David Oh

22 June 2023

Erik M. Conway,
Interviewer

Q: I'm Erik Conway. I'm talking to David Oh. Today is the 22nd of June 2023. We're talking about his experience on Psyche.

So, David, first, my biographical question. Who are you, where are you from, how were you educated?

Oh: My name is David Oh, and I was born in Alabama in 1969, which is the year we landed on the Moon, so I'm a child of the Space Age. I grew up in Alabama, went to school at MIT, got my Ph.D. there in aeronautics and astronautics, and then in 1996 went to work in the commercial space industry for seven years. I worked for a company then called Space Systems/Loral, now called Maxar Space Systems, where I became eventually their principal system engineer for electric propulsion.

Then in 2003, I came to JPL, where I have done a variety of jobs, including working on the GRAIL project during its earliest phases. I was the cross-cutting domain lead and the lead flight director for the Mars Science Laboratory, otherwise known as the Curiosity Mars Rover.

Then in 2013, I became the capture lead for what was then the Psyche proposal, so I led the initial proposal effort in the Step 1 proposal. Then after Psyche was selected in Step 1, I became both the capture lead and the project system engineer in Step 2, and then after Psyche was accepted, I became the project system engineer until about a year ago, when I was promoted to chief engineer for operations. So now I am Psyche's chief engineer for operations.

Q: Thanks. That was a great, concise summary. So, first, tell me what does it mean to be a capture lead on a Discovery proposal?

Oh: Capture lead on a Discovery proposal is basically the person managing and leading the proposal, so it's equivalent of a project manager, but for a proposal. I was given a pot of money, I was introduced to Lindy, and together we built this team that became the proposal team, building the partnerships with our science partners and with our payload partners, with our spacecraft partner, and eventually putting together the whole architecture and building the document, which was hundreds of pages that was submitted to NASA as the proposal.

Q: How did you come to be chosen to be the capture lead? Was that a JPL appointment? Did Lindy have some role in picking you?

Oh: Oh, well, it was a JPL appointment, but Lindy definitely had a role in picking me. So I started working for Brent Sherwood, who was then leading the Solar System Exploration Formulation Office. I guess I'll go back to—after MSL, after having spent seven years on MSL, and having worked a long time on it, and having landed successfully on Mars, and having worked on surface operations for 100 days, rather than deciding to continue on in the Mars program and work on the Mars 2020 Rover (Perseverance), I decided I wanted to go off and do something different, so I went into Mission Formulation, working on new missions to explore other planets, inner planets and asteroids and things like that. So I worked for Brent Sherwood, who was leading that office in Solar System Exploration, as his lead system engineer.

Then when the Psyche proposal came in, it came as an idea from Lindy. I think it had been through an A-Team study. I sat through an A-Team study with it. When they were looking to turn it into a real proposal, they were looking for capture leads and I had a good background for it because I had worked on electric propulsion when I was at Space Systems/Loral, and this mission looked like it was going to be some flavor of an electric propulsion mission because it was going to an asteroid and needed to get into orbit around it, a successor to Dawn, that kind of thing.

So Lindy interviewed a few candidates, and I was the top candidate out of there, and between Brent and Lindy, they selected me as the capture lead.

Q: It's a good segue back to the next question, which was how did you wind up coming from MIT and going to Space Systems/Loral and winding up in their electric propulsion organization?

Oh: So for my Ph.D. work, I worked on a thruster technology called Hall-effect thrusters. These are a form of electric propulsion which at the time was brand new to the West. It was this technology that the Soviet Union had developed in the seventies and eighties during the Cold War, behind the Iron Curtain. In the West, we didn't even know they had these thrusters until the Berlin Wall fell and they started trying to commercialize this technology, and they made what seemed like wild claims about this technology they had for this advanced electric thruster, which we in the West didn't really actually believe.

Then John Brophy, who's here at JPL, led a team out to Russia to go look at one of these Hall-effect thrusters and make measurements on it using American equipment, and verified that they had, in fact, invented and fully developed this new electric propulsion technology, which had been abandoned in the West.

So I worked on that and I did some of the first plume models of Hall-effect thrusters that that were done in the West for my Ph.D. thesis. At the time, Loral was this company which was looking to bring electric propulsion into its technology portfolio for use on commercial geostationary satellites for stationkeeping, and there was an opportunity that I had to go to Loral to work on bringing this relatively new technology into commercial satellites. So it was a great opportunity that I had that I couldn't turn down, so I went off to Loral and did that.

I actually did a whole bunch of other things at Loral first, because it took *years*, it took a decade to get from this thing which we were studying in the lab to actually get it to fly. And in the meantime, I was an electrical system engineer, I worked on a bunch of flight programs and doing power system engineer work, working on things. But electric propulsion was always a bit of a passion for me, so that took me to Loral.

