IP HOT TOPICS
The Podcast | Episode Transcript

Sterne Kessler
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Innovation Conversations: Allen Chen

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Kathryn Holmes Johnson: Welcome to *IP Hot Topics*, a podcast of Sterne, Kessler, Goldstein & Fox, where we interview innovators and explore interesting aspects of intellectual property.

Trey Powers: Welcome back to Innovation Conversations, a special series of Sterne Kessler's *IP Hot Topics* podcast. I'm your series host, Trey Powers, a director in Sterne Kessler's biotech and litigation practice groups. Joining me today as our guest is Allen Chen, the Mars 2020 entry, descent and landing team lead. Allen and his team are just coming down off a monumental success in putting the Perseverance rover safely down on Martian soil. During the seven minutes of the EDL, the vehicle is completely autonomous and must perform a complicated series of crucial actions to slow the craft down from over 12,000 miles per hour to about one mile per hour and place it safely at the exact correct spot on the surface of Mars. Allen and his team accomplished this engineering feat as the world looked on. No pressure!

Al, thanks a lot for being here today. Let's start at the beginning. Can you tell us how you became interested in space exploration?

Allen Chen: I'm of that generation actually where some of our earliest memories of space exploration is really the Challenger disaster. That happened, when I was I think in first grade and I very much remember that happening. It's strange. Other people have positive first memories of the space business, but to have one started by tragedy, I think is the curse of my generation.

Trey Powers: So what was it about that that led you to decide to become a space explorer?

Allen Chen: I think engineers in general and explorers don't like to walk off the field with tragedy or any other kind of a setback. I think that folks like me looked at that and had the opportunity to say, "We can do better. We can try to fix the things that are stopping us and we can move forward from this." I think it's about taking on those issues and trying to push through them.

Trey Powers: That's super admirable. So you are the entry, descent and landing, or EDL, lead for the Mars 2020 Perseverance mission. At a high level, can you remind our listeners what had to happen during those crucial minutes of the EDL phase of the Perseverance mission?

Allen Chen: Well, for Perseverance and any other spacecraft trying to land on Mars, landing on Mars is really about finding a way to stop. And stop in a safe place, not just anywhere, and the place you want to go. Perseverance hit the atmosphere going about 12,000 miles per hour, but needed to touch down safely going about one and a half miles per hour to land safely at Jezero. To first do that, Perseverance first needed to use the atmosphere to slow down. It streaked across the Martian sky like a meteor, not only having to survive the intense heating and deceleration that you see during entry, but also steer its way to the landing target using little rockets to orient the vehicle, to fly to exactly where it was trying to go. That takes the vehicle from 12,000 miles an hour to about a thousand miles an hour or so, still going about supersonic speeds, almost twice the speed of sound.

Then Perseverance had to deploy a 70 foot diameter chute while traveling still at about 1.75 times the speed of sound. That slowed the spacecraft down even further. So while coming down on this parachute, Perseverance needed to figure out where it was. That meant jettisoning that heat shield, the thing that protected it during entry from that intense heat, and then using a radar to figure out how high it was from the ground and how fast it was going. Then also firing up a new system we call the terrain relative navigation system to figure out where it was. This system allows it to take pictures of the ground and match them up with an onboard map to figure out where exactly she was in a latitude, longitude space. But even then, while still under the parachute, the vehicle is still going about 160 miles per hour.

I don't know if any of you guys have skydived, but that's about the speed that somebody jumping out of a plane going head first toward the ground would be going. You're still going race car speeds and that is just too fast to stop safely. At that point, Perseverance had to light up its rocket-powered jet pack, what we call the descent stage, which had another eight set of engines and really slow itself down even further from that 160 miles an hour to that one and a half miles or an hour or so, to touch down. It flew to a safe spot nearby and started about 60 feet above the ground and separated the rover from below that rocket power jet pack, deployed the wheels from that rover and touched right down on its wheels. Once we had detected touchdown, once the Perseverance rover detected that it was safely on the ground, that rocket power jet pack was cut away and flew away to a safe distance.

Trey Powers: That's amazing. Yeah, I skydived once and that was enough for me. You worked for nine years, if I'm not mistaken, to orchestrate those crucial seven minutes in Perseverance's mission and the whole world was watching. As the team lead, I'd imagine the buck stops with you, and there's always the possibility that something could go wrong. How did you deal with the pressure and how did you celebrate your success?

Allen Chen: Just talking about it again gets my blood pressure going and makes me feel like I want to sweat again. You come to realize that we're all in this together. And of course, the entire mission and indeed the whole sample return campaign. The set of missions that we're trying to do here, to bring back evidence of past life from Mars to Earth, depends on us getting off on the right foot. So there's a tremendous amount of pressure on my team. I think it certainly is wearing over those years to understand how much pressure is on us.

