions.

In fact when we were still Resource Prospector, I under my own authority paid to have independent teams come in. Not because of any gate reviews or anything in the Agency. We held these TTRs, tiger team reviews. I brought in JPL experts, Goddard [Flight Space Flight Center, Greenbelt, Maryland] experts, Marshall experts. I brought in academics from the University of Central Florida. I brought in all these people to critique our work. Man, was that a gold mine. That was the best money I had spent during Resource Prospector. Because you'll find that beyond lessons learned captures in some sort of big spreadsheet, the thing that humans still have over that data collection is they can synthesize and they can listen to other people in the room and have those lightbulb epiphany moments where they're like, "Oh, one of the things we were worried about on our mission that ended up not being a problem because XYZ, you don't have XYZ. So you might actually have that problem that we didn't have to worry about." Can you imagine how worthwhile that knowledge is? That could save the mission potentially. Yes. We're big on standing on the shoulders of people who have relevant experience. To not do that is to your own detriment, because it just means you're going to learn it on mission. Maybe it's benign, but maybe it's going to really take you out. Man, learn that.

JOHNSON: When we've talked to other people, they've mentioned that. Going back and talking to the guys and women too that are still around hopefully, because that information is priceless. It's priceless. Hopefully we're gathering some of that information for future generations.

The design reviews, like the critical design reviews [CDRs], the preliminary design reviews [PDRs]. I know your team has to go through them. But the commercial partners like CLPS, Astrobotic, do they go through a separate one on their own? Or how does that work?

ANDREWS: Boy, this is another really interesting area. If NASA had written into the contract that they wanted these commercial parties to behave like NASA, NASA could do that. Then the offering parties would price that, and say, "This is what it takes." That is kind of a traditional NASA way of behaving. The Boeings of the world, the Lockheed Martins of the world, they all know how NASA works as well as NASA, because they've worked with NASA all these years and work on contracts.

The CLPS Program, the requirements and the task order was intentionally written differently. It was recognizing that if you really want new players to come in, smaller teams, younger, less experienced teams, and lower-cost teams, if you're going to project all of that NASA-ness on them, you're just going to get all the usual responses. Or smaller players are just going to have to bail out because it's too heavy for them.

What the CLPS premise says is if these guys know what they're doing and they have their own way of doing it, maybe it's some innovative new way to do testing and skip this part and do this thing and not do that thing, if you don't want to clobber that by saying, "You got to be NASA-fied," then let them do it, and you get the end result benefit. You don't stand in judgment of what they need to do along the way. That's a big risk. But that's also an opportunity to let them be their best selves, their most effective selves, their most cost-effective selves. The CLPS task orders tend to look a little more like that. When you say they have their own version of PDR, CDR, and so forth, there are a few different milestones that are tied to

payments in the contracts. By the way I don't own these contracts. I'm just telling you what I'm aware of. But this is between the CLPS Office and the CLPS vendor. I'm just a payload provider is how the system works.

But I know they have certain payment milestones where NASA has to be satisfied with their progress on something. Then NASA gives them a check if they are satisfied with it. So there is that, but it is not anywhere near as rigorous and constraining as your traditional NASA mission. Even that is pathfinding. Is that going to work? Will that work for smaller missions but be harder for bigger missions? These are all questions yet to be answered.

JOHNSON: Yes. I would think that the risk tolerance of the mission would have a lot to do with that, whether that's tolerated.

ANDREWS: You bet. Dollar value. Yes, absolutely. This is why there are some who argue that VIPER is an awfully big project to be going into CLPS this early. There's many other CLPS missions that are flying and they're bringing a mass spectrometer, or they're bringing a mass spectrometer and a drill, or they're bringing a neutron spectrometer. It sits there on the deck of the lander and it takes its measurements and that's what it does. That is a completely different order of magnitude of complexity than bringing something as expensive and heavy and large as VIPER and enabling it to roll off its back and go do its mission. Order or magnitude different. Should VIPER have maybe waited a little bit and gone on something a little bit later? That's a debate that you can have. But that's an open question I guess at this time.