Then when Loral went through the economic downturn that happened after the dotcom crash in 2003, I had the opportunity to go out and work at JPL, which is kind of a dream destination for me, because it does space exploration, going out and exploring the planets. So I got to come to JPL and got to work on Mars rovers. Mars rovers were kind of a bucket list item for me, getting to land a rover on Mars. And flying a Hall-thruster mission into deep space has also been a bucket list item for me, and Psyche has given me the opportunity to do that. So I've had the opportunity to take this technology that I learned about as a graduate student, that was, like, brand new, and actually see it now applied to the first mission that's going to take it and fly it beyond the Earth-Moon system.

Q: That is kind of both a rapid and kind of a dream career trajectory. Congratulations on that. Not many people can actually do it. [laughter]

Oh: Rapid in that it's taken twenty-five years, but yes.

Q: You know at least as well as I do that some missions take forty to get off the ground.

Oh: Oh, yeah. Psyche went through the first time it was proposed, so the Psyche mission actually is really only ten years old, but the Hall-effect thruster technology, in the West, it goes back twenty years plus.

Q: So quickly, since we're running out of time if you go into too much detail, tell me what's the difference between the Psyche Hall-effect thrusters and the previous electric propulsion that JPL's done in Dawn and DS1.

Oh: So Deep Space 1 and Dawn use something called a gridded ion thruster, where you have two electrically charged grids that are used to take ionized Xenon atoms and accelerate them across an electric field. Hall-effect thrusters, the ones we use, also accelerates Xenon ions across an electric field, but instead of using grids to contain the electrons, they use a magnetic field. So they're gridless devices. This makes them inherently simpler to build, because you don't have to have these precision designed and aligned grids that have to work across wide temperature ranges. So it's a simpler technology that has taken many years for us to develop to the point where we can fly in deep space.

Q: Great, great. Thank you. That's great. So back to Psyche. Who else worked on the proposal, on the Step 2 proposal?

Oh: Wow, a whole bunch of us worked on the proposal. Dan Goebel was the lead engineer, I guess Systems Engineer, in the Step 1 proposal and then helped greatly as a lead engineer in the Step 2 proposal. We had Lindy, of course, and the whole science team. We had our project scientist Carol Polanskey. Eventually we had our management team. We got Henry in there. Karen Lum was our proposal manager in Step 1, and she actually still works on the program part-time, helping us with our command and telemetry dictionaries. I mean, a whole variety of people. The science team, including Ben Weiss and Jim Bell and Lindy, were some of the first people I met on the project.

The two JPL engineers who were the first people to come up with the concept - Daniel Wenkert and Bruce Bills- are still on the team. So, yeah, so, like, a whole bunch of people, yes.

Q: And you just said "came up with the concept." Do you mean the science concept or the mission concept?

Oh: So the science concept started with an email that I'm sure Lindy has told you about, between Bruce Bills and Lindy way back at the beginning, where Bruce, I believe working with Daniel, reached out to Lindy and said, “Hey, based on this paper, would you be interested in doing a space mission that could prove or disprove the things that you’re saying in here?”

They worked a little bit with John Brophy, who had worked on the Dawn mission, to do the initial A-Team studies. By the time it got to me, it had just been through enough of an A-Team study to have a destination—they knew they wanted to go to Psyche—and to have an outline of the science goals—I don’t think we even had a full payload worked out yet; we were still going through the different science options—and to know that it was likely to be an electric propulsion mission. But we hadn’t picked a spacecraft provider, we hadn’t picked a spacecraft at all, right? We were just starting from a few science goals and a whole suite of possible instruments to pick from, which we narrowed down to the three which we’re flying today.

Q: So those major decisions, the instruments and so forth, are made into Step 2 process?

Oh: They’re made in Step 1. A lot of them were made pre-Step 1, because we build the partnerships in Step 1, right? We had to pick the companies and the labs that we would be working with to build those instruments, and the scientists who went with them. Yeah, those are some of the *very* earliest trades I was involved in. I think Lindy said I was the thirteenth person to work on the project, so it was a very, very small team when I started.

Q: Since we’re talking still about the proposal, I guess I have two questions. What were the early challenges? You’ve mentioned trades. What do you think were the biggest trades you had to deal with in the proposal process?

Oh: The biggest trades on the instruments was really how many instruments we would have, and then the biggest trade with the spacecraft was who was going to provide us with the spacecraft, because there are very few providers that can provide what you need to fly electric propulsion out into the solar system.

On both of those, I guess I'll start with our strategy. We had to pick a core strategy for the mission, and the strategy that we chose for the proposal was to pick a core set of science and then to build the simplest spacecraft which could achieve that science, because we wanted to be a simple and affordable Discovery mission. We wanted to be efficient, we wanted to be relatively inexpensive, but we wanted to get the science done, so we weren't going to build something that had extra instruments we could descope. We weren't going to build in extra destinations. We were focused on: set a science goal and get down to just the instruments necessary to meet those science goals. And that was tough, actually, because, like, there were a lot of reasons to put, for example, a laser altimeter on, and there was a lot of discussion about whether we should have one, and it would have added tens of millions of dollars to the cost of the proposal, and there were people who felt passionately that we should have one.

