DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

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INTERVIEWED BY SANDRA JOHNSON
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JOHNSON: Today is June 8th, 2022. This interview with Dan Andrews is being conducted for the Discovery Program 30th Anniversary Oral History Project. The interviewer is Sandra Johnson. Mr. Andrews is in San Jose, California, and talking to me today over Microsoft Teams. I want to thank you again for joining me today. Let's talk about your early years, your education, and please briefly describe how you first came to NASA.

ANDREWS: Sure. I grew up in Livermore, California, and when I finished high school, I knew I wanted to be an engineer but wasn't quite sure what discipline and how to go about it. So I went to a community college outside of Livermore called Chabot, got my basic preengineering math and science work done, and then ended up transferring to San Jose State University, where I got my bachelor's degree in electrical engineering. They have a good electrical engineering program there. Then as I was finishing up that program, one of my professors in control theory, which was a topic that was beguiling me—I was struggling with it, yet I was fascinated by it—and I saw him quite a bit. He had a previous student say that he worked at NASA and he would like to see if there were other good engineers that this professor would recommend, and he recommended me to go in for an interview.

I was not his best student, but I might have been one of his hardest-working students, and so I always appreciated that. I went in for the interview, and I got the job. A couple years into my career with NASA, I competed for a full-time graduate study program, and that was a

competition. I ended up getting that, and then went to Stanford University for my master's in mechanical engineering, because I always liked robotics, so the electrical engineering, mechanical engineering mix was a good fit for what I liked to do.

JOHNSON: Let's talk about those early positions that you held at NASA, and how that helped to prepare you for your work with LCROSS [Lunar Crater Observation and Sensing Satellite] and the proposal management and as the project manager for LCROSS.

ANDREWS: It was a really great branch that I was hired into. The branch was filled with senior level, midlevel, and then junior people like myself. It had a really healthy mix of experience and energy level and everything else. I was one of the few electrical engineers and the branch was mostly mechanical engineers. That ended up being very formative for me because while it may feel like I was out of place, I was picking up all sorts of understanding of the physical world as opposed to the electrical world, and it started becoming apparent that the equations that define both of them are the same, they just apply differently. That helped broaden my understanding of robotics in general, and also just broadened what I could work on. I remember six months after I was hired, I was given this job to create an aerodynamic foil flipping mechanism that would take an aerodynamic wing and flip it from 0 to 60 degrees in 25 milliseconds. That's really really quick. You're trying to study the nonsteady flow lift characteristics of a wing when it's moving very quickly. I actually had to design the whole hydraulic system. I didn't know anything about hydraulics but I got with a mechanical engineer. I wrote all the equations, had this massive equation system that defined the whole thing.

I remember when I was presenting it to the management, the division chief there, he leaned over to the branch chief, who was my boss, and said, "I thought we only gave jobs that were possible to our new hires." So it was really a fun challenge to do that so quickly out of school, and I think that's sort of the story of NASA, at least in my experience, which is you're going to be given the opportunity to work on very strange and very challenging things, and if that excites you, you'll have a lot of fun here.

JOHNSON: That's interesting that they trusted you enough to challenge you and that you had the opportunity to learn so much in those early positions.

ANDREWS: Yes, and it was a small team. I was leading it, but there was one other person, a mechanical engineer, so it was a dynamic duo there. But it did start forcing me to understand what it's like to have leadership positions, even though it was a small group. Someone had to figure out the schedule, someone had to figure out how much time this was going to take, what are the pieces of the work you're going to do, how are you going to price that, where are you going to buy the stuff that you need. As a fresh out, you're not taught any of those things in college. You're taught to be a very good engineer. All that type of thing you had to learn live, but in a relatively contained small project. You could fail incrementally and learn and so forth. Then in subsequent positions that came along I found myself leading four people, and then I still was doing technical work. Then that just keeps accelerating over the years. Probably the first third of my career I just saw that natural movement.

I remember the very first job I worked on where I no longer had a technical position, and it was at a point where I realized I'd probably done four or five technical jobs prior to that. I was

starting to see how they go, it was starting to feel familiar, and so it made sense that then I maybe elevate into a position where I have a bunch of folks who are doing the technical work and helping them to organize and to set priorities and "Don't go down that route, trust me, I've been there. Focus more over here," and let them do the work. That's just that natural thing that I think many technical folks' careers follow as you become a little more experienced and seasoned, and your value comes in guiding others along that route. That just kept on moving up until the really big calling, which was the LCROSS mission, was asked to actually lead a flight project, for what felt like a huge amount of money, even though for flight projects it wasn't. Less than $80 million, but I mean, $80 million. That was a really big deal and a very big learning opportunity for me and the team.

JOHNSON: Did you have any mentors as you were coming up as far as managers that you were working for?

ANDREWS: Yes. On some of my technical work and then even when I was leading groups of 10 people, that was part of a bigger project in which I was answering to a project manager over 150 people. So I was both expressing management within my team but also being part of the team to a bigger level project. There were three or four different people who I took as very aspirational leaders, and a couple leaders who I learned a lot from by recognizing what they were doing wrong, why I wasn't happy working with them, and then internalizing that as a note to self, remember how this feels right now, remember when you're on the other side of that to try to not do what you're experiencing right now.

JOHNSON: Discovery as a program was first proposed by Wes [Wesley T.] Huntress as a way of flying these low-cost high flight rate community-defined, as far as the science community, planetary science missions. It followed that faster, better, cheaper model that Dan [Daniel S.] Goldin was promoting. Talk about that model for exploration. I was reading your book [*Shooting the Moon*], and you mentioned that Dan Goldin also said, "It's okay to fail." What did he mean by that, and how does that apply to these kinds of missions like LCROSS?[1]

ANDREWS: In current times the advent of CubeSat type missions I think are the current instantiation of the intention of the Discovery Program. Of course CubeSat missions are not the size of the Discovery Program, but I really think they embody the intention of the Discovery Program, and that is if you do more missions, and in doing so you're able to accept some failures along the way, in the end you're going to win, because you're going to get more done, you're going to advance the cause even with some setbacks, and in aggregate it's going to be worthwhile. I've always been a fan of that. At Ames Research Center [Moffett Field, California] with LCROSS we actually became some of the purveyors of risk-tolerant management at the scale of LCROSS. I think the NPR is 8705.4, to get wonky a little bit here, but in that policy requirement it defines the different risk classifications of missions. NASA has four, A, B, C, and D. A is the least risk-tolerant, so that would be big multibillion-dollar activities or activities in which humans could be in harm's way. You really want to have very low risk on those. But they're going to cost a lot to do so. Then D would be the other extreme. That would be the Agency's most risk-tolerant. LCROSS was categorized as a Class D.

[1] Shooting the Moon, by Daniel R. Andrews:
https://ntrs.nasa.gov/api/citations/20130014470/downloads/20130014470.pdf

But when you took a look at the examples at the time of LCROSS, what D missions there were, they were not missions. They were parachute drop tests. They were individual instruments. They were down on the order of a couple million bucks maybe.