JOHNSON: Those missions you're talking about, those precursor missions with some of those same instruments that will be on VIPER. Does that help with the risk, to manage that risk? Knowing that at least those instruments will work if they work on these early missions?

ANDREWS: It's interesting. This point I think sometimes confuses people. They think well, you're flying versions of your instruments on earlier missions. But those earlier missions have been getting delayed because they're not ready as they're working through their own issues. Does that hurt VIPER? The answer that I always try to very clearly give is VIPER was never dependent on earlier flights of those instruments. We planned on flying all of our instruments for the very first time on VIPER. When you get that in your head then you realize any earlier flights of them is opportunity. That's bonus. Just like you alluded to. Let's say I'm flying the Neutron Spectrometer System, NSS, from VIPER on an earlier mission. It isn't just whether or not NSS functions. We may find that it functions but it does this weird thing when it's in the sunlight. Or it does this strange thing when the temperatures go between this and this. We may not have time on VIPER to go redesign it. In fact that might be a stupid thing to do because we already have a fully mature instrument. It's packaged. To go backwards we won't have time.

But if we can know from those earlier missions that there's behavioral things or it really behaves really well if you keep the temperature between X and Y, just all that learning whether it's good learning or negative learning, it's learning. Then maybe operationally during VIPER we try to play to that learning. We, what we call, fence off areas where the behavior is not so good. If we can. We might not be able to. Do you think having that knowledge in advance is an advantage to us? Oh, you bet. Even if we can't do anything about it. Even if it acts funny in the way that we need to use it and we can't fence it off. Even knowing that it's acting funny on that

other mission, we could start conjuring okay, what could that be, how might we do things differently. Instead of being surprised ourselves when the same behavior happens on our own. Yes, every flight of any sort in advance of ours is happiness for us.

JOHNSON: Hopefully some of those missions will get off before VIPER.

ANDREWS: That would be good. It should not be that VIPER is proof-testing $500 million roughly activity as proof-testing for a $23 million. That doesn't quite make sense. But whoever's last will get the most benefit.

JOHNSON: That's true. We talked about some of the public attention I think the last time that LCROSS received. Do you think that when VIPER launches the public will be paying attention? It seems like for whatever reason the news has been covering a lot of what NASA has done lately, which is great for NASA. But do you think when VIPER launches it'll get the amount of attention that LCROSS did or more?

ANDREWS: This is something that I talk with our OCOMM [Office of Communications] person about quite a bit, because I feel there are a lot of lessons learned about the LCROSS public engagement experience. One thing that's fundamentally different about LCROSS is it was very much like DART [Double Asteroid Redirection Test]. There was no mission after we landed because we were an impactor. We landed with vigor. There was nothing after that other than did you get the data. On top of that, when you look at the range—I think we talked about this before, but—of what could have happened, everything from giant explosion, rocks and light

shooting out of that hole when we hit it to virtually nothing being apparent and everything between those two bookends are scientifically relevant. Every single thing in there. There's no favorable. All of it is learning. But the problem is I think we pitched a little too hard the excitement of the impact. We didn't call it this, but that notion that we were bombing the Moon, which of course we weren't. The rocket wasn't even propelling. It was just drawn in by gravity. But people got excited, which was good, but then disappointed when we landed in such soft soil that it was visibly invisible or invisible to the eyes of all these people with their telescopes looking up. That was unfortunate because it gave a negative connotation to what ended up being an unbelievably important scientific discovery, which is those permanently shadowed regions [PSRs] have the softest soil. It was almost like throwing a Nerf football in there and it was just softly caught as opposed to explosion and stuff kicking up.

What came up, of course there was ejecta. But it was mostly visible in the infrared. We were heating the soil and all this vapor came up. That's good. It showed that there was water ice and water vapor that was coming from sublimating ice that was there. Yay. Giant success. And yet everyone who was visibly watching was like, "Ah. Why'd I get up that early?"