But at the end of the day, Lindy and the core science team decided that to do the science, we didn't need a laser altimeter, and therefore we cut that from the payload. That actually impressed me a lot with Lindy, from the very beginning, because she was willing to make the difficult choices to make the mission fit the strategy, right? Like, she was not just saying, "Well, we're going to do something like this," and then kind of like letting these decisions hang out. She was willing to do the study and then be decisive so that we could build the mission we needed.

The trades around the spacecraft were difficult because although Dawn had flown out to the asteroid belt before, we knew that the thruster technology, the particular thruster that they were using was obsolete, no longer available in industry, and therefore we knew that we had to use something different, and yet we had to use something different and still do it in a way which would be really reliable and would fit within the cost constraints of a Discovery mission. That led us on a hunt across the industry to look at what was commercially available out there, whether we should use something provided by NASA, whether we could use something that had flight heritage, whether we needed to finish developing something that had only been qualified in a lab. So there were a whole bunch of trades which were done around that.

In Step 1, you don't know everything you're going to know, so eventually we collected all the information we could, and we had to make the decision on who to go with, and we decided to go with Space Systems/Loral, now Maxar, with the Hall thruster system that they use commercially.

Q: Would it be fair to say you viewed that system as one of your potential challenges simply because it wasn't deep space-qualified, different operating environment, different lifetime requirements probably, so something you had to prove to the reviewers at first?

Oh: That's right. We had to prove to the reviewers that the thruster system would work in deep space. We had to prove to the reviewers that a Loral spacecraft bus, what we call the solar electric propulsion chassis, that the core spacecraft bus would work in deep space, because Loral has never flown spacecraft in deep space. So the core choice we had was between picking a provider like Lockheed that had flown something in deep space but had never flown big electric propulsion systems, or picking someone like Loral, who regularly built these 20 to 25 kilowatt spacecraft, more than enough power for what we needed to do, and had flown dozens of electric propulsion systems, but had never flown in deep space.

What we chose to do was to grab the provider that had the best technology in power and propulsion for us and then work with them to qualify what we needed, and also teach them to make sure that we could build something that would actually be able to work out in the outer asteroid belt.

Q: When JPL has done this before with Discovery programs, picking a contractor that has never done deep space before, we always wind up with overruns. [Oh laughs.] Were you worried about that?

Oh: Yes and no. The first thing I'll note is that, you know, the thing that I think in the past that JPL had had experience with—that worried me more than just the cost, as the project system engineer - was that there were times in the nineties when JPL picked providers who hadn't done things at Mars, for instance, and then they went and built a spacecraft, went to Mars, and it didn't work when it got there because it had a problem with it related to how it was originally used in Earth orbit.

So we did not choose to give the entire spacecraft just whole over to Loral. Instead, we chose a partnership where Loral was building a bunch of the hardware for the spacecraft, but the core software and the core fault protection systems and the core autonomy and the core telecommunications are all actually built by JPL. So we wanted to build a partnership where we could take JPL's experience in deep space and use that to build the parts of the spacecraft that were most important for deep space, and then marry that with the stuff that Loral could do. So we were trying to build something where we had the best of both organizations working together.

Now, one of the advantages of using Loral is that because they have a commercial product line and because at the time they were building a dozen spacecraft a year - big spacecraft, big geostationary spacecraft - their stuff is relatively inexpensive. We could have used that to build a very cheap proposal, but instead what we did is we built a lot of cost margins in the proposal. We anticipated from the beginning that there would be additional costs, and then we built that additional margin into the proposal, and the beauty of using a commercial provider is we had room to build all of that into the proposal. So we didn't have to build the mission concept while trying to slim down the cost or anything to fit in the cost cap. We actually had quite a bit of room to be generous with our costing, and we used that because we knew of these risks.

Q: That's really interesting. It is a different way than JPL has typically done this in the past.

Oh: It is.

Q: It does give you the challenge of marrying two different kinds of software, right? Because they still must have propulsion software that then has to run on some of your JPL equipment.

Oh: Actually, no. JPL is building ***all*** of the software for the spacecraft. Loral is building none of the software for the spacecraft.

Q: Oh, wow!

Oh: Yeah. Their hardware is controlled via a serial data interface called an M-bus interface. All of the data from their equipment goes into a Router, and an Attitude Control Electronics unit (ACE) on their side, and then those connect digitally to their computer via this serial data interface. We just replaced their digital computer with our computer and then put our software there. It's like plugging in USB into your laptop, or something like that. Of course, way more expensive, way more complicated than that, but you get the idea.