Along comes LCROSS at $80 million and it's being categorized as a Class D. That was a very large Class D type of mission. But it did fit the Discovery paradigm of risk tolerance and trying to get the most you can out of an opportunity if you do accept some risk. We're big fans of that. We're carrying that forward even all the way to the VIPER [Volatiles Investigating Polar Exploration Rover] mission that we're executing right now.

JOHNSON: VIPER is classified how as far as risk?

ANDREWS: What's interesting about VIPER is the Agency, SMD [Science Mission Directorate] in this case, who's the [NASA] Headquarters customer for VIPER, has gone so far as to categorize VIPER as a 7120.8 mission as opposed to a 7120.5. What that means is a .8 mission is considered strictly speaking as a technology demonstration type mission, whereas .5 missions, which are the vast majority of flight projects, are standard NASA flight projects. So to get to your answer, .8 projects are not given a risk classification. They themselves are already considered to be a risk-tolerant activity because they're a technology demonstration.

VIPER actually has no class. There's no A, B, C, or D assigned to VIPER. We're .8. We're pathfinding that now. What does that mean to be a .8 and yet do a pretty substantial mission? Very interesting results yet to be seen there on how all that executes.

JOHNSON: That is interesting that they would do it that way. Let's talk about the beginning of LCROSS. In 2004 President [George W.] Bush announced *The Vision for Space Exploration*. Along with that there was a call for NASA to undertake these lunar exploration activities to enable sustained human and robotic exploration of Mars and beyond.

There was a push then for these lunar activities. Of course LRO came out of that, the Lunar Reconnaissance Orbiter. At what point did you find out or did NASA announce that there would be an opportunity to do this secondary type of mission along with LRO?

ANDREWS: LRO was chugging along after its selection going through its preliminary design review [PDR], and somewhere between PDR and CDR [critical design review], LRO needed to make a change on its launch vehicle. It moved to a different launch vehicle. It moved to an Atlas launch vehicle provided by United Launch Alliance, ULA. In doing so, you can't custom size your rockets. You have to buy from what rocketry is available. In doing so there was extra mass afforded, upmass, at launch. Of course LRO has already gone through its preliminary design and knows what it needs. The Agency could just waste the mass, not use it, and just launch LRO. Or it could decide that there's opportunity here. That's the direction it took, and so there was nominally 1,000 kilograms' extra mass that was available.

Exploration Systems Mission Directorate [ESMD] Associate Administrator, Scott Horowitz, known as Doc Horowitz, said, "Let's go have a quick competition and see what sort of interesting ideas there are out there to use this extra mass and catch up with LRO, because we haven't even selected them yet, and the main mission is already post PDR."

They set a competition that was intended to be NASA-internal but it was across all the NASA centers. I believe that was in the 2005, might have been early 2006 timeframe. An

announcement was put out, and it was a competitive announcement, so in that way it was very similar to the model of Discovery. But it was done kind of quickly as you can imagine, because there's no time to waste. They set some parameters. They set a mass limit. They said, "It shall cost no more than 80 million bucks, the grand total." That includes operations, reserves, everything. I think they gave some guidance in the memo. It was put out through a memo that said missions associated with the water topic on the Moon, something to do with water, will be given preference.

At Ames we created something that we had labeled the Blue Ice team. It was a group of us from around the Center whose job it was to go hunker away locked in a conference room on the far side of the base and just start coming up with ideas for what would fit within that mass arrangement, get done in the amount [of time] that we had before LRO needed to launch, and fit within the dollar amount. We were just literally throwing around different ideas. Impactors were in there. Hoppers were in there. There's a bunch of ideas. I think Ames had put in for four or five of them.

In total the Agency received 19 proposals. It was pretty competitive. Then the program office downselected to four. Then they downselected to one. Of course LCROSS was the one that was selected.

JOHNSON: When you were in that Blue Ice team and you came up with—I think you said Ames had four different ideas. Were the teams for those four already starting to form? For LCROSS were you already starting to be the management for that project? Or were you all still working together, and whichever one got picked then that would be the team?

ANDREWS: That's a really good question. It's an interesting answer. There were like I said four or five, it's been a few years, but four or five proposals went forward. I was the proposal manager for one of the not selected missions. Not LCROSS. I was the proposal manager for LOHM. That was a neutron spectrometer mission with very large neutron spectrometers from orbit that would give us unbelievable resolution of hydrogen signals in the polar regions of the Moon.

It was considered apparently, we were told during the debriefs, one of the highest-rated proposals, but was not selected because it was seen to be overlapping some of the capability of LRO. It was seen as well, this is great, and this is a good proposal, we're not getting as good as what you're proposing from LRO, but it is overlapping, we'd like something more unique. In the end the selection was made for LCROSS, and then Center management asked if I would come over and lead the LCROSS mission upon selection. I had some passing familiarity with it and all that, but I had a quick learning curve. Had to say goodbye to my baby, which was not selected, and then quickly came to see obviously the excitement of the LCROSS mission. Come on, sending an impactor into the Moon, and flying through what kicks up and then analyzing it and then impacting with the second one, so it's like a one-two punch of the Moon and getting all this data. Come on, there's nothing better.

JOHNSON: Do you know why they asked you to lead that?

ANDREWS: I was told that they wanted, even though I hadn't done a flight project before of this size, I was told that they just had confidence in me seeing this through based on what we did with the other mission proposal. Proposals, there's a lot of reasons they're not selected. Some of

them are just really bad proposals. Some of them are ideas that are either after or before their time. There's many many different reasons. I never took it personally I guess when LOHM wasn't selected. I understood their selection criteria. I might even have agreed with them. But yes, I was very happy to move on over to LCROSS, quite a career pivot for me.

JOHNSON: Were some of the other team members already in place for LCROSS like Tony [Anthony] Colaprete? Was he already the PI [Principal Investigator]?

ANDREWS: As you can imagine, the Blue Ice team was pretty small. There was a lot of cross-fertilization going on. It wasn't like there were four or five distinct teams. What that meant was I was partially involved in some of the other proposals, Tony worked across multiple proposals. I know the premise of the Center was let's go in with all these. We know we have our favorites and we would rank them a certain way. But if we land even one of them then we will realign and coalesce around that one with a team that may have people who directly were working that proposal and folks who may have been adjacent to the proposal.

JOHNSON: Let's talk about putting that team together for LCROSS. Who were the members of the team from Ames? Also talk about some of the stakeholders like Northrop Grumman and how that team was developed and then how it was used. I'm asking a lot here in this one question but just some things you may want to cover. I was reading about how the team members acted as liaisons with Northrop Grumman to learn the spacecraft and its operations. I think some of those team members went on and became flight controllers. Maybe talk about the way that team was designed and who was part of the team and how big the team was.

ANDREWS: We followed the standard Agency approach to creating a work breakdown structure for a project, so we had WBS [work breakdown structure] 1 through 11. We broke up the work in exactly that way. Then we started assigning who would be doing what from an organizational point of view and then from a people point of view. Obviously, some of the folks who were involved with the proposal and the Blue Ice activity were already presumed to be in certain slots there like Tony as project scientist. Me later as project manager once that decision was made.