I don't want to repeat that on VIPER. Now VIPER is fundamentally different. Is landing going to be important? My God, yes. Landing is going to be important. But it's not the end of the show. It's also not going to be something that you could see from the naked eye or from most telescopes. It's down in the south pole. It's going to be hard to see.

But the first time we go into one of those permanently shadowed regions, which I just told you was unbelievably soft, because of what was found from LCROSS. Oh yes. That's going to garner a huge amount of attention. Are we going to go into quicksand? Not likely. But as we're going in there, we designed our rover to be able to pull one wheel up and move itself

back on three wheels by changing its center of gravity. You can't do that on any rovers anyone's used to seeing going to Mars or anywhere else. That's not an accident. We don't know the environment we're going in, so we tried to create a relatively capable rover in case we need it.

Now we'll be happy if we're wonderfully surprised and it's actually easy to drive around in permanently shadowed regions. Okay, good, we didn't need to do all that, but we had a good mission. But on the chance we're not lucky like that and it's actually very hard, I want the best capable rover that I can afford, going back to the whole PM-managed thing, to accomplish that goal.

Longer event horizon than LCROSS, VIPER will have. We're going to be going roughly four months. We might be able to eke out more with further analysis. We're going to be going to some very foreign places. We're going to be the first rover with headlights—rovers haven't needed that before—because we're going to be going into areas that there's just the blackness of shadow. Remember there's no atmosphere there. There's no way to scatter light. What's in daylight is bright, really bright, and what's in shadow is as black as black can be.

We need those headlights. It's just going to be brave new world. It's going to be just really so foreign. I think that'll garner a lot of attention. The excitement that we might die. This is a tough mission. Remember, what was it, the 11 minutes of terror as the rover was going in on Mars. A whole period of time where we didn't know what was happening. Then out the other end it was either going to be crushed parts on the surface or a success on the surface. The public wants NASA to take a chance. If not NASA, who? We're not afraid of taking those chances, but we just need to fully make them aware. "Plausibly, this is what we could see. Could be anywhere from here to here. We want it to be successful but this is risky stuff. Here's a really risky part we're about to go in on." Bring them in on it. I think it engenders excitement. But

not only excitement, it keeps them realistically engaged. This is really hard right here. I think fans of NASA and even people who aren't especially interested in NASA, they'll respect that if NASA isn't doing especially hard things why does it exist.

This is exactly why NASA exists. This isn't worth a private party doing because it's too risky. It's not worth the money. That's exactly where NASA should exist.

JOHNSON: You mentioned talking to someone at OCOMM. As it gets closer to launch, is that something you're coordinating with OCOMM to make sure that whoever the press wants to talk to is the right person and that sort of thing? I imagine you'll be very busy at that point talking to the press or doing those type of events—especially right before and then after landing.

ANDREWS: A lot of us will because it's going to take a lot of people on the team to be able to speak to all the different demands. But yes. So closely coupled that we actually have a work breakdown structure [WBS] that organizes our entire project and WBS 11, our highest WBS number, is public engagement, Office of Communications. They actually get a budget from me. They put together a plan against that budget. Yes, these aren't just people that we talk to; they're part of the project. Then they interact with the broader Agency infrastructure of communication. Everyone's all coordinated across centers, Headquarters. We're all messaging the same thing as it should be. But yes, I've got them under the tent so that they can get the level of access. They attend all my staff meetings. They know what's going on. It isn't just sound bites or tweets or whatever that we choose to give to them. They really have an inside track of what's happening. Sometimes they have to ask me, "I heard you say this in the meeting. I heard so-and-so say that. It sounded pretty scary but I don't understand why." I have to take the time to say, "Here's why.

Here's why this worries us. Or here's why this doesn't worry us." I think that pays for itself in the end, because then you're not trying to educate someone who's completely in left field. They've been going along with you. Smart people figure things out and they start to put two and two together. It doesn't even matter that they may not be technical. If they're engaged enough, they'll be picking it up.