The electrical interface is actually relatively simple, and we even demonstrated that the electrical interface worked in Step 2. We brought their equipment down to Pasadena, hooked it to a JPL computer so they could all talk to each other. We did all of that as part of the Step 2 proposal.

Q: That was actually one of my questions, because Lindy had mentioned to me that when you first got money for Step 2, you were very excited because you were going to be able to do some testbeds and demos and stuff like that. So the question was, so what were those? What kind of testbeds and demos did you do to try to convince the reviewers?

Oh: A big one was that we brought Loral equipment down and hooked them to the JPL computers and showed that JPL software could operate Maxar hardware, or Maxar simulated hardware, in a testbed. It showed that they could play nice with each other. Then we brought their thruster down, which had been used in deep space, and we brought it to the vacuum chambers here at JPL, and then we operated it like we would operate it at Psyche, at low power, and we used the modified version of their power processing unit to do that. We showed that we could expand the hardware that they had to operate in deep space. We showed that we could make their hardware operate with our software. Then, of course, we did all the design work associated with that. So all of that came together to produce a strong proposal and to convince the proposal review board that we had a viable proposal, because, of course, one of the core challenges was for us to prove that we could make this partnership with a new partner work, and we did a very good job of that. We convinced them. [laughs]

Q: Yeah, clearly. Fantastic. So once you're selected, you become the project systems engineer. Tell me, first off, what that job entails.

Oh: I was the Project System Engineer and the Engineering Technical Authority, so in that role I was responsible both for making sure that all the different pieces, big pieces of the project - the spacecraft, the launch vehicle, the science payloads, the ground systems - all worked together and interacted together well from a technical point of view. But as ETA, I was also responsible for the overall technical integrity of the system, to make sure that all the pieces would work together and were built to the proper standards, and that all of the JPL design principles and the many lessons that we've learned over many years of operation were applied throughout the system.

I also acted as the architect, kind of the top-level system architect, for the system, because I'd been the system architect through Step 1 and Step 2, so I had the history to be able to act as the architect trying to make all these pieces work and get through the more detailed trade studies that we were doing after we were selected in Phase B.

Q: And then you said you were the Engineering Technical Authority [ETA], which I think is kind of meant to be the reporting authority in the event of—how do I even want to put it—disputes in the project over things that are required by NASA.

Oh: Right, among other things. Yeah, that's right. That's right.

Q: Have you ever had to use that authority in the project?

Oh: There's a formal way that it's used and there's an informal way that it's used. There's a whole formal way that it can be used to report—anyone on the project can actually report an issue in a manner that bypasses the project manager via the Engineering Technical Authority chain, which leads through the project ETA to the Office of the Chief Engineer to the head of the Lab and eventually up to the Chief Engineers at NASA headquarters. That I've never done. But there's also a role within the project where the ETA serves as the place that people in the project who are worried about technical issues and are worried that they're not being heard or that they could be a threat to the viability of the mission or whatever can come directly to the ETA, and that is a way of getting straight to the project manager, bypassing intermediate managers, and if the project management doesn't respond, then the ETA can go through the formal path.

I was the direct path through which the launch slip happened. The folks who were working in Guidance, Navigation, and Control, the GNC subsystem, did call a meeting with me and my deputy to sit down with us and say in essence, "Hey, we don't think we're going to make it to launch. We think we see all of these problems in here, and we think that the project management is not aware of that."

So after they talked to me about that, right, within twenty-four hours we had engaged the project management, and within forty-eight hours, we had a tiger team formed to go after it. So that is an example of where the ETA path was actually used in its internal-to-the-project form.

Q: I had wondered how that came up, because it wasn't obvious from the Young Report how exactly it came to light, so that was a later question. It helps tie those events together.

I've got a lot about the site visit from Lindy, but tell me your experience with the site visit.

Oh: Boy, the site visit was—how would I summarize it up? It is one of those, like, career moments [laughs] to walk through a whole site visit. It was a very interesting experience. Ultimately, I think it was a great experience for the project.

We held the site visit up in Palo Alto. We did that because we knew we had this new spacecraft provider and we knew people would be worried about them. Maxar—sorry, Space Systems/Loral was headquartered, is headquartered in Palo Alto. That's where their factory is. By holding the site visit there, we were able to take the review board into their high bay so they could see all the satellites that were in work, and I think when we were there for the site visit, there were fifteen or sixteen satellites that were in the high bay. I believe that on that day each reviewer got to see fifteen or sixteen satellites as they walked through the high bay on the tour, and for many of them, that's probably the most satellites they've ever seen in one place. Prior to SpaceX building all of its Starlink satellites and stuff, at that time there were very few places in the country that had that many satellites in one place. And these were *big* satellites, not like little CubeSats. These were the size of a bus or something like that. So that was why we did it up there.