Basically all the WBS structure was managed out of Ames, including the overall project. The partnership with Northrop Grumman was essential because Northrop Grumman would be providing the actual spacecraft bus. Ames had all the instrument and science experience, and so we had a total of nine different instruments that we put on a panel that would later be bolted to the spacecraft bus from Northrop Grumman. We worked very closely with NGST [Northrop Grumman Space Technology] and NGTS [Northrop Grumman Technical Services], which were two different offices within Northrop Grumman, one on the east coast, one at El Segundo, California, southern California. Yes, we worked very very closely together. As you can imagine Northrop Grumman has some very very big projects, over-a-billion-dollar projects, military projects, NASA projects. This was a pretty small one for them, and that worked to our advantage.

It worked to our advantage because since it's small, they were willing to accept more levels of risk on it just as NASA was with our Class D designation. That's good. Because just because NASA says they're willing to take risk does not mean a commercial party is. The commercial party has stakeholders to answer to, they got stock price if they're publicly traded, they've got their stakeholders, and so forth.

It's very important that we came to a congruent sense of relative risk. We worked pretty hard to get that in the early days. It was also important that the project manager at Northrop Grumman and then me, the project manager of the overall mission at NASA at Ames, had a very good working relationship. We really grew to have that level of relationship. We would talk on the weekends, work through issues that were happening on the teams. All the normal stuff. We had that level of conversation. He's in his backyard, I'm in my backyard, and we're chatting through things. I think we need to go this way; I think we need to go that way.

Pretty standard organization for the work. Northrop Grumman was a pivotal part. We also came to realize some of our limitations. The Moon is a weird place. What I mean by that is gravitationally speaking it's lumpy, and that's known, everybody who's in the community understands that. Which means designing a system that's going to impact a specific place on the Moon where you're using the gravity gradients to help vector you in means you really have to have a pretty good understanding of how that works and have a good model. We worked with Goddard [Space Flight Center, Greenbelt, Maryland] on the flight control part of it, the nav [navigation] and orbit determination stuff, and brought them in, because that made sense. The expertise existed within the Agency. We didn't have it. We slowly grew our partnerships with others as needed. But you can't get too big with that. That drives cost and complexity. It was always this balance that I was trying to navigate there on getting the right people at the table but understanding we are not a $1 billion mission, we have to keep costs as low as possible.

JOHNSON: I want to go back to when LCROSS was first selected. You mentioned the other one you'd worked on really had a high score but it was too much like another instrument on LRO. What do you think set LCROSS apart? Why do you think that was chosen?

ANDREWS: It's a pretty clear answer actually. I like to joke that it's kind of like the Kobayashi Maru maneuver by Captain Kirk in the original series *Star Trek*. That is, we cheated. I don't mean we literally cheated, but we used something very clever in our mission design. Let me go back to the 19 proposals. There were 19 proposals that were all submitted. They were all variety of proposals from all different places. Goddard had a few in, JPL [Jet Propulsion Laboratory, Pasadena, California] had a few in, Ames had a few in. I can't remember who else, but 19.

When they downselected to four, two of those missions were impactors like LCROSS. I think one was a hopper and I can't remember what the other one was. We had two impactor missions. JPL had the other impactor mission, and what JPL did was within their mass construct they had to allocate a certain amount of mass to the impactor, the thing that's going to go in, and then a certain amount of mass to the spacecraft that's going to watch it go in and take measurements, sense. When I say that we cheated, what I mean by that is we actually took the rocket that brought us to the Moon and made that our impactor. We cheated; we didn't need our impactor to come out of the mass that was allocated to us. We could actually use the entire mass that was allocated to us for what we called the shepherding spacecraft that followed in and watched the impact plume and flew through it. We cheated in that the upper stage of the Atlas rocket, which was a Centaur rocket, we made a very big impactor out of it, and then basically got triple the mass effectiveness that anyone else who was trying to live within their allocation could have gotten. That was very clever and we heard from the selecting official that that was the thing that pushed them over the edge. What a clever way to use a resource that's already going to be spent, it's garbage now, and actually use it to deploy it within the mission and get more literal bang for the buck, three times the size of what anyone else could have proposed.

JOHNSON: That was clever. As far as site selection for the impact, was that in the original proposal? Or was that something that was decided later?

ANDREWS: We had indicated in the proposal that we'd be going to the south pole. My recollection is that we had indicated some regions of interest where there were permanently shadowed regions that of course most scientists believed would be the wettest area if it is indeed water ice. Remember, prior to LCROSS it wasn't entirely clear if it was actual water ice or if it maybe was just hydration or just hydrogen, elemental hydrogen in the soil. We all knew concentrations were high. That was already demonstrated by previous measurements. But is it water?

We had targeted areas that we thought would likely be by measurement the highest hydrogen levels. Then over the course of the mission we zoomed that in. We actually dialed it in, got it exactly where we wanted it. In fact one of the beauties of being comanifested with LRO, LRO commissioned themselves before we impacted. Remember, when we're launched LRO is sitting on the back of LCROSS, which is sitting on the launch vehicle. LRO shoots away, enters orbit, begins commissioning, it's on its own, it no longer cares about LCROSS or the rocket.

LCROSS does its own thing. It vents the rocket because we don't want to insert the very measurements that we're trying to measure by seeding it, sending the rocket in. We do our own thing, and then we're on around a 110-day polar orbit around Earth waiting for the Moon to come around and be in perfect placement so we can drop and hit it in the south pole. During all that time LRO is commissioning and getting data. We actually were able to inform our final

selection for where we impacted based on early measurements from LRO. Which we didn't bank on, but it proved to be valuable. We actually used that to inform our final decisions. Again, with our clever design that we had on the mission, we did not have to decide that before launch. We had to decide the pole. We knew that you're not going to change that midway through. But through firings, trajectory correction maneuvers, as we're going around those 110 days, you can dial in. Moving a little bit this way or a little bit that way, as long as you're staying on the south pole. We used that to our advantage.

JOHNSON: That's clever too.

ANDREWS: Yes, it was a nice little feature of it that we didn't have to commit to a specific X-Y location at launch.

JOHNSON: Going into this and knowing that you were going to do the impact and that the shepherding spacecraft would be able to fly through that initial one and then also impact, what did your team hope to learn? I know you mentioned people weren't sure about water ice. Talk about what you were hoping to learn and what you were trying to demonstrate.

ANDREWS: Water ice was the big question. That was even specifically called out in the memo offering this opportunity from ESMD [Exploration Systems Mission Directorate] when the 19 proposals were written, as I noted earlier. We knew we wanted to fill out a suite of instruments that could see all different variations on the water ice premise. We didn't want to just have one instrument that if it failed, oh, well, mission over, no data.

