DISCOVERY 30TH ANNIVERSARY ORAL HISTORY PROJECT
EDITED ORAL HISTORY TRANSCRIPT

HENRY STONE
INTERVIEWED BY ERIK M. CONWAY
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CONWAY: My name is Erik Conway. I'm interviewing Henry Stone of the Psyche project today. I think we're both at JPL [Jet Propulsion Laboratory, Pasadena, California]. It's August 1st, 2023.

So, Henry, first tell me how you got involved with the Psyche mission.

STONE: Well, it was kind of interesting. I was previously working on the InSight [Interior Exploration using Seismic Investigations, Geodesy and Heat Transport] mission, also a Discovery-class mission, and I was the deputy project manager and flight system manager on that. My principal focus in those combined roles was working with Lockheed Martin, the system contractor, on the build, development, delivery of the spacecraft itself, so to say the bus portion of the spacecraft as opposed to the instruments. That part of that program was very successful and delivered on time for the original expected, or intended, launch.

As folks may know, there were some very serious issues with one of the contributed instruments, the seismometer coming from European partners, and despite all of our collective best efforts in working with them, we were unable to resolve those issues in time for that first launch, so there was a stand-down of the project. The spacecraft was moved into storage. [NASA] Headquarters decided to go through with the program at the next launch opportunity, which was in basically 26 months later, the typical Mars cycle of optimal launches. So those teams went off to work that particular issue.

There was not as much to be done on the spacecraft. We literally had delivered the spacecraft to Vandenberg [Air Force Base Space Launch Complex] for the launch. So some of my time was available, and as luck would have it, I was asked to participate and help with the proposal, the Step 2 proposal that was being put together, coincidentally, at that time, and so they put me in as the proposed or anticipated project manager for that mission, and I began working with David [Y.] Oh and Lindy [Elkins-Tanton] and a bunch of folks that previously worked the Step 1 proposal.

Much to everybody's surprise, the institution included, I think, that proposal ended up being selected, and having been named in the proposal as the project manager, that was largely a commitment there on behalf of myself and the institution, and so that's how I moved over from InSight. We had another individual come in on InSight to pick up that role as they prepared for the new launch activity on that. So that was my involvement, how I got involved initially, and it was really exciting. It was very exciting to go through that proposal activity, in part because, as many folks probably know, you often propose to these competed missions several times and go around. In the case of Psyche, Step 1 went through and was selected first time through, and much to everybody's surprise, on Step 2, we won right out of the bag and got awarded the mission. So that was a real fun way to start a project.

CONWAY: Why do you think it was a surprise? Only because it was the first time through?

STONE: A combination of things, a lot of stiff competition the first time through, and a couple of other firsts that folks might otherwise raise eyebrows on, so to say, for this risk-class of missions was a first-time partnership with Maxar [Space Systems], first time that they would ever be

involved in a planetary mission, combined with the first time that we, JPL, or NASA at large, has ever really worked with Maxar on a planetary mission or any mission, for that fact.

I think our going-in position, one of our biggest hurdles, was trying to convince the review boards that this merging, that this hybrid merging of trying to leverage Maxar's heritage and Maxar's capability in electric propulsion missions and these large spacecraft, combine that with the unique needs of a planetary mission, accommodating science instruments versus Xbox and all the other types of things was really unique.

And how are we going to do that? How are we going to merge the cultures? The driving motivation for those two organizations is very different, and particularly Maxar. Unlike some other contractors we've worked with, Orbital [Sciences Corporation] and Lockheed Martin, we've worked with them a number of times, so they have an established capability and understanding what JPL and NASA expectations are for planetary missions and the rigor. It's a bit different or differently motivated. So that was at least one of the major things. And telling the story technically of how do we merge essentially the bulk of the spacecraft bus from Maxar and cleanly put together flying a JPL-heritage avionics system, C&DH [Command and Data Handling], the brains of the computer and the brains of the vehicle in combination with our software—we weren't flying any of their software—our X-band telecom subsystem, and how do we accommodate the science instruments? What pieces do those scientific instruments really interface to? If they are interfacing directly to a lot of the Maxar-provided electronics, that can be a very tricky situation, and we had a very unique arrangement or answer for that, but we had to tell that story in a very convincing way in order to win the proposal, which inevitably we did.

I think also one of the reasons why that contributed to the success of the proposal was the degree to which we focused very specifically on a very specific goal or set of scientific objectives.