JOHNSON: I would think you would have to have some coordination, because not everyone is good or wants to talk to outside press or people that would be asking those questions, so I would hope that you did have that help.

ANDREWS: That includes that they tend to coordinate when to get training for different people. Because there's plenty of smart technical people who you'd love to stick in front of the public. Because they are in the most capable place to answer questions and all that. But they're not tuned up for engaging with the public. Okay. Let's go get some media training. Let's go practice. Let's do that type of thing.

JOHNSON: That's important. What about education outreach with VIPER? Is there any planned education outreach for schools?

ANDREWS: Back on the LCROSS days, we actually back then had within our authority and responsibility to have budget for education and public outreach, E/PO. Actually I think the requirement was that you budget 2 percent of your budget for that. Which when you think about it is a pretty generous number. We did that. We had an educator on the team, a lead person who

worked with communities, schools, Navajo Nation. Just all kinds of interesting parties. I think a lot of good came from that. That was the best 2 percent you could spend anywhere. Because it's a relatively small amount of money but that small amount of money goes a long way when it comes to education. Putting together teacher guides, engagement. Even without that budget those of us on the team would frequently go out to schools. Elementary, middle, high, college. Like I said, I've given a guest lecture at Stanford. The whole range.

What's happened since then, that was a long time ago, that was 2006 through '09, various [presidential] administrations have changed the rules. At one point the rule was made that why is NASA's budget being used for education at all. That should be the Department of Education. I think that was personally a mistake because Department of Education just isn't tooled up to understand how to convey deeply technical and complex ideas there. Even though they are the agency for education. Now we're in a very strange place, I personally feel, in the Agency, where we have raw materials that are just amazing for education. STEM [Science, Technology, Engineering, and Math] engagement and advocacy. My God. We could do it just with stuff falling out of our pockets. But we have an ambiguous lack of clarity associated with what we're required to do, what we're allowed to do. It's not as good to me for VIPER as it was on LCROSS where there was clarity and I could actually bring my attention to meeting with an individual, working through a budget, choosing activities. It was very rewarding and it was very worthwhile.

Now it's more about the public engagement part. We have that. That's the OCOMM part and all that. But we're not developing educator packets and doing that kind of stuff. That's left to others and I think that's unfortunate.

JOHNSON: Yes, I agree with that. We have about 15 minutes, and I have a few more questions. But more kind of gauging, so if we talk in the future we can compare. But what would you say is the most difficult problem? We talked about some of the delays because of COVID and the things that happened during the pandemic. But is there anything else that you would think would be the most difficult problem that you've found at this point in the timeline of VIPER, that you've found that's caused you the most angst, or you've worried about the most?

ANDREWS: This one is a really hard one to answer because remember under Resource Prospector a lot of the very early technical issues that would keep me awake were addressed there. So we're not getting a fully complete picture there. But that said, VIPER is different than Resource Prospector. One of the key things that are different between them is that VIPER has to make it multiple lunar days, which means there's periods of darkness that we have to navigate. We are not powered by any nuclear fission materials or radioactive decay. We're not even warmed. Because sometimes some missions don't power themselves but they just get warmth from that fissionable material. We are 100 percent electrically powered by solar power. That means what we keep in our gas tank, which is a battery, what we keep in that battery is all we got when we fall out of view of the Sun. By the way, when you fall out of view of the Sun it gets very very cold, because again there's no atmosphere to equilibrate temperatures. When we walk here on Earth in the Sun, then into the shadow, we feel a little temperature difference because the Sun isn't hitting us, but it's basically the same temperature behind the shadow as it is in front. On the Moon, night and day, because there's no air to move around.