We premised that if there is water ice there, we know that when we hit it, we might actually see ice crystals, maybe. Depends how much is there. We don't know. We also know that we could see water ice vapor. Of course in the vacuum of space there's no liquid water, so you're either going to see water ice or when it sublimates because say it gets up in the Sun it'll immediately go to vapor phase. We had instruments that could see all that, plus ancillary things like thermal signatures, ultraviolet measurements, and so forth.

We specifically designed the instruments to be able to have that visibility. When we executed the mission, we saw it all. We actually flew through ice crystals that had been kicked up and not yet sublimated by the Sun. We also saw water vapor, a giant water vapor plume. It was really truly definitive. We touched the water ice. We kicked it up. We saw it in all of its forms. No liquid again because you can't see it as liquid. It really was the ground truthing of yep, folks, it's water ice.

We also hoped though to be able to get a sense of how much. Now that was a bit of a stretch. But a lot of good white papers have come out of the LCROSS data and still come out to this day, it's now been 13 years. LCROSS data still is coming out. People looking at it with interesting different lenses. But early on remember LCROSS has an impact, we had estimated what the impact size would be. We had estimated how much soil would be thrown up. But even that is an estimate because it depends how you hit. Will it be shot up vertically? Will it be spread high, low, wide?

Then LCROSS also has a limited field of view with its instruments. Even if it spread around a 180-degree cone, maybe we're only able to see, based on our height, this much. There was all of this analysis that had to be done. We knew what we had seen, and we could quantify it, but what does that mean about the Moon in general? They had to do all this extrapolation.

Then remember there's a north pole too. On the north pole what might be happening there? The north pole actually looks a little different than the south pole. It's had different history from comet impacts and so forth. We were hoping to be able to get a thumbnail on how much water ice is there.

We did. There were many different estimates associated with how to estimate the water ice quantity, and it was pretty impressive. Even though it's relatively dry compared to deserts, say, it's also usable enough to be able to actually harvest the soil.

JOHNSON: That's the future use, to harvest that ice for any kind of lunar permanent presence?

ANDREWS: The water ice as a resource is the question. Why do you care? Why does anybody care about the water ice? What's interesting there is that water, first of all, is very heavy. If you were to bring all your water needs from Earth to sustain humans or other activities on the Moon, it would be incredibly expensive. I had estimated at the time of LCROSS that a half-liter bottle of water we all walk around with, the standard half-liter throwaway bottle of water, by the time you add all that up to launch it from Earth and get it down to the surface of the Moon, we're talking somewhere between $15,000 to $25,000 for a half-liter bottle of water. So imagine that at scale.

If you could actually live off the land and harvest the water right there in situ on the Moon you could save a lot of money. You could save a lot of logistics. Frankly, when you just look at United States history and when we all started moving west and the gold rush and all that, it's always about resources. Can you live off the land? You can't expect you're going to run

back to the east coast and grab everything and bring it back again. To what degree can you do that?

Water itself as water is pretty self-evident why that's important. Humans can use it and so forth. But remember that you can crack it into hydrogen and oxygen. Oxygen of course we need to breathe. Not only do I need water to live as a human, I also need to be able to breathe something, so oxygen. Hydrogen and oxygen when you put them back together of course are rocket fuel. You also can create rocket fuel from this. Manufacturing. If you want to make bricks out of the silicates and the regolith soil on the Moon, you're going to need a lot of energy. That's a different problem. But that's solvable. And you're going to need materials, and that's going to include the soil that you have there in situ, and then water. Some sort of kiln, and now you can bake bricks that you could actually make habitats out of.

If you plan to grow things, if you plan to have greenhouses to be able to grow plants and other things, water again you need. There's even crazy ideas that I think are really interesting like since there's no atmosphere to speak of on the Moon, very very tenuous atmosphere that the LADEE [Lunar Atmosphere and Dust Environment Explorer] missions and others have detected, how do you protect against radiation? Imagine making glass out of the soil that's there on the Moon, you could do that by fusing the silicates and so forth, and then creating a dome that's filled with water. Water is an excellent insulator; it's why microwaves work so well. They absorb radiation really really well. Could you use water in a habitat to actually protect humans and plants that are up there? You can just go on and on with all the possibilities, and they all go back to that water question.

The importance of water cannot be understated. The only question since LCROSS that said, "Yes, there's water ice there," the next question is all right, fine, there's water ice there,

yay, but where is it, how hard is it to get, in what quantities. That's why the moment LCROSS happened, the next natural question was so what's the next step. If we want bottled water here, we want bottled hydrogen, and we want bottled oxygen, if that's our end state that we want, what's next. That's where the VIPER mission comes in.

JOHNSON: LCROSS being basically a piggyback type of mission—and you mentioned CubeSats earlier being similar but much smaller versions—do you think NASA appreciated the fact that they could get so much information out of that type of piggyback mission that it's something worth continuing maybe on the same scale as LCROSS under that $80 million, those same kind of parameters that you worked under?

ANDREWS: I think so. I think that the opportunity that the LRO situation afforded, which couldn't have been seen, they changed launch vehicles, hey, suddenly now this extra mass, the reality is as capabilities like CLPS continue to come online, Commercial Lunar Payload Services capability within the Agency, there will be more and more commercial entities not only providing launch vehicles but also providing actual transport services like the spacecraft, like delivery to the Moon.

They're going to come in all different sizes, all different flavors. The Agency must be adaptable to that and be able to make use of those little opportunities that come along. Instead of expecting that you're going to design a spacecraft whose sole purpose is to do this one thing and you optimize around it, start to think of more the Uber [ride-hailing] model. That is okay, there's this much opportunity launching in December. January is going to have these two other parties,

they're little landers. Oh, here's a big lander coming in March. What opportunity can NASA make from those?

I know right now that is being pathfound through the CLPS Office, and NASA has come to realize that you should have a stable of potential candidates big and small that you can take advantage of these when they come along.

JOHNSON: LCROSS itself as far as the team and you being the project manager and Tony as the scientist on the team. Did it follow the Discovery model of PI-led team, the same kind of roles that the managers and the principal investigators had in Discovery? Or was this completely separate and you ran it in a different manner than the regular Discovery missions?

ANDREWS: That's a good question. The Agency has two different mission execution models. They have PI-led execution models and PM-led, project manager-led, execution models. Each have their context that makes sense. PI-led models are good when you are opening up an opportunity broadly. You don't quite know what you're going to get. You would like to entertain all possibilities. The principal investigator model makes sense because all sorts of interesting ideas, maybe Venus-based opportunities, Mars-based opportunities, lunar opportunities come along. You adopt the PI-led model.

PM-led models, project manager-led models, are I would argue the superior solution when you're looking to direct a mission where you pretty much know, plus or minus, what you're looking to do with the mission, and you also have constraints. You need to fit within this dollar amount. You need to get it done in this amount of time. Those types of things.