So, for example, we went with the absolute minimum set of scientific instruments that were needed to meet the scientific objectives. We didn't have anything peripheral, nothing descopable, which often missions will go in and they'll have, for lack of a better term, some bells or whistles or things that are nice to have, but not absolutely needed. To stay within the cost constraints, to try and meet the criteria for that, we wanted to be very, very, very focused, and I think my sense is that the selection committee recognized that and appreciated that strategy and that thinking.

CONWAY: So telling the story well was a major focus, as well as a very constrained payload. You had nothing to descope.

STONE: Absolutely. And in the terminology, right, there's often a baseline mission and then a minimum mission. Those were one and the same for us. We literally said that right up in the proposal, "There is nothing descopable from a scientific standpoint."

CONWAY: So I have a question here. What makes your Maxar contract different than those that JPL has had with Lockheed and Ball, etc.? You've sort of hinted at it. It's a very different vehicle, to start with, but what about the contract? Is there something different about the nature of that?

STONE: Oh, absolutely, and that also played into this being a competed mission with cost caps and things like that, is that the contract with Maxar was fixed-price. When we worked with all these other contractors, they were cost-plus. It is the way that Maxar operates normally. That's their business model. They are not accustomed to doing cost-plus, and, in fact, did not want to do it that way, because they would have to change a whole bunch of processes and things that they do.

As a result of that, we got a great deal, assuming that we wrote the contract properly and managed it properly to make sure that they were on the hook, right, for everything that we might need. That largely worked out exceptionally well for us.

I think where we stand now, both Maxar and JPL have learned some lessons about how we would do this in the future. I think if we did something like this again, we would do it fixed-price for the majority, for the delivery of the bus to JPL, but the latter portion of the support that we need during the integration of all the instruments and the ATLO [Assembly, Test, and Launch Operations] activity, which was conducted here, which is not how it's done with our other contractors, Lockheed and others. They do the full system integration at their facility. Here, JPL was leading that activity, but we needed Maxar integral support in doing that, and that part we've learned and Maxar's learned does not fit well into the fixed-price model, so I would imagine if we were to do it a second time, we would split that into pieces. The bulk would be a fixed-price and we would use another vehicle that's easier to work with for the end game in ATLO and then into support for operations.

CONWAY: Some sort of a support or services contract.

STONE: Yes.

CONWAY: Interesting. So that's a great lesson learned. Now talk about why Maxar. We've already kind of suggested there was a price advantage, possibly, but what else did they bring that was important to Psyche?

STONE: Well, the most important thing is that they had a spacecraft bus, commercial bus that they produced—literally they have some 200 spacecraft that they built and flying, so they know how to do electric propulsion. The smallest of their series of vehicles, the 1300 bus series, met all of the fundamental needs that we had from a power generation and electric propulsion capability to get us to Psyche, and that our environments were similar to what they have already designed to, even though they only deploy these in Earth orbit, and they also have very reliable spacecraft that operate for tens of years. So we didn't have to start that over from scratch. And they could produce and build those very, very quickly.

So I think one of the other interesting things about, well, how did we know that? It turns out, as you've probably spoken with David Oh, who was a former employee at Maxar, in fact, he is himself an electric propulsion expert and, in fact, was very instrumental very early on at Maxar with developing the whole EP [electric propulsion] capability, so he had direct authentic knowledge of that when David was working to conceive of this relationship in the first place. And it's not only the EP system, but the architecture of their control system, the separation they have been the C&DH, the brain of the vehicle from all of the peripherals, there's not a direct connection. They go through two other devices here that are all electronic hardware devices, no software, and with a very simple two-bus interface, back to the C&DH. That allowed for a very clean way to cleave that off, not fly their C&DH brain and software or ask them to do that, because that's out of their wheelhouse for a planetary mission. But we could come in and connect very simply with those two buses, our brain with our flight software, heritage flight software that has all of the behavioral aspects and the fault protection that is needed for planetary missions that is not needed or characteristic of what's needed for COMSATs [communication satellites]. So I think that was that unique thing. We had a huge leg up and a starting point for a spacecraft that they could, first

order, largely, go and build for us. So it was all about trying to keep them in their wheelhouse of experience and JPL providing ours that was unique to make this mission viable.

CONWAY: So the clean interface essentially allowed a spacecraft to be procured almost off the shelf without any customization like what JPL typically has to do.