My biggest concern is that as we go through all the normal engineering development and horse-trading, against a constraint on mass, you can only weigh a certain amount, that's what we

agreed to in that contract with Astrobotic, that mass keeps us from putting more batteries on that we might like to carry. That makes it too heavy. It keeps us from putting even bigger solar arrays or more solar arrays on to generate more power, because it makes us heavy. And yet, when we go into a permanently shadowed region if I don't have enough energy capacity to get that done, I may find myself going in, barely getting anything done, and then I have to get out to get back into the Sun. If I'm spending all my time doing that, jump in, jump, jump, and jump back out, jump in, jump, jump, jump back out, I'm not effectively doing science and that permanently shadowed region is really important. Every mission that I have ever heard of as they get to that place where we are right now, finishing everything up and about to build the thing, struggles with mass because maturity equals mass. As you mature things you spend mass. It's just how it is. We're tight on mass.

We've looked at a lot of different options. We have them in our back pocket. We'll choose how far down we go down that list based on how desperate we are to save mass. That one has been one of my biggest challenges so that we have the capacity to do and recover from all the tough things we're going to have to do on the surface. There's no one there to rescue us. We got to bring everything that we need to survive whatever it is that we encounter there.

When I was asked about lessons learned from LCROSS after LCROSS was done, I was called back to Headquarters to give a briefing to the mission directorate AA [associate administrator]. I think I came up with nine different lessons learned. One of them that really served us well in LCROSS was to have technical freeboard somewhere. What I mean by that is is there some technical parameter, power, mass, heating, some technical basis where you can have more than you need. That's what I mean by freeboard. If I needed 500 watts, is there a way I can get 525 out of my system and have that extra 25 for something that I might not know

that that 25 could save the mission? That happened on LCROSS. A hot solar array—what we mean by hot is producing more power than we needed—ended up saving a major issue while we were on our way to the Moon. Having that freeboard, not because you know how you're going to use it, but specifically because you don't know how you're going to use it, and to trade that when you find yourself in a pickle on the surface is going to be everything.

Right now our biggest freeboard that we have on VIPER is that our traverse planning tools for the rover have become so impressive that we have literally thousands of variations on a theme of our traverses. Like too many to sort. As we're going down this route and oops, we get stuck somewhere, the clock is ticking, the Sun is moving like really fast, because we're in the polar region, so relative shadows move quickly, if we can't get back onto that original plan are we done? Are we toast? No. We use that planner and we gin up something new. Oh, now I guess we're going to that safe haven instead of the original safe haven. That I promise you, I promise future me, is going to save ourselves at some point or multiple points in the mission where we encounter something and we have to go to a plan B or C in order to get into the Sun before Earth sets relative to the Moon and we can no longer drive the rover.

That helps me sleep at night that we have that robustness. I applaud the traverse planning team for coming up with both the tools and picking very robust missions. Not an esoteric mission that really everything has to work perfectly or you're doomed. No, we have a nice region that we chose, and a robust plan.

JOHNSON: I hadn't heard that, that the team had planned all these different things. But yes, have that plan already in place in case, because you don't really know what you're going to run into.

You'll have team members. You'll have the rover drivers, and then you'll have those team members, scientists, and everybody, sitting next to them helping with that.

ANDREWS: Even that. Think about what you just described there. You got the scientists and the rover there. Rover is doing its thing. Rover driver is driving it. Scientists go, "Ooh, I just saw something. Ooh, let's go back. Let's do this." Okay, that's great for science. Let's say they find something just mind-blowing. Oh my God, look at the water density here. Those two are not in charge. They're trying to optimize the science within a bigger framework. But the bigger framework is the operations planning team who's looking at their watch, looking at where we are on the surface, and saying, "You guys got this much more time before I need to start heading for that hill. I know you're getting great science there. I know this is very exciting. Maybe we can come back here if we have time. But it's going to be game over if we don't head to that bright yellow spot in our model." We model them as yellow. If we don't head to that bright yellow spot up there, you're not going to have any option for anything other than that data you just got now. They order that we move out.

There's even nesting priorities that we have to execute for the broader interest of the project. Yet another example of why you can't have science as the ultimate discriminator. You have to have the global needs of the whole mission—which is science-driven—but trying to maximize the whole global environment. That might mean at the expense of some local interesting scientific thing.