LCROSS was a PM-led mission, and so that was me. Then Tony Colaprete was the project scientist on the mission within WBS 4. Remember the WBS structure, the work breakdown structure I talked about earlier. I'm in WBS 1 per the Agency standard WBS structure. What that meant was I was the final authority on the decisions associated with the execution of the project but I worked very closely with the project scientist to make sure that the decisions that we were making were maximizing the science potential of the mission. The project scientist, frankly the mission systems engineer, all these key leads from across the project were all involved as we were making decisions based on risk, where we would choose to mitigate risk, where we would not choose to mitigate risk, and we would understand always what does this potentially mean for the ability to detect the water ice, quantify the water ice, and then just resiliency associated with that.

For example, we were not interested in a single instrument giving us the answer. That's brittle. That's a bad choice. Instead we had a bunch of instruments that were looking at the elephant from a bunch of different angles, and if one of them died during launch or died during mission execution, that's unfortunate, but you can still answer the fundamental question. We tried to design, even though we're very risk-tolerant, remember we were Class D, one of the premises of being a good Class D is that you're resilient, so that when things don't go exactly as you had expected it's still okay.

JOHNSON: Since it was a different model as you said, it was that PM-led model, and you had such a quick turnaround, as you mentioned that LRO was already past that preliminary design review, did the LCROSS move through those same phases that NASA expected from missions in

Discovery once it was selected? How was that handled as far as NASA monitoring as you progressed to make sure that you were going to be ready for flight?

ANDREWS: Exactly. The Agency wanted to make sure that even though they were willing to accept higher levels of residual risk on LCROSS, we still needed to behave and develop a mission in a way that the Agency understands. Of course it has its methodologies there with the different project and mission phases and so forth. We did adhere to that. We had the standard gate reviews that every mission has. We had our system requirements review. We had our preliminary design review. We had our critical design review. We had system integration review before you start building things. We had our operational readiness review. All of those are normal whether you're a flagship project or little LCROSS at 80 million bucks.

I consciously tried to stay in line with that because I was concerned that if we looked too very foreign to NASA, if we looked too unusual, the stakeholders would not understand what we were doing, and it in the end would slow us down. Like speaking an entirely different language. That is our enemy, slowing us down is our enemy. What we chose to do was let's look very much like other NASA projects, and follow the standard methodology going through it, but let's interpret those requirements at each of those gate reviews as efficiently as we possibly can.

Just to give one simple example, the Agency has a whole series of plans that need to be developed that you show in draft form at your preliminary design review. This isn't a fun topic. It's a lot of work. It's kind of boring. But it's required by the Agency as you go into your preliminary design review, and then as of critical design review they're all expected to be signed.

What I did was I recognized all right, there's some key fundamental plans that are required, you got to have a project plan. You got to have a systems engineering management

plan. These basic ones. But there are many many smaller plans that the Agency also asks for that can require you to have a gigantic team just to write them. We didn't see the value in some of those plans taking all this effort. So I synopsized the plans very tersely in the project plan, and then checked the box for these three paragraphs in the project plan, that's my plan for that particular topic.

It was embraced by the Agency because we weren't cheating in anything and we were addressing the topics. We were not ignoring any important topics. But we were addressing them at a level that was appropriate for a Class D project. That was pathfinding too, and we've continued to do that. We more than halved the number of plans that would normally be required with LCROSS, cut them by 50, 60 percent. That saved a lot of time. In hindsight, we didn't lose much for doing that. We weren't especially risky; we didn't get into audit trouble or anything. It's how you interpret things, and that fits into the whole paradigm of tailoring.

We did not waive talking about any of those plans, and why did we not waive them? Waivers mean you're sitting there as a project and saying, "I don't think I need to do this." Can you imagine the amount of defense you have to do to explain why you don't think you need to do something when all other projects do? Bad call. Will take a bunch of time.

But if instead you tailor it down to this is what we think we need to talk about and that's it, but we're not waiving it, we agree these are worthy topics, but I'm not going to give you 35 pages on the topic, that worked.

JOHNSON: It makes sense, considering the amount of time to get this going was so short.

ANDREWS: And the investment by the Agency. If the Agency is putting $1 billion into something, the Agency probably wants to have a really detailed understanding of what all the project is planning to do, because that's a good part of somebody's budget, some mission directorate's budget. At $80 million, I actually had this conversation with Doc Horowitz, "Do you want me to spend a good part of that $80 million talking about the mission or do you want me to spend that $80 million doing the mission?" He said, "My God, that's easy. Just do what you need to do in order to have a sufficient answer to convince us that you're on the right path."

We still had an independent review team looking at us, just like Discovery and any other missions. We weren't running rogue. They were filled with experienced individuals who would look at us and just make sure we were on track. I occasionally brought them in on purpose to be a consult. "Hey, folks, we've got this dilemma. This vendor's capability is only this. It isn't what they claimed. We could go this way; we could go this way. We're thinking we want to go A direction as opposed to B or C direction. What do you think?" Actually used them as kind of a consultant. They would ask us important questions and do some soundboarding. Pretty much every case I can remember, they said, "Yes, you got a dilemma here, but I think you're picking the best of the options you have."

That works for me, because first of all you got an independent view of things, like an independent doctor consult. But equally as important, that independent review team then will go off and speak to the stakeholders and say, "A, the team opened up to us and shared with us the dilemma. B, we took a look at it. C, we think it's the right answer."

Look at all the work that just did for me. Look at all the headache that cleared out for me by getting their endorsement. Always thinking about the schedule, always thinking about how to leverage continued forward movement.

JOHNSON: Always moving forward. This is more of a Discovery question, more philosophical. But since LCROSS fits into that because it was competed, talk about that competition model that Discovery uses and has been used now with other programs too. But what do you think is the benefit of running a program that way with that competition and with those limits on how much can be spent and that sort of fixed price model?

ANDREWS: I have many thoughts on this. I think the idea of competition as it's done in the Discovery model is really good for the stakeholder, because if I'm the stakeholder, I'm saying, "I have a bag of money here, I have a generalized goal to go to Venus and understand Venus science better, or the moons of Jupiter or Mars or whatever. Or maybe I'm going to open it up to all of them. Just give me all your ideas, and I would like to pick the ones that are most relevant to me or connected to the Decadal Survey." Whatever your rationale. That's fantastic because then all this candy arrives on your desk, all these wonderful proposals, and you have the burden of figuring out which ones you want to go after. But look at all the quality and possibility that's been given to you, so there's no question that's smart from an Agency point of view.

I think though what is required in that case is to be responsible about what you demand from all the proposers. It takes a lot of time and money to be able to put together a proposal, and so it's the responsibility I think of the stakeholder to make sure that there's enough resource available in order to get all those great proposals. I sometimes think we as an Agency don't do that part as well. It'll affect in the end the quality of what you're putting together as a proposal, which ultimately affects the stakeholders.

JOHNSON: Let's talk about the team itself with LCROSS. Why do you feel that the people that worked on that team and the dynamic between them worked? Were there ever any issues that had to be resolved within that team as far as the way things were working? Again thinking you had such a short period of time. But had any of the team members worked together before? What were those relationships like? How did it turn out?