STONE: Yes. Very little, right? And the spacecraft, in terms of its size, its power generation, also fit very well with what our needs were, and designing a bus like that from scratch is a huge job. You could easily ask, for example, could we have flown a smaller bus. Yes, we could. You could customize that and hyper-optimize it to be as small as possible, but there's no advantage, no purpose to that in our particular case. Use what they have. It's already designed. There's only a few places where we need to make the accommodations to hold our electronics boxes versus their electronic boxes and the means by which to hold the scientific instruments.

Now, one of the things—and you can see it in a model. Back of me there [gesturing], we've got fixed towers that are on the spacecraft to hold the scientific instruments. We don't have articulated deployment booms and things like that. That was also intentional, to keep it simple, and because those booms of the towers that are underneath that thermal blanketing is also exactly in Maxar's wheelhouse, because they build those type of truss structures to hold all of their COMSAT antennas that get deployed and moved around, so they have expertise there that we didn't need to try and redo or replicate, and we could have them make those, configured height-wise and everything else, specific for our mission and put our instruments out on them, and it worked really well.

CONWAY: I guess one exception was I read something about having to change the spacecraft a bit for DSOC [Deep Space Optical Communications].

STONE: Well, there is an accommodation for DSOC that had to be made, and the DSOC instrument, obviously it's a separate technology demonstration, but we had also agreed with Headquarters that we would accommodate it as a ride-along, but that instrument is very large compared to our science instruments. And it required significant accommodations from a mechanical and thermal point of view as a result of that relative to our science instruments. But again, that instrument also does not interface, from an electronics and behavior and control standpoint, it does not interface directly to the Maxar SEP [Solar Electric Propulsion] chassis-provided hardware. It goes to our computer, interfaces with our computer, the JPL-provided computer and the JPL-provided power subsystem that distributes power to that instrument. So, again, there was a good separation so that we didn't have to be working as intimately with Maxar to figure out how their electronics control the DSOC technology experiment or those science instruments, and that's where you get into a lot of subtleties. That's where JPL has huge expertise in dealing with those subtleties, and we didn't have to have Maxar trying to come up to speed on that.

CONWAY: Okay, great. Talk about working with Lindy, working with an external PI [principal investigator]. How do you do coordination and that sort of thing?

STONE: Well, working with Lindy, it's been a wonderful experience right from the get-go in terms of her style and her focus on team building and the way in which teams in large projects and groups

of people work and interact together, and I think that in particular, she and I and many others synced up very quickly with her approach and the emphasis that she wanted on teamwork and constructive interactions between everybody, and making and creating a space where everybody is producing at their maximum ability. I think I maybe mentioned this one time before, where there's not these artificial divides and separations between sub-teams within the project, and particularly between the engineering and the science, and trying to merge those two together so that each appreciates the others' interests, needs, perspectives, etc.

This, I think, was the first project I've ever known that at team meetings—typically we refer to projects having science team meetings, and the science team, twice a year they go off and they have a lot of conversations and maybe the project manager goes and gives a little status on the spacecraft, but it enforces this kind of divide and a lack of understanding and appreciation for the challenges that each has. It propagates the PIs and the instrument leaders just kind of pounding on the table, "I need this and I need this and I need this," without deep explanations as to why, to understand the risk trades against engineering challenges to accommodate those instruments.

It was a team meeting, and any of the engineers were invited to participate and encouraged to participate as well as the science team members. It was very exciting and interesting for me to watch how that played out. And the cohesiveness that that brought, now when the scientists were talking or the instrument PIs were talking about their needs and interfaces, they actually understood everything we had to do on the engineering side, and the engineers understood and appreciated what it is that they're trying to do. We got a good meeting in the middle to address those challenges.

I've worked on other programs where it's not like that, and the instrument providers are just hollering they need more and more. Their inherent goal, right, obviously is to get as much as

they possibly can. But we, on this particular mission, unlike a flagship mission, were cost constrained, schedule constrained, all those sorts of things, so you need to make those changes, and these team meetings was just an example of that.

And I distinctly remember, after the first couple of those, when some of the engineers, for example, were talking about "What is fault protection?" They don't have an opportunity to really appreciate the thinking and the design work that has to go into doing fault protection on these missions, and after this meeting, several of them were coming up, like, "Those were fantastic. I never understood that before. Now I can better appreciate when somebody's asking me about issues with my instrument and how that folds into the design of the overall system." And also explicit comments from scientists talking about, "Now I have a better appreciation of what it means to do system engineering."