JOHNSON: The purpose is to map those areas. If they can't get what they want, then you know where they are.

ANDREWS: Understand that when you're in a particular permanently shadowed region, maybe there's something very interesting there. We won't know till we get there. But in general our premise for the mission is that we're going to go into multiple permanently shadowed regions, multiple ice stability regions. We have four different types. The permanently shadowed region is just one of them. There's four. We're going to hit multiples of all of them because even if you hit one PSR and get data from one PSR, you're not going to feel like you really got a good statistical sense of what it's going to do till you hit a second. Maybe a third. Anything beyond that is even gravy beyond that. You really want a statistical representation of all four ice stability regions. Our plan has that. It isn't about any one place. But I do wonder about when we go to one place and there's just this mind-blowing what the heck is this. That's going to be really hard for us because you're going to want to drill. You're going to want to do everything. Meanwhile the rover systems people are going, "Uh, people, we're almost out of gas, we got to go." That's the fun of the mission, honestly, to make those trades.

JOHNSON: Sounds like it. Looking again across where you are in your timeline now, is there anything that you're most proud of that you and your team have been able to accomplish with VIPER so far?

ANDREWS: The technical prowess of this team is very impressive. I'm sure most every team can say that. Honestly for me the ability of this team to work through the level of adversity that we've had to. Doing a NASA mission is hard in a normal decade. Doing a NASA mission now not only in just COVID, wildfires shutting down facilities, power outages in both Texas and

California, rotating and otherwise, political unrest, the great resignation, COVID, yes, is underpinning some of those but not all of those. We're just in a time of great turmoil. To expect people, who some of them are still at their homes or partially at home, partially at work, to keep the focus on this mission. I'm astounded by that. That's a big ask. And oh, by the way, you're not getting wealthy working for NASA. You might say, "Well, but at least I'm getting rich off of this." No, you're not.

Why are you doing this? Each person needs to be really thinking about why are you even playing. The part I'm personally proud of is that we've created an environment where people want to come in and still work with whatever part of that I feel I've contributed to that. But it's bigger than that. This is a very exciting mission. People are still so far keeping the faith. They want this in their resume. They want to be able to look back at this and say, "Yes, I could have made two or three times the amount of money perfecting this new hard disk that has unbelievable access times or whatever. Or I could go do a mission to the Moon that's going to go find water and help humans live there going forward." But even with that, I'm very impressed by this team's, despite the stress, and it's showing at times, stick-to-itiveness to keep pushing on this very worthy mission.

JOHNSON: It's not easy. It reminds me historically speaking of the '60s and Apollo and having all the political unrest and the things that were happening in the '60s. Then accomplishing great things, and that focus that it took to do that. Yes. I think it's important.

ANDREWS: Almost in spite.

JOHNSON: Is there anything we haven't talked about—we have about 5 minutes—that you wanted to mention?

ANDREWS: You've kind of walked all over the place. I appreciate that. I love the connection to LCROSS. I personally feel a great professional personal privilege that while I didn't work on those missions in the '90s that first went, "Huh, something curious going on in the south pole region, I wonder if it's water," but we stood on the shoulders of that and we did LCROSS, and yep, it's water ice. We'd be blessed to be able to stop there and never work on a NASA mission again. That would be a real high point in your career. The fact that honestly partially because of our stick-to-itiveness but also luck and advocacy and soft influence and all that we got to an RP and then RP got to a VIPER. While we haven't flown yet and bad things can still happen, the premise that we have the opportunity to then follow up on that very work and now go understand the nature of it, and that 20 and 30 and 50 years from now when I'm gone there will be people walking around the Moon potentially drinking the products that we helped figure out. I mean come on. That's awesome. Really a gift that only a fraction of a percent of humankind gets to ever say that they did. What's better than that?

JOHNSON: I couldn't tell you. That's for sure. I think it's a privilege to get to talk to people like you who have the opportunity to do those great things. It really is. I appreciate you taking the time.

ANDREWS: It is a privilege.

[End of interview]