ANDREWS: We all have participated in teams that went very well and were inspirational and other kinds of teams. The question is what's the magic there and how did that work for LCROSS. Our team was largely on the NASA side constructed of people who hadn't flown any major missions before. There were individual instrument developers and scientists who had participated in missions. I had not flown anything of this size before. The Agency was taking some risk. But there's always that first mission for everybody, so maybe an $80 million project is the perfect place to do that as opposed to a full Discovery $600 million project.

I got to say one of the magical things about LCROSS was—and I've heard other people tell me this—because we were made up of individuals who had not seen the face of war before so to speak, meaning the idea of doing battle to try and bring one of these projects to successful fruition, we didn't always know what we didn't know. That was powerful. A lot of people think not knowing what you don't know is a negative. Not knowing what you don't know means that the sheer weight of all that's in front of you is not fully apparent to you at any moment in time, so everything you can incrementalize. This was one of the things that was applauded by the Associate Administrator when we finished LCROSS, and that was every time we hit a wall he said, this is Doug [Douglas R.] Cooke, every time we hit a wall, we would shake ourselves off,

get around the wall, and move on. That happened multiple times as it does with all projects. But the point was we kept getting tougher and tougher and seeing our way through it.

That was essential. What was the magic there? We could probably make more money definitely being out in the commercial sector. What was the driving factor? Were we at threat of being—you know how it is at NASA. That's not the case. We had tried to cultivate a culture on the team of joint reliance. When you're a small team there's no room for arrogance. There's no room for dedicated expertise. We all need each other to be successful.

There was this undercurrent of not wanting to let down your fellow teammate. If I don't deliver this thing when I said and to the specs that I promised, I'm going to affect the whole rest of the Project. I'm not going to be that person.

While Murphy might be out there lurking and trying to screw you up, and we had a fair amount of that, in the end it's how you behave to come out of those that creates the salt of the team. It was really quite an amazing team. At the end of the mission I had a Northrop Grumman exec tell us that he had been on one project that reminded him of LCROSS and he was an old guy, and he was a vice president, and he had never got to work on a mission like that again. He worked seven more missions for the rest of his career, and not one of them was like that one mission. He said watching the folks on the LCROSS team, he says, "This is yours. This is the mission that is sheer magic, that the people are so well aligned. It's badgeless. Northrop Grumman guys, Ames guys, Goddard guys, JPL, all these people, they're all about the mission." Probably a lot of missions can say that. I'm not saying that's entirely unique. But it is the magic that keeps us focused and keeps us directed when we fall on hard times.

We did have a big anomaly on mission that we had to survive, that could have been the end of us and the end of the mission. We came out of it, and all that investment we made as we were developing the project and developing our internal relationships came through right then.

JOHNSON: I think working on a team, like you said people have not been to war yet, it's like being in the same foxhole with people, trying to survive. It's of course different than that, but it's that whole team feeling that we're all doing it at the same time for the same purpose.

ANDREWS: Yes, there's a brotherhood, sisterhood, there's a somethinghood that takes over that I'm sure is not anywhere near what it's like to be in an actual foxhole and be fearing for your life and the life of the people alongside you. But there is a grain of similarity there. It may not be your life at risk. But it's that you don't want failure, and that you're reliant on each other, and you've come to trust that you can be reliant on each other. Because you're a relatively small team, it actually helps because it's at a personal level, as opposed to an organizational level, well, we'll throw this thermal issue over there to that group, and we'll do this over to that group, and it's just very compartmentalized. You can't have that on an LCROSS type mission. You really need to be personally reliant on each other to deliver.

JOHNSON: Have you had any other missions like that, as the gentleman from Northrop Grumman mentioned to you that LCROSS was yours? Have you had another one since LCROSS?

ANDREWS: There is something about your first that's different. You can't have every mission be run by a bunch of people having their first mission, because there is value in bringing in people

who have experience with missions. It changes the cultural dynamic of the team. What I have since come to appreciate as well, I very much agree in hindsight with what the Northrop Grumman VP had shared with me. Totally agree with what he said. There's different ways of coming at success.

Now I have the benefit of both having more experience myself and being surrounded by individuals on my teams who also have more experience. Now, like different ages of relationships of people, young in their relationship, midlevel in their relationship, people who've been together for a long time, the nature of the relationship necessarily changes over time, and so the nature of a project team varies by the experience base as well.

When I lead teams like that, I try not to compare one to the other, and instead organically look at "Oh, wow, this group is a lot smarter going into this mission than this other team I had." Which means I can rely more on expertise with this project than with just raw hard effort with this other one and inspiration. I have to turn the knobs on how I manage it based on the makeup of the team. I think every good project manager has to do that. Every project is its own child. It's a new baby. You can have had lots of babies before, and yet this one will look somehow very unique than all the other ones and you need to manage it accordingly.

JOHNSON: Talk about managing LCROSS. I'm sure every day was different. But as a project manager for a mission like LCROSS, which was somewhat unique, talk about what a normal—a friend of mine once told me normal is a setting on a dryer, so there is no normal, I understand that—but what a typical day leading up to that mission was like for you as a manager, or what were some of the things that you did on a day-to-day basis.

ANDREWS: I think if you get out the microscope, which is what you're doing, and get down to the day-to-day basis, it's probably harder to differentiate LCROSS from any other mission. Because on a day-to-day basis all missions are trying to do the same thing. They've got a series of requirements they're working against. They're executing with a team of size X. They're having at any given week an issue of I don't have enough staff or I have to change the staff because they're not quite the right people or whatever. There's the monthly cadence of reporting that you have to do as being a mission in the Agency, including this Class D project. There are headaches with vendors who overcommitted and aren't delivering or aren't doing what they said for the price that they said they would. Then just logistical stuff.

What I found was I'm a very in the moment individual, and so I'm managing what is in front of me at the moment, and then I tried to make sure that I would have opportunity, and this isn't always very easy, to abstract myself, to step out of the moment at the beginning of the day or at the end of the day or at the end of the week, and just sit and think about how's this going. You have to be out of the moment and sit there and say, "Do we look like we're on a trajectory? Yes, I got the schedule report that I get weekly and that I give a big report monthly. I got the dollars. I got all that data. But how are we doing?" I found that I would reflect on that myself, with my Deputy John Marmie, and just think about how we're doing here and if we need to make some course changes. Which you don't necessarily feel in the day-to-day, but you're steering everyone now this way as they're doing the day-to-day.

Then there's also topics of staff and suitability. On LCROSS I had my first opportunity to change out people, which is not fun. It's very hard. I had to do it with three individuals over the life cycle of LCROSS. All very different people, very different reasons at different times in the project. I quickly came to realize that your best way to navigate through that is understand

that in the end you're always thinking of the best interests of the project. This isn't about ego; this isn't about personality. It's about what is the best for the project. One of the individuals was getting totally overwhelmed and in her e-mail replies that I was part of to other people getting panicky, telling everyone, "Just stop, I can't keep up," and all this. This is an excellent individual, just was not a good fit. I sat down with her and said, "We're going to be making this change."Interestingly enough, she thanked me. She was completely overwhelmed but didn't know what to do about it. That went well.