And our deputy PI, Ben [Benjamin P.] Weiss, specifically talked to me about that and said, "Wow. I'm really taking this back and folding it into both my team working on the instrument," as well as classes and other things that he's teaching as a professor, to have that appreciation. So that was really quite remarkable.

So I think those things set off a—going back to your original question—probably going too long here on this, but setting up that environment became a hallmark of this mission and was recognized both internally to the project, externally to the lab, and witnesses very clearly outside of the institution. When we went into major reviews with the SRB [Standing Review Board], comments that emerged from that, is explicitly in the report is, "You know, we went to the PDR [Preliminary Design Review]," or the CDR [Critical Design Review], "and we never quite knew if the person talking or presenting at the moment was a JPLer or from Maxar or the scientists." They are so integrated and one team. I think that's how it manifested itself, and I've enjoyed it.

So I've enjoyed tremendously working with Lindy. Also she's just great at communicating what it is we're trying to do from a scientific standpoint. I mean, after all, there's a lot of engineering that goes into these missions, an enormous amount, to get a relatively small amount of scientific instruments out to take the measurements, but the goal is the science. And she's done a fantastic job of building excitement for that inside and outside of the team.

CONWAY: Thank you. Now, Lindy's all about teamwork, as you said. She certainly talked to me about it too. But then we wind up in 2020 when your team gets separated for what turns out to be a couple of years. You and I talked a little bit about impacts on Psyche through May of 2020. What happens after that? There's a year and a half, about, before the rest of us are allowed back to JPL, but I know some of your people are allowed back pretty soon after that May talk we had.

STONE: Oh, you're referring with regard to the pandemic impact.

CONWAY: The pandemic impact, yes.

STONE: So that had a huge impact. For example, all of these interactions and these joint team meetings went on hold. That, just from my standpoint, from a leadership standpoint, it was particularly difficult. There's an enormous number of people that work on the project, either full-time, part-time, a lot of belly-buttons, as we referred to it. You go into virtual online Zoom mode and just phone, you cannot get the situational awareness and the pulse of what's going on as broad as you can when you're sitting in an office or talking to somebody like I am with you right now, and somebody walks by my door with a pop-in for one second and makes one comment that

answers something, as opposed to having to wait till I've finished all my meetings to see if I can find when they're not in meetings for a thirty-second blip that either puts me at ease or tells me that I've got a critical issue to work or address. So from my standpoint, it was very, very challenging to try and keep a pulse on what's going on, and I believe so for a significant portion of the leadership team.

I think the flip side is there are aspects of it where people, perhaps not being in as many meetings as they would otherwise, at the working level, many of them found it to be more productive. They could focus better, etc., as opposed to somebody knocking on their door, like me, saying, "Hey, what about that thing," you know, blah, blah.

So it's mixed, but I think in the end, at the end of the game, I think it is really important for face-to-face contact, to be able to really read people's body language about their discomfort, and I think it becomes more important the farther you are into the life cycle of a project. I can imagine that early on in preliminary development and design work, that type of a mode of interacting can work satisfactorily. I think when you start building the hardware, you're doing the V&V [Validation and Verification] in the latter phase of the project where things are jumping really fast and you need to make really quick decisions to stay on a planetary launch cycle, being face-to-face for a significant portion of the team is really, really, really important. And I know there's lots of differing opinions about that, but that's where I've come down to on this.

CONWAY: I think that's where your IRB [Institutional Review Board] came down on too.

STONE: Yes, the IRB chair in particular is a very strong proponent of face-to-face, and I largely agree with that. I think where we've managed to land now, with the pandemic officially kind of

passed, is good. We have more flexibility or more opportunity to be able to work remotely. But when we were forced into that situation of not having anybody here except those doing touch labor, that was massively painful, in my opinion.

CONWAY: It's very highly disruptive, at the very least, yeah, and particularly because you hadn't been able to plan for it in advance in order to restructure work and that kind of thing.

STONE: Yeah, and I think timing-wise, it hit this project arguably at the worst time. Right as we're in integration and test.

CONWAY: Was it right before or right after your CDR?

STONE: I'd have to go back and check. It's all a blur now, right around that time frame. I think it was after CDR but before the SIR [Systems Integration Review].