That being said, I know that the work that we've done and the team could be trusted. We had done everything we could do to deserve success at that point. Really, all that we were finding out at that time was whether we were right. I think at that point, I had slept pretty well up to that point in general because our work was based on sound engineering. We had done a lot of testing of our system, both in actual the physical world and in the simulated world. So we had a pretty good idea that we were going to have a good day that day.

Trey Powers: Let's talk about that testing. I imagine you have to be limited in some capacity to test components that are going to be deployed on the surface of Mars or in the Martian atmosphere here on Earth. How can you test your EDL equipment? What's the best way to do that?

Allen Chen: Ideally, you want to put your system through exactly what it's going to go through when you're doing it for real. There's a mantra at NASA and at the Jet Propulsion Laboratory that you should test as you fly, and fly as you test. In other words, you want to put the system through as close to the real thing as possible. But how do you do that when you're going to a place like Mars, where everything is different than Earth? The atmosphere is different, the gravity is different. The terrain of where we're trying to go is unknown. There are so many things that are different, that it's really a tricky problem to deal with it here on Earth and to try to deal with how to figure out how to verify that your whole entry, descent, and landing system will actually hold together.

In the end, it's really just not possible to do a full end to end system test. That's what we call being able to do the entire landing sequence here on Earth, because so many things are wrong. In the end, what we do is test individual components of the landing system. Build models of those components and then try to assemble it in simulation. It's a world where we do individual tests instead of a whole system test, and then build this detailed simulation from it, and then live in a world where we have to simulate as we fly, and fly as we simulate.

Trey Powers: So NASA wouldn't let you send four prototypes up and see which one worked the best.

Allen Chen: At some point, if the only way to test your system whether it's going to work on Mars is to land on Mars, you might as well try to get it right the first time. That's where we're at. But there are things you can do here on Earth to try to mimic Mars as best as possible, but it's really tricky. For example, we talked about that supersonic parachute, that 70 foot diameter parachute that has to come out going supersonic speeds. To get to the right type of atmosphere conditions at the right Mach number and the right densities here on Earth, you have to go really high in the atmosphere because Mars' atmosphere is much thinner than that of Earth's. It's about 1% the density.

So to get those kinds of conditions or at least conditions that are similar enough to Mars, we took our parachute up to 130,000 feet in altitude here on Earth. To get it to supersonic speeds, we launched it from a sounding rocket. These are big rockets that we shoot up into the upper atmosphere and this time deployed a supersonic parachute and did that over the Atlantic Ocean. This is one way that we can test one component of the system, even if we can't test the whole thing together.

Trey Powers: That's fascinating. Can you give a particular example of a piece of equipment where you had to go off best calculations rather than actual tests you were able to carry out here on Earth?

Allen Chen: Sure. Everyone talks to us of course, about the sky crane and the power descent. This is the part where we light up that rocket powered jet pack with engines. We have these big 800 pound engines, and eight of them, that fire up to allow us to slow down from that 160 miles an hour, fly to a safe spot, and then do that sky crane maneuver where we separate the rover from that rocket power jet pack under cables. Everyone asks us, "Did you ever do a hot fire test?" a full engine test of that whole system and try to fly that. And the answer is no, we just can't do that here again, with gravity being different and the performance of this engine, in some sense, being different as well in our atmosphere than on Mars. So we could not do that kind of test.

Again, we had to assemble in simulation. We could put the rover down with its mobility deployed onto different types of terrain on its own. We could fire up individual engines themselves in vacuum chambers that simulate the Mars atmosphere on their own, but we could never put the whole thing together. That's where we had to rely on simulation. And to some degree, part of the reason why we built the sky crane, why we built that system, we came up with that architecture, was to make it a little bit more analyzable than stuff we've done in the past.

Trey Powers: Looking back on those seven minutes during the EDL, was there a particular aspect that metaphorically kept you up at night that you were worried about? Or were you just super confident in it all?

Allen Chen: Well, I think one of the major challenges of course, is that everything has to go right for an entry, descent, landing. There's no one piece that you can get partial credit for. This isn't a test where if you get nine things out of 10, you pass. You have to get all things right or it's not going to work because it's just a chain of things that have to work in order to land successfully. I think that's part of one of the biggest challenges is just the fact that the sheer complexity of what has to happen autonomously. The vehicle has to do this all on her own. There's no way that we're going to joystick this here from Earth, given how much time it takes for our radio signals to travel all the way to Mars and then back. So this is something that has to happen autonomously. Just the challenge of having all those steps occur in perfect sequence and each one of them going correctly, I think is the central challenge.

Trey Powers: Let's talk a little bit about the sky crane. It's a fascinating design to me. And why was that advantageous? Can you talk a little bit more about that? Compared to previous designs like an airbag system, what's important about the sky crane?

Allen Chen: Yeah, the sky crane was first invented back when I was working on the Curiosity mission, which is the Mars Science Laboratory mission. The mission that a lot of Perseverance owes its heritage too. It's the father of this mission, in some sense. Back on that mission, when we came up with the sky crane, the big thing that we were trying to do was land a much bigger rover on Mars and land it in places that we couldn't go before. That's where we began to understand the limitations of airbag systems. We had just come off the landing of the Mars Exploration rovers, Spirit and Opportunity, and their respective sites on Mars and understood what the limitations of that system were.