Had another person who very much didn't thank me but was completely lost with what to do. He came up to me and he says, "I don't know how I'm going to close on this, so tell me what to do." On a small fast project I cannot be telling anyone what to do. We're all in a band together. I can't play your instruments, just because I might be the conductor. I really need all of you to be playing the instruments. I'll be looking at the big picture and steering us and flipping the sheet music. I had to find someone who could do it. That individual left the project and was very successful doing other stuff. That's why I say you cannot look at this personally. This is about suitability of individuals and the best interests of the whole team successfully moving forward. That was a real learning for me because other people did that for me before. Suddenly I found myself in the position where no, this is your burden and you got to do it.

JOHNSON: Would you consider that among pitfalls running a project like LCROSS in a short period of time? Do you think some of those could have been resolved if you'd had more months to deal with those people and get them up to speed or to work with them differently or mentor them differently?

ANDREWS: Hard to answer that. I'll tell you that my personal management style is that if I'm not doing it right it's probably because I'm waiting too long to pull the trigger on personnel issues. Meaning there could be a kerfuffle going on between two parties over here and all that. I'm not going to be the guy to go down there and start removing people from their positions. So I'm already defaulting to a position of trying to resolve it. In two of the three cases I just described, I probably let them go a little too long in hindsight. Meaning I should have been even faster. Because what happens is in a small group like a family, one person who is having trouble and is either vocal about it or whose performance is suffering that it's affecting the whole, either psychologically bumming everyone out or a defeatist attitude or actually missing product deliveries, that will crash your whole team.

With one of the individuals that I had to remove, I had one person come up to me and say, "Who's next? Are you going to start firing everyone?" They got concerned about that. But for that one individual, four other people came up to me and said, "Thank you, that was needed." Which told me I probably waited a little too long. They were relieved because this had to be addressed. In answer to your question, I'm probably already defaulting on the side of giving it as much chance as I should, and maybe even too much. I don't know that if I had a longer period of time that would have been better.

JOHNSON: Thinking about that relationship with NASA but also the LRO team, talk about that and how that worked, and how closely you worked with that team, because you were launching on the same rocket. Maybe talk about that relationship and how you worked things out with them.

ANDREWS: First of all, thank you for this question, because this is a really important topic, and I'd like to make a couple acknowledgments here along the way. Imagine you're the LRO team and you're the LRO project manager. Forget LCROSS. You're going through your design. You're recognizing you need to change launch vehicles. You're it. You're the only party on that launch vehicle. You're in control of your destiny. You make this change. Ah, we got extra launch vehicle capability. Ah, that's kind of too bad, it's a waste. But off we go. Some guy at Headquarters says, "Ooh, we could include something else in here." Put yourself in the position of the LRO team or the LRO project manager. I have done that multiple times over the years and I would not be happy. I would not be happy having a comanifest shoved on me late in my flow that I have to deal with, that I have to be compatible with, more people to deal with. Oh my God.

I always looked at that relationship being the secondary PM with great reverence because I know how I would feel. Then when I actually got to meet the project manager, Craig Tooley, and his deputy, Cathy [Catherine L.] Peddie, it was wonderful working with them. They were much more wonderful than they should have been. What I mean by that was they were able to take the big picture and recognize that the overall lunar understanding and knowledge that we're going to get from these missions is better with LCROSS. LRO and LCROSS, as opposed to just LRO. We're getting a free mission—a free mission—because we're going on the same launch vehicle. Yes, you had to throw 80 million bucks at it, but it's a whole second mission that's answering a fundamental question. Because even LRO can measure the water ice, but it hasn't confirmed it's water ice. It won't touch it. LRO is still in orbit. A miraculous mission that just keeps giving, but it's different than LCROSS. They recognized that.

Further, you have a center, Goddard, who's leading LRO, and then in comes another center, Ames, that's leading LCROSS. You have even interorganizational things going on center to center. All of these things and probably 10 others that I'm not mentioning are recipes for this to not go well.

But the relationship that we had forged PM to PM, DPM to DPM, deputies, made all that go away. There was great reverence of each other. In fact what LCROSS did was it said, "Look, in the best interests of the taxpayer and of the Agency's budget, since we're behind on development because we were entered into the flow late, why don't we take the avionics package that LRO has developed for LRO and just times two it?" Meaning you're not going to buy it for us, that's our problem, that's our budget, we're not going to be a burden to your budget. But why not just make it times two and then we can go ahead and use it? Think about the taxpayer. Think about the Agency. Why would you pay us to design a whole new avionics system with all the cost and the time and the risk? Just do two of those, and then we will make it work for our needs. We did that, and we paid for it legitimately. So no financial burden to LRO. But again if you're Headquarters, you're loving this.

Further, we actually found as we were developing, we got out ahead of LRO. We actually found ourselves testing some of the computer boards before LRO had gotten to them. Fast-forwarding in time as we're getting towards integration tests, we discovered a problem with the single board computer. There were things about their single board computer that were new from the vendor. New network capability. We were struggling, going, "What are we doing wrong?" We're testing and testing. We concluded there was a problem with the board. I get on the phone with LRO and I said, "We really think there's a problem with this board." They're saying, "Oh no. We haven't started looking at it yet. Let us pull that out."

They started doing tests and confirmed what we found. Now LRO and LCROSS both have a problem with the same board, different instances of the board, but the same design. We worked that through the program office, which we both shared, same program office, and made this whole activity start with the vendor to the mutual benefit of LRO and LCROSS. Both teams participated in that dialogue with the vendor. It was very powerful. We had joint interests to the Agency, to the taxpayer, and to both of our projects. Those happened throughout the project. What that led to was this kind of meta level team across the two, even though we're two distinct missions and we're just stacked on top of each other. When LRO who's sitting on top of LCROSS has an engine bell that comes out the bottom and sits actually partially inside of LCROSS just by the nature of the design, we had to make sure we stayed out of that zone even though it's inside our spacecraft. We could have made a big deal about that. We could have forced a big spacer to be put in there and all that. Or we could work collaboratively together and make sure that's not an issue, which we did.

It became something where we were very much the subordinate to begin, but we really became equal teammates and with equal benefits to each other throughout the whole thing with two wonderfully successful—in the case of LRO still wonderfully successful—mission projects. We by definition had a very finite end to what we were doing. But LRO just keeps plugging away getting better and better imagery and mapping data and all that. I just really love that story. It was much more likely to go badly than well just by the whole nature of how it came out. We had to actively work to make it the success that it was. I very much appreciate the LRO team and its leadership in particular for enabling that to happen.

JOHNSON: You think that's due to NASA management that the two worked together so well? Or did they express appreciation for coming up with those innovative ideas to save money and keep things from getting out of hand as far as between the two teams?

ANDREWS: I'll be honest. I don't think Headquarters realized that the concoction they were creating was so susceptible to being problematic. I don't think even to this day they've fully appreciated just how rife this was for failure and how well managed and the cultures established on both teams to be collaborative and make it successful.