CONWAY: Different track for this question. I understand it initially had trouble staffing Psyche, and so where were those troubled spots?

STONE: Yeah. Perhaps a little bit of clarification in terms of initially and what "initially" means. I think when we got selected and we officially started in the beginning, we started staffing up, and that was going okay and pretty well. It was later in Phase B and C where we started to hit challenges, I think. As everybody knows, the laboratory during that period of time and to today, has a lot of work on its plate, and we had 2020 going. That was, as they say, the gorilla that had a

lot of clout and focus. On one hand, that is understandable. The impact of that to us is that the balance of more junior people with people who, particularly in the leadership level, had very high levels of experience, was not what we would have otherwise liked or felt was needed, and I think that that came to fruition or obviously as a contributor to the issues we eventually ran into in not being able to make the 2022 launch.

Now, when we did not make that and we were working, both as the project and institution, to recover from that, 2020 did get launched and was farther along, the institution was able to make available resources and particular individuals that were not previously available, and those additions helped us get past that and get the program back on track to get us ready for a launch now in October of 2023. So it was a contributing factor and part of the whole workforce-availability ecosystem at the laboratory, as the laboratory goes through these ups and downs of work and how other missions are aligning phase-wise, how many are in the latter phases of the mission, getting ready for launches, where they inevitably need to pull in resources to take priority. So it's a difficult balance.

CONWAY: So the staffing wasn't—and I didn't think it was—it wasn't a part of the Step 1 or Step 2 problem; it came really to fruition in Phase C.

STONE: Yes. No, it had nothing to do with Step 1 or 2 or the earlier parts of Phase B. I think once we got selected, bear in mind that we did not get selected for the primary launch opportunity that we had proposed, so we had to do some changes anyway in Phase B to accommodate that, and, in fact—and I think perhaps we've spoken about this before, that the backup option was a 2023

launch, as it turns out, but shortly after selection, Headquarters says, "Well, what could you possibly do? Can you shorten this if we go in '22?"

Now, bearing in mind that in the proposal we were not allowed to bid on a launch in 2022, that was ruled out by the guidelines and constraints imposed by the proposal activity, and as it turned out, there was a very optimal launch trajectory that we found for 2022, so it is unfortunate and a bit disappointing, for the other reasons and things we talked about, that we were unable to make that opportunity. So that added also to some of the things that were going on in terms of a change in direction.

I think we have perhaps also discussed—I don't recall—in the past about—and this is not directly related—it is related to the staffing in a way, but a bigger item was that we originally proposed to fly the JPL heritage C&DH [Command and Data Handling] and flight software architecture. Shortly after selection, the institution came to the conclusion or a decision about the project that they would not be able to support two different flight software architectures. Right around this time, the institution was planning—or avionics folks were intending to move to a new architecture based on space-time partitioning, which was going to be flown on Europa, and they decided at that time, after we'd already proposed to fly the heritage and signed up for that, that, "No, we can't support the old heritage and develop this new one. Psyche, you need to move to the new one." But the belief was that we would be able to leverage on Europa, which was launching ahead of us.

It wasn't very long after that decision was made that Europa, for other reasons which you can check on or talk with others about, slipped beyond us, which put us in being a first on a cost-constrained mission to fly a completely new architecture, and I think that was painful. So the growing pains and issues associated with that also contributed to us not being fully prepared to go

into the final stages of the V&V program to make the ’22 launch. So those changes had technical impacts on our ability to still do the mission for what we had originally committed.

CONWAY: So you had a cascade of issues that were not of your own design or responsibility, I guess is a better way of putting it, that exogenous to the project is the word.

STONE: Yes. We were doing our best to respond to some things that were not anticipated for or in any way accounted for in the proposal and the original plan that we had for how and what we would do on the program. That said, that’s part of the business as well.

CONWAY: You always have limited flexibility to respond to outside environments.

I wanted to ask you about your ATLO and what challenges you’ve had during ATLO, other than the pandemic-related issues that we’ll talk about in another question, but talk about your ATLO.

STONE: You may know that because of the slip the ATLO was broken into two pieces. There was the ATLO 1 proper leading up to the ’22 opportunity. Then there was a stand-down, then we picked up and went into the ATLO 2.0. But I think across the board, ATLO, to the first order, has gone really well. We did not have any major, major, major problems arise per se. It was more the usual vein of things.