I think the process was challenging. One of the challenges was that on the management team which we had, including myself, not a single one of us had actually ever attended a site visit before. Not only had we not attended as leaders, we'd actually never actually sat through a site visit before, even in the audience. So we were building the framework for the site visit, constructing the site visit, based on the advice of a handful of people that we knew at JPL who had been through parts of a site visit, but as a leadership team, because we had never been through it before, we were making a bunch of decisions without experience, just based on our best judgment of what would be the right thing.

I think Brent said afterwards that he actually thought that our inexperience ultimately helped us, because in some ways we made different decisions from other teams, and that helped our team stand out from the crowd. Eventually we got to a very, very strong sense of camaraderie on the team from working through this, which I think was palpable at the site visit. The reviewers told us that. The reviewers had trouble telling which people were JPLers and which people were Loral people and which people were payload providers, because from their point of view, the team was operating seamlessly. So that was, I think, quite an achievement.

But because of the lack of experience our dry run was pretty brutal. I mean, we made a lot of mistakes, and then we learned from them and we recovered. I think on the site visit day, we finished like an hour and a half earlier than the deadline. The review board ran out of questions. They were happy with us. That was a good sign right there. If you ever finish early, you know that's a good sign.

Q: How did you find out you'd been selected?

Oh: Lindy called me just after New Year's Day when I was out in Florida on vacation. I knew that we were going to hear from the review board one way or the other in the next couple days. I think I was one of the first people she called, because we had already been working on the proposal together for probably three years, two or three years at that time. So I was thrilled to hear it.

Q: Then that sets you out on your path as the project systems engineer. One thing I wanted to ask about, which was talk about developing the requirements for the project, since that's one of your major tasks. How is that done? You have to take the more general requirements from Step 2 and translate them down to the lower engineering levels and so forth. How do you do that? How do you assemble the team to do it, etc.?

Oh: Well, it's a pretty standard process. I don't think we did anything that different than what I call a standard JPL process. We pulled together a technical team of experts. By that time, we had the resources to pull together subsystem experts. We started up at the top level, at Level 2, with the project-level requirements, and we worked our way through the detail on them as teams. Then once we'd solidified those, we did the same thing at the next level down.

The process is very conversation-intensive. It takes a lot of time. I think I, as a management philosophy, realized that it takes time and wanted to make sure that there was adequate time and adequate conversation in there. We have a lot of tools to do these things, DOORS-NG [a requirements database] and various things, but the process itself, the tools themselves are not what make good requirements. It is the interaction between the people and the mutual understanding that we reach between engineers and between organizations that make for good requirements. So we spent an awful lot of time talking in person, especially with Loral, which had never worked with us before. We met with them almost on a weekly basis, either in person, either while they were down here in Pasadena, or we'd go up to Palo Alto. In fact, even during the Step 2 proposal, we were doing that, and during the nine-month Step 2 proposal, we met with them in person about thirty-five times, so it was basically once a week, because we were building these new relationships. A similar kind of thing was needed to build these requirements and to do it effectively.

So I see it as this combination of technical process but also a very human process, where humans have to interact with each other, and in that sense, I've never been a strong proponent of model-based system engineering or the idea that you can just put requirements into a database tool and have them approved by email, because I think that that misses the core of what needs to be done, which is to reach this mutual understanding.

Q: You see engineering as a social process, then.

Oh: Systems engineering is definitely a social process, and it depends on the people and the organizations involved. You wouldn't do it the same way if you had different people at different experience levels or different organizations involved than the ones you are dealing with at a particular point in time.

Q: Interesting. JPL, of course, is famous for our design principles and our management principles, and at some point you must have had to go through those and decide to ask for waivers for some things. Talk about that.

Oh: So the most interesting part of the process there was with Loral, because Loral had never interacted with the JPL design principles before except at a very superficial level. So we literally took every single design principle and sat down with Loral and walked through every single one of them, one by one, to say, "Do you think you can comply with this principle or don't comply with this principle, or do we not know?" We had to start right there with every single one, because unlike working with a Lockheed or another provider that's familiar with the JPL design principles, they have no template to start from. So we did that first in person and then we identified which ones were clearly 'noes' and clearly 'yeses,' and we had probably sixty or seventy that were in the "We need to go do research on these to understand."

Then we met with them again and again over the course of multiple weeks to work our way through all of this and to understand "Do you comply? Do you not comply? Do you comply with the intent of the principle? Do you comply with what we're trying to get at here as opposed to the exact words on a sheet of paper? If you do not comply with the intent of the principle, then do you comply with the words, and then do we need a waiver or not?"

So it was a fascinating process to go through with them, because they have a very mature set of practices. They've built *way* more—they've probably built ten times more spacecraft than JPL has, and some of their practices are different, but their practices are generally rooted in their experience, and they do have deep experience. So where there were differences, it was important to listen carefully to why they did things differently and what their rationale was, and then to understand whether because we go to deep space we need to do something different, or because they have a bunch more experience doing something in a relevant similar environment, that what they're doing actually might be the better approach. So, yeah, it was a fascinating and expansive set of conversations that took place over the better part of a year, I think.