We on the teams and we who work at different centers and have all that experience that sometimes Headquarters folks don't necessarily have, we very much get how amazing this was and what a feat it was. I'm not sure others in the stakeholder community fully understand just how wonderful it was. They just kind of expected well, sure, we'll add them in, it'll be fine, what could go wrong.

JOHNSON: That's typical sometimes of decisions that are made on high.

ANDREWS: That's exactly right. I don't even fault them. This isn't a statement of begrudging. You just have different altitudes of what you see. Sometimes people have to be in the thick of it to really understand the implications of decisions that are made by higher-ups. It's just how it is organizationally.

JOHNSON: We've got a little less than 10 minutes before I told you I'd let you go. But in your book, you talk about managing in the middle, or from the middle. I just thought that was

interesting, as far as the stakeholders, and then you had your team, you had the stakeholders, and you had that. You were in the middle. Just describe what you meant by that. Just talk about that situation for a few minutes.

ANDREWS: I love this topic. But it also has multiple variations on a theme, so let me try to organize my thoughts here. There's managing *in* the middle, and there's managing the middle. They're related but different things. Let me start with managing in the middle. Managing in the middle is the case where you have stakeholders above you and then you have other parties below you. I don't necessarily mean hierarchically. But I mean more detailed individuals who answer to your work. Managing in the middle can mean that you're stuck being the bridge necessarily to taking care of the needs of say technical developer type people or issues associated with mass or thermal or whatever and conveying those up to people at high levels who really maybe that isn't their discipline. They might not even be engineers honestly. You have to translate that and move it up and down. It goes the other way too. When a certain budget valuation or a decrease is given to you—LCROSS saw no budget decreases thankfully, but that can happen—then how you translate that back.

That's the managing in the middle problem. It's not fun. But you're the ultimate translator and messenger bidirectionally and advocate. There's some really big influence chains that you're having to work both directions because you don't want a mutiny by your team down below of good capable engineers who simply cannot understand why this dumb thing is coming down from on high. Your job is to understand why it's coming down on high and explain carefully to them, "This is why this is this way." Because if you lose hearts and minds, what? Am I going to do it myself? No. You need them. You need them not just working, but you

need them feeling the charge of the cause, carrying the banners, and going forward. We still got this.

Similarly the stakeholders has to work the other way. They have to understand the implications, since they get to eat it as the owners of the mission, as the funders of the mission. My job in the middle is to make sure they understand the implications of that. Between LCROSS and VIPER, there's a good span of about a decade in there. There were two or three other flight projects that I worked on and led that ended up going away because of issues here, where the stakeholders saw that something technically was very interesting to them, so they said, "Ooh, that means we could do this, this, and this," and an activity that started at $250 million quickly grew to $450 million, which then grew to $670 million, which ultimately topped out at $970 million as they kept piling on on what was supposed to be a little focused technology demonstrator and instead became a mission that would go to Mars, visit both moons of Mars, and then go hit a asteroid that would be in the vicinity.

It was maddening to me. While I don't take it personally, I was not able to convince them that you're getting way off of topic here and you will not be able to afford this. I can't say that. But you're at $970 million, started at $250 million. Ultimately, they came to realize they can't afford it. Chop chop chop chop chop over the period of a year, and it eventually died. Criminal shame because I had built up a really good team across two centers. But this is an example of when it doesn't work. Managing in the middle carries great weight there.

Actually of more interest to me though just personally is managing *the* middle. Managing the middle. I actually have a lot more experience with this even than on LCROSS with VIPER and with Resource Prospector, another mission right before VIPER, which VIPER is kind of built from.

Managing the middle is, and you see this in any large organization, the person at the top, whether he or she is a CEO or a center director or what have you, they of course chart the course for their organization. I early on was used to the idea that if I could convince them, everyone else would fall in line. Big wake-up call on that front. Because those individuals, while they are the CEOs, they are the key director, they do chart the course, but they do also come and go. They're not necessarily political appointees but they do come and go. The core culture of an organization is the middle. It's the middle management area. That's where, as leadership comes and goes, as projects come and go, the behavioral model and expectation for people in that organization are right in the middle. The division chiefs, branch chiefs. That whole area in there.

I remember trying to leverage on LCROSS and also on Resource Prospector going right to the top and speaking to a center director. Totally won him over in this case. I'll leave the particular Center out of it. He was a big fan of our activities, and knew that the work would benefit his staff, because there's a certain part of your staff that want to work on these fast turnaround exciting robotic things, not necessarily human stuff. Because those are slow and heavy and formal. Everyone has their own thing that they like, that's fine.

But then I noticed that just because he said so I still was fighting to get the resources I needed out of the middle and getting whole bodies instead of partial fractional time individuals. It became apparent to me I can't rely on the leadership to make that happen to his own organization. I had to go make that happen.

I flew out to the Center, having done some homework in advance, and met with the five, most important to me, division chiefs throughout that organization who 90 percent of the staff that that Center was giving to my project came from. I remember walking in and I said, "Please

invite anybody that you'd like. I would like to give you an overview of the mission. I'd like to spend half my time talking about the mission and give you the other half of the time, answering any questions you have. Ask me anything."

I remember I arrived in the room and I saw a bunch of managers with their arms crossed, like convince me. I got much bigger fish than your little project here. Which is true. I gave them a presentation. I really showed how innovative it is, how you have—I know this because I've spoken to your staff—people that have no interest in working in what your Center is normally about. They want this work. You will likely lose them if not. I know that sounds a little threatening, but I'm really making sure they understand that I understand their staff too.

Then I started talking about all the benefits of this. I did some homework in advance and knew what were some of the key thrusts of that Center. I've actually done this across three different centers. Each one has their own thrusts and interests. I played into that with my project. Without exception by the end of it they appreciated that I took the time to fly out and visit with them on their turf. I fielded all the questions including the crunchy awkward ones. I fielded every one of them.

What came out of it was a sense of trust. In every case, all of a sudden resources started freeing up. I don't mean budget. I got the budget. But I mean people resources. Then people who I had for four-tenths time, three-tenths time, suddenly I had them for 100 percent time. Which means I can be their full attention. They can bring their full attention to LCROSS or to Resource Prospector or whatever.

Managing the middle, that's what that whole part is about. I know I'm not revealing anything that others haven't figured out. But in sharing this I'm hoping that I'm sharing for someone who's listening. Hey, don't learn this for yourself. Understand this. Pay attention to

this. It'll save you all the learning curve and grief that comes with it. Go out of your way to use your influence to win people up and down the organization over, and especially those who require nothing from you, because they think they have the least to benefit by you being there. So go convince them otherwise.

Convince them why they should be your cheerleader, why they should work for your little project, they should work to get you the staff you need, because it's going to be worth their while. Not as a favor to you. Show them why it's good for them. Do some homework and go talk to them.

JOHNSON: That's all good advice that you're sharing. That's always our hope, that these types of lessons learned will be shared and people will be able to read them and read about those experiences. But we've run out of time for today so I'm going to stop the recording. But I appreciate you talking to me today.

ANDREWS: You bet.

[End of interview]