I think probably the thing to point out most is back to the issue of the Maxar way of doing things and JPL. Keep in mind that the bulk, volume, mass-wise and hardware-wise, of the spacecraft is Maxar-built and provided, and it was essentially built up in Palo Alto in their facility

and then delivered here as this huge integrated system. So they did not send us a box of parts and then we integrated in ATLO here like we do for in-house missions. We start with all the sub-elements. They delivered this whole mass—it looked like a spacecraft that walked in there, essentially, and then we started bolting the rest of our pieces, the JPL-provided components and instruments, onto that. So that was fundamentally different and unique for this mission.

Because it was occurring during the pandemic—and I'm probably leading to your next question—we had had intentions all along, because Maxar's just a 45-minute flight, of having our teams and ATLO teams being at Maxar to not participate, but observe and witness, in a sense, and be right there on the floor to see how they conduct what is effectively their ATLO or system integration. With the pandemic, we were not able to do that, and we clearly paid a price, because we didn't have that opportunity before the SEP chassis was delivered to the ATLO here at JPL to really wring out and get those cultures together, and we had to deal with the differences in how they operate on the floor and around hardware and yadda, yadda. And the way they conduct testing and their whole documentation system and the way they do QA [quality assurance], all of that is quite different, and we had to deal with that, and all of a sudden—bang!—once we started ATLO 1.0 at JPL.

So there were a number of growing pains and issues that we had to work through to get everybody onboard with what JPL was going to accept as ways to operate. And it's a tough thing because we bought this spacecraft and we bought Maxar's capability, yet at the same time, you know—so we didn't pay for them to "Do it like JPLers" or "Do it the way we do it" or "Be JPL." But JPL has a hard time with that in general. We were ultimately responsible. We're the ones signing on the dotted line. They do as well, but NASA comes first to us and they say, "If you selected that contractor, that's not an excuse, etc., for anything."

So working out the details and getting to a place that worked for everybody took some time to go through. They operate *very* quickly. When they build these spacecraft at their facility, from the start of a program with a customer to delivering a spacecraft, is a year and a half. That's absolutely unheard of here. That's all the design work that goes into those payloads and turn around and deliver a fully integrated spacecraft. One can only imagine that they follow some very different processes and techniques than we do. Now, it's warranted in some sense because they're a production house. They're doing it over and over again and they're not developing and working on spacecraft that are fundamentally unique or different, one that lands on Mars versus it drives on Mars versus it flies around Jupiter sorts of things.

So I'm not sure if that totally answered your question, but I think that was one fundamental thing. I think the execution of ATLO, despite all that, we kept on time. It was really great that Maxar delivered that chassis on time to us. That's the great thing about a fixed-price contract: they're motivated. They want to get paid and they've got milestone payments. They just don't get paid because they're working hard. So that gave us a leg up in that sense, despite some lateness and other things, deliveries to ATLO. But I think the execution of the ATLO and its management was very successful.

ATLO 2.0 here has been going extremely smoothly. We haven't had to use any days of margin. The activities are clicking off really well.

CONWAY: Great, great. Tell me your version of the story of how the guidance and control problem came to light. I guess it's in April of 2022.

STONE: My version of this story.

CONWAY: Yes.

STONE: Well, that is an interesting story. Let me see. Where would I begin with that? Well, first of all, probably the trigger or the key issue that came up was when there were a set of tests, some things that we were trying to conduct down in our testbeds, GNC [Guidance, Navigation & Control]-related. The teams were always kind of struggling and they thought they knew what the issues were and were working these things around the periphery.

I think some of the folks involved perhaps did not have—back to the workforce issue—as much experience, or we didn't have one or two single leaders that had real in-depth experience from a lot of other missions, and did not recognize that there was a fundamental problem, very subtle timing problem, in our testbed hardware and configuration. This testbed is unique in that it is a combination of JPL-provided electronic testing equipment with Maxar, because we have to have all these simulators for the Maxar hardware, so there's a whole bunch of computer racks that all have to be integrated together.

What we did not know, and folks did not realize, that really the underlying symptom to being able to make adequate progress and properly interpret the results that were coming from GNC testing, was this timing issue between those two different sets of racks. And it wasn't until Swati Mohan was brought in, who previously worked 2020 and other missions like that, came in and looked at what we were doing and said, "Wait a second." We did not go through a walk-up of testing out the capabilities of that testbed's preparedness for doing these tests, as we had done before. It's called a shakeout tester. There's a couple different terms for it, a GNC shakeout. So she came in and helped the team, and very quickly discovered that there is something more

fundamental here. This is not just an issue with GNC algorithms, and we're not going to be able to comprehensively test without addressing.