Q: For the ones that turned out to be noes, what did you have to do within JPL to gain approval? Because I think there's a process for that.

Oh: Yes. We were using—well, first of all, there's an online system called WSPIR [JPL's electronic waiver processing system], for which we were one of the first users of the system, that let us do it electronically instead of paper signatures, and that turned out to be good. But we had to talk through each waiver with all of the different stakeholders in the institution, and we had to assign them a category and give them risk ratings. We had to make sure that the institution itself, that the experienced people in the institution, in the Office of the Chief Engineer and in the line section managers, understood each waiver and all bought into or agreed with the risks that were being taken, and if there was a serious disagreement, we might actually go back and tell Loral to change something in their practices or whatnot. There were actually very few instances of that in general.

Q: You think the Lab line orgs were generally willing to accept Maxar's experience?

Oh: I think it varied heavily. It varied heavily with the individual. JPL is less process-driven and more individuals-driven, and some individuals have had no experience with things outside of

JPL, and some individuals have a lot of experience with things outside of JPL, and those who've had experience with things outside of JPL, I think, tend to be a little more open in their thinking about, "Okay, what are the differences and what's happening here?"

I remember when I worked on the Mars program, I started working on the Mars rover. The Mars rovers use these lithium ion batteries, which were different from the nickel-hydrogen technology that was kind of standard at the time. I remember talking to the JPL engineer here, and him saying proudly that JPL had flown the first lithium ion batteries in space on these rovers. And I told him, "I just got finished on a 13 kilowatt lithium ion battery for this communications satellite at Loral, and it's flying in space. It was launched on the IPSTAR spacecraft." And he actually had no idea. He was not aware of it because he'd only worked within the JPL environment, and he honestly thought that this little battery on the rover was the only one flying. I was like, "Noooo. There are much bigger ones that are flying. They're cutting edge, they aren't commonly used in the industry, but there are other places out there that have real knowledge and technology to bring."

So that's an important—I think that just socializing these ideas that other organizations have within JPL is important to expose people to a wider, broader set of experiences and ideas so they can understand where their assumptions are good and where their assumptions need to be challenged.

Q: Sounds like we need more outreach to industry just to understand what others do, then, and have done.

Oh: Yes. An aspect of the commercial space industry is commercial industry has a lot more mobility between organizations—their engineers are switching organizations all the time—and they also have a real fear of being overtaken in the marketplace, so they spend a lot of time studying "What are my competitors doing?" We spent a lot of time when I was at Loral deconstructing what Boeing was doing in their spacecraft, to try to ask ourselves, "Are they being smarter than us?" or whatever. JPL, we're pretty sure that we're smarter than everybody else, so we don't spend as much time doing that, and that may or may not be true.

Q: May or may not be a good idea. [laughter]

Oh: That's right.

Q: Next, what's the project's state in early 2020 when JPL's about to shut down, though didn't know it yet?

Oh: The project had just finished its preliminary design review probably six or eight months previously and was heading towards critical design review just a few months later. I don't think we had our testbeds up and running yet. We had some hardware starting to build at Maxar, but not very much. We were just really entering the phase of starting to put together pieces of the spacecraft and really get software into testbeds and start testing things.

Q: And JPL, of course, closes down for what turns out to be nearly two years, in March of 2020. What does it do to you in the short term, that first year of 2020?

Oh: Well, the effect was dramatic. I mean, first of all, our testbeds, which were just on the cusp of coming up and running, went down for—I think it was six weeks or eight weeks of basically no-touch labor on the testbeds. The testbeds immediately became months behind in terms of starting up, and they were already late starting up because of issues with delivery of our FPGAs (Field Programmable Gate Arrays). So our testbed schedule immediately started going to the right.

Our CDR was coming up, and the project kind of dropped into crisis mode because nobody knew how to do a CDR with a huge review board and do it all remotely. Our CDR was one of the first that NASA ran on Webex. We were still learning how to use Webex. We were telling people to, like, turn off the video because the bandwidth was collapsing and the Webex wouldn't stay up.

Then more than that, I think we lost immediately the high level of interaction which we had both within the project and with our partners. I alluded earlier to this core idea that we were working with Maxar face-to-face on a weekly basis, that we were having all of these meetings with our partners and meeting with our teams and training our folks in person. All of that went out the window, and I think that hurt the project. I mean, I think it hurt the project's performance. I think it hurt the project's culture, because the culture was built so strongly around these personal interactions and the strong teams that we built like that. So it was a real impact. It was a real impact.

Q: And it's, I think, about six weeks before the Lab starts figuring out how to bring touch labor back, and that must further contribute to the delay, since I guess, as you say, there were quite a number of components being built by JPL.

Oh: That's right. I think Maxar came back to work a little faster. I mean, they didn't go through a six-week shutdown. They were shut down for only a couple of days, because they're a spacecraft defense contractor, so they have all the exemptions and whatnot, which I guess JPL could have had, too, but we chose not to exercise them or didn't exercise them. I actually don't know all the details about these decisions, right? There was so much happening.

So, yeah, and then remember CDR was only a few months away, so immediately our schedule goes into crisis. From my point of view, like, that started a series of crises, not only just for the project, but just on the individual level, right? *Everybody* is in crisis because they're trying to figure out how to keep their household going when there's no toilet paper in the stores and how to get food and how to get their kids out of school and keep them educated, right? It was like crisis across the project at the individual level, at the group level, at the organizational level, and it started a whole series of crises which pushed us from being in kind of a project running normally into a project running in crisis mode, which is, I think, where we stayed pretty much up until the launch slip, because we started slipping time and we were working under crisis, and then crisis, crisis, crisis, crisis… going from there as we're trying to hold to our fixed launch date, but with an organization and people who are operating not nearly as efficiently as they were in the pre-COVID environment.

Q: There was huge productivity loss that I'm looking for the person who has calculated, but to me it sounds like we are talking 25 or 30 percent in straight productivity [glitch in recording] terms.

So when did Psyche start coming out of that purely kind of reactive crisis mode, or didn't it? Did it not until the launch slip, as you just suggested?

Oh: I don't think it fully came out of it until the launch slip. The schedules are all going to the right. The cost, of course, also went up because of trying to operate under COVID. I feel like it was not until—it's not even the launch slip. We hit the launch slip, and then the next crisis was to go through the continuation review with the review board. It's really not until several months afterwards, fall of last year, that the project could finally, like, drop out of crisis mode and have the resources and the time to actually let people operate in a truly non-crisis mode. There were some breaks in there. There were times when we had a project "quiet week." Right after the slip, we tried to give people some time off and whatnot. But really the sense of impending crisis on top of this is something that I believe persisted until we were reconfirmed for our 2023 launch.

Q: Tell me how the CDR was done entirely remotely, given no one had tried to it, or almost no one.

Oh: Well, we assembled a Webex that had over 100 people on it, and then we appointed a moderator. Then we all logged in at 7:30 in the morning here time, and then the speakers started talking one by one. It was a distinctly different dynamic, I think, than I was used to. I think of JPL reviews as very interactive when we're all sitting in the room together. The JPL reviewers and the members of the review board don't hold back, right? There's, like, questions and there's responses, and it can sometimes get into heated discussions and whatnot, and that's all good, because that's all part of the process. That's where the reviewing and the learning is really happening.

What struck me in these Webex reviews—I think we were supposed to go all week; I think originally it was scheduled like a five-day review—five days in front of a screen, just starting at Webex, it's like the most boring reality TV you've ever seen, right? [laughter] You feel like you're watching TV, only every once in a while somebody on the screen calls out your name and turns to you to say, "What do you think?" And then you're like, "What?!" [laughs] So it's this weird dynamic where there's not nearly as much interactivity, and I did feel like by the end of the week just—you know, the review boards and stuff were tired. You would give your talk and you'd get no questions back from the audience, because everybody was just exhausted.

So, yeah, it was a weird experience. I think we put together a good review, despite all of that, but I very much missed the interactivity that was happening there and really getting to have that deeper conversations with the review boards and the people in the audience over what the design looked like and what the implications were.

Q: I want to ask whether you thought it was effective to do it that way, but it almost feels like not a fair question because you have no way of comparing it to anything.

Oh: Effective, yeah. I mean, it's less effective than doing it in person. Going into it, I don't think we were sure we could pull it off. It was at a time when the Webex infrastructure and the JPL IT infrastructure was so thin that they warned not to turn on the video like you and I are doing now, because if you turned on the video, some of the audio would become inaudible because the bandwidth was being overwhelmed. Two or three years later, this is not a problem which we have anymore because the technology has advanced and we have more bandwidth, but that Webex, I remember this distinctly, it was *barely* staying up through the whole thing. It was very on the edge of, like, what was doable using the technology of the time.

Q: You've already told me how the GNC problem came to light that causes the delay, but talk about how you think it happened.

Oh: Can you clarify for me what you mean by that question?

Q: How it came to be that the GNC was essentially unfinished, testbeds weren't done, testing hadn't been done. As I understand it, and I may be wrong about this, but I understood it didn't come to light until after the spacecraft had been shipped, so you would think that that would be a known entity by then. There's a pre-shipment review and so forth. You told us the mechanism of how it came to light, but I'm trying to understand how the problem came to be.

Oh: Okay, I got it, because those are two different questions.

Q: Yeah.

Oh: There's the problem of how the problem came to be, and there's the question of how it came to light or why it came to light so late.

Q: Yeah, that's true.