So we did this huge deep-dive activity, found the problem, and eventually were able to fix it, but by that time, it was too late to do that overall recovery. There's a lot of talk about some of the announcements of the problem, the software wasn't ready and it was this to blame and that to blame. A lot of that's been sorted out, I think, through the investigation, and some of the early language was probably not the best or appropriate characterization. There was a lot of software delivered by the software team with all of the capabilities that needed to be tested, so it wasn't a software team screwed anything up here per se. It's a combination of this testbed issue, particularly how it related to GNC, some other things as well, but particularly it showed itself in GNC. Guidance and control is where you have this real subtle timing is critical to everything. So that was kind of a blocker there.

I think getting the specifications at the system level and what have you properly laid out to do the high-level GNC functions, not the sub-system, but the overall is where some things were behind, and those were all contributors. But it's that one event of all of a sudden there's a fundamental problem deep down in the bowels of that testbed that was the kicker or the canary that finally arose, much to everybody's surprise. It was hidden down there. Some folks may have had concerns, but it did not get bubbled up about that concern clearly to my level to be able to jump on it. Had I known, I would have jumped on it obviously a lot earlier.

I think that in the recovery of that, it further pointed to that issue of there are key positions—every sub-team doesn't need to have completely experienced experts in everything. You need a mix. But we found that we needed more experienced individuals in targeted areas working in some of these teams where the junior folks were perhaps given more or had more

responsibility than was matched up with their experience level to act as a backstop, as a safety net for the team at large. So it's those sorts of things that had to be addressed, and like we've talked about earlier, the institution came to the realization that requests that perhaps we had made, concerns that we had were indeed real and needed to be addressed, and when they were addressed, then we got moving again. And then we're back on track.

Does that kind of answer your question?

CONWAY: Yes, yes. You focus, I think, as much on the timing issue as David's is. It's great to have the stories line up.

STONE: You're getting all the liars not in the same room; you're getting them separately!

CONWAY: Separately, right. Exactly. So then I know this comes up sometime in late April and it's about another six or eight weeks before you decide to delay. What's done in that period before making the decision? What sort of work goes into making a decision to delay the launch?

STONE: Well, I think when we finally got a discrete cry, so to say, with Swati and some other folks coming in and looking at this and saying, "Wait a second. I think we've got a smoking gun down here," we wanted to spend a little bit of time making sure that that was the case and that there wasn't either something larger, or we were perhaps not looking in the right area, and maybe this was not as big a contributor. So it took some time to do that. We were obviously doing everything we can do preserve the '22 launch opportunity. So it was a very, very difficult time, very, very stressful time as to when do we feel we know enough, confidently enough to say that we can't

make it? That's a huge and very difficult decision to make, especially at my level, but the project at large. Nobody wants to have to do that, and there's a tendency to hope for every blessed things that you could turn it around in time.

So it took us a while, like six weeks or whatever, before we fully grasped the full extent of the implications of what had been found and discovered and what would be needed to be able to launch with an appropriate level of confidence for a mission of this class, and it was after those six weeks or so that we came to the conclusion that we just cannot, and we need to raise our hand and go to the sponsor and say, "We cannot in good faith tell you that we can make it, that the chances of us making the '22 launch are sufficient enough to warrant taking the risk." Nobody wants to see a mission launch and then fail and be unsuccessful. That's worse.

So there was a lot of angst among a lot on the project and at the institution and clearly myself. Ultimately, I'm responsible no matter what. Whether I was privy to or aware of the right information to know that and when is immaterial. I'm still responsible. I think we definitely made the right decision. Clearly that's borne out by history, by the amount of work that we had to do to recover from that and then complete a robust V&V program. There's no question about that. But trying to convince folks, or tell them that we should still keep going, to see if we can squeeze it out, get ten pounds into a five-pound bag before that launch, would not have been the right thing to do, and I think in the end, I hope that it goes down—the integrity of the laboratory institution and myself, I hope, to go and finally raise our hands, even though it was exceptionally painful for the lab and everybody involved.

CONWAY: Everyone involved, you and the rest of the project as well, yes. And we're out of time, so thank you, Henry.

STONE: Thank you.

[End of interview]