Oh: The two questions are related but are not the same question. The IRB, I think it addressed—well, let's talk about the how it came to be, right?

Q: Okay.

Oh: I'm going to go back even farther than the IRB did. The IRB identified, I think, that the organization of JPL was, let's say, under stress, right? A lot of people, a lot of jobs coming in, and experienced people on the project spread pretty thinly.

From my point of view in architecting the system, I am an expert in electrical propulsion, I'm an expert in power, somewhat in avionics, and so when you look at the way those systems were architected, they were architected with very clean technical interfaces between JPL and Maxar, because we knew that the technical interactions between JPL and Maxar would be challenging. But you can mitigate that using the architecture by deciding where you're going to put the boundary between the two organizations and what things you are going to assign to each of the two organizations.

The GNC area was an area where I feel like we had less expertise from the very beginning at the system engineering level, and so when we went through and we made our trades on how to split the work between Maxar and JPL, we made a set of trades which were very hardware-centric. In many cases, they seemed like the decisions of who would build things in the GNC subsystemwere very close decisions, which is to say either JPL could do it or Maxar could do it – there was nothing driving the trade either way. What we ended up with was a system where the GNC's responsibilities were actually split between Maxar and JPL, where JPL was responsible for a lot of the software and Maxar was responsible for a lot of the hardware.

I actually went back and looked at my notes from the very first ideas that I had at the beginning of Step 1 on how we should split the work between Maxar and JPL, and the very, very first trade that I did when I was writing down, like, theoretical how to split it, I wrote down on there "ACS," (attitude control, navigation) which is the same as GNC, "should be all JPL." I actually started in my head with an architecture that said 'have JPL do all of it and hold it together.' And then we walked away from that in Phase A and Phase B, because we made these trades, and I think what we didn't understand, because we had weak systems engineering and testbed support/understanding, was that as we made a trade to pick up, let's say, a ring laser gyro (RLG) from Maxar instead of from JPL, we weren't just buying a ring laser gyro, we were also buying their simulations and their pieces that go in the testbed, and that Maxar's testbed simulation then had to sit within a JPL testbed simulation environment, which is itself a simulation, right? We had built this complexity into it, but the folks who were doing those trades, including myself, did not have the expertise to understand the complexity which was being built in. This is something that I think the IRB just didn't manage to go far back enough in time to realize, that that actually sits at the core of this. We built in complexity in the GNC interfaces where we didn't need it, because we didn't have the expertise to know better.

Now, then you get to the question of why we didn't have the expertise. Part of it is because many experienced people were working on other projects and we had some relatively inexperienced people working that, but part of it is also inherent in the way JPL organizes its testbeds and its guidance and navigation and its system engineering, because they sit in three different organizations. What we need to do, in retrospect, is to form what in industry would be called a testbed integrated product team (IPT), where there's a single lead who's in charge of looking at all of these pieces that go into the testbed, and that person would be the person who goes, "Wait. By buying this ring laser gyro, here are the things you've done to the testbed simulations. Now these consequences have happened because of that." And we really have within JPL organizationally no position that's appointed to do that. We have individuals who choose to do this task because they're smart people and because they take it upon themselves to do it, but if you actually pointed at an org chart and said, "Which of these boxes is responsible for that?" you'd be hard-pressed to pick the person. Doing these trades on the split of the GNC subsystem, I think, we squarely hit into this organizational weakness which, along with JPL's personnel staffing weakness, which then led us to make these decisions.

Now, from there we've built in this complexity into the GNC subsystem, and now we need to implement to it, and that's where we get to, again, the experience level, the line oversight, the people who are working, and eventually to COVID, because I do think that, in my opinion, a strong reason these issues were not detected is because once we entered COVID, these organizations where we had broad interactions across the project, where we had these conversations, all turned into silos, because everybody is suddenly working in a crisis. They don't have enough time, they're just trying to hold their own team together, they don't have time to, like, go out and explore all of these other things. I think that probably contributed to it not being detected, because they were operating in a much smaller silo than JPL is used to having organizations operate in. I suspect that the line also suffered from that, because I do think that the line organization had a chance to pick this up, too, and also didn't.

Q: Yes. Thank you, and we're out of time, unfortunately, because that's a great answer. There were some interesting silences in the Young Panel Report around this, and maybe it is because, as you say, they didn't go back far enough, but I had wondered, and that's why I asked.
[laughter]

Oh: Okay. Well, you've got my honest opinion. [laughs]

Q: It's very helpful. Thank you. I may come back to you after—well, you're going to see this transcript before then in order to finish this conversation. I only had a few more questions, but as I said, we're out of time. So you'll hear from me again probably in—my transcriptionist has been very fast, so you'll probably get this in a couple of weeks.

Oh: Okay, great.

Q: Thank you so much for your time.

Oh: Thank you, Erik. Great to meet you.

Q: Have a great afternoon. Bye-bye.

Oh: Bye.

[End of interview]