In particular, the airbag system itself delivered these two rovers (Spirit and Opportunity) that were about 170 kilos each. By comparison, the Curiosity rover itself was about five times heavier than that. The Perseverance rovers were six times heavier than that. One thing about airbag systems is they are energy absorption systems and they don't scale well. When you try to increase the mass significantly, we started ending up needing materials that we just didn't have, things that we couldn't build. We couldn't build airbags in that way. Then something else we talked about earlier in terms of designing for the ability to analyze it, the ability to simulate it, since we can't do all the system tests, well, airbags themselves and the way they interact with the ground are not very amenable to analysis. It's hard to think about how an airbag hits a individual set of rocks or different shaped rocks or rocks in certain quantities near each other without actually just doing a lot of physical testing, which is both time intensive and of course, very resource intensive as well.

But one of the key things for us was once we decided to land a much heavier rover, it was also a rover that was much more capable of dealing with terrain, because it was much bigger. The Curiosity rover or the Perseverance rover are much taller and much wider than Spirit and Opportunity. So we already had, in some sense, a rover that was capable of dealing with a lot of terrain, the ability to drive off big rocks, rocks up to 50 centimeters tall. Be able to drive around on slopes that were up to 30 degrees in steepness. So we had a system already as part of that rover that could deal with the terrain and conform to the terrain, even if the terrain wasn't as flat as a parking lot or a landing strip.

So what the sky crane really did was take advantage of the fact that we had a capable rover and turned that mobility system that was built for driving around on Mars and use that capability as a landing gear. That's really where the sky crane begins to shine. Because if you have a rover that's capable of dealing with all that terrain, you can use it to touchdown. Then suddenly you get a whole lot of other benefits. You usually think of back in the day, landers with engines on the bottom. But if you put engines on top with the rover below, you actually move the engines much further away from the ground. That has a lot of benefits. For one, if you saw some of our landing video from Perseverance, you know that those engines, because they're pretty strong, are kicking up a lot of debris and dust all over the place. If you imagine them down low, really close to the ground, you could imagine that they can create trenches and other issues that are problematic for us touching down.

So by flipping the problem on its head, by putting the engines up further away from the rover and above the rover at touchdown, the descent stage is still over 20 feet from the ground, you have much less of that plume debris concern with things getting kicked up by those engines.

Lastly, with the rover below us there, suspended from the descent stage, we get another advantage and that's detecting touchdown. With other systems, like three legged landers like Viking and Insight and Phoenix landers, things like that, when you touchdown on a slope, you have to shut down the engines right away, or you're going to skitter along the ground and it can cause some problems where you flip the vehicle over. When you have the sky crane system with the rover below you, you don't have to have your hair trigger on the instant of touchdown and figure out exactly when you contact the ground.

Because what the sky crane is actually looking for when we touchdown that rover, is the weight of the rover being offloaded by the ground. That's something that has a nice long signature. It doesn't happen in an instant and it's present for a long time. It's not something that's easily mistaken for something else. And that was a problem for us in the past. The Mars Polar lander, one of the reasons we think we may have lost it was that we incorrectly detected the touchdown event. We thought something that happened earlier was actually a touchdown event and cut the engines, stopped the thrust too early and fell to a hard impact. That's something that's not a concern when you have the sky crane, when you have the rover below this descent stage, looking for that offloading event, once all those wheels are safely on the ground.

Trey Powers: That was a really wonderful explanation of sky cranes and their advantages. I really appreciate it. All right, the very beginning. You have a rover that's six times heavier than has been landed on Mars with airbag systems. How do you and your team even begin to imagine the process for EDL nine years ago or whenever? Is it old school, big team meetings with dry erase board and brainstorming, or is it something more sophisticated?

Allen Chen: I think it's a little bit of everything, in some sense. Curiosity, of course built upon those smaller rovers many years ago. That was actually around, let's see, I guess it's now 17 years ago. Wow! It's been a long time since we came up with a sky crane system. I very much remember when the sky crane system was created. That was about 12 or 13 of us in a conference room for two days with a whiteboard, trying to brainstorm how to do this. While the sky crane looked certainly new to everybody else, it actually built upon some of the ideas we had in the past systems. One of the things that we saw with that airbag system with Spirit and Opportunity, was a lot of vehicles connected to each other, with soft goods. With lines to each other prior to the airbags being used on the ground, the air bag was connected to the back shell, which had rockets, which was connected to the parachute.

So we felt that we had a pretty good understanding of how vehicles connected to each other with lines could work. That's how we had the confidence to build a sky crane. Fast forward to after Curiosity landed to the Perseverance mission, to Mars 2020. The idea of that mission being to leverage what we learned from Curiosity to build a whole new mission. To go to a site that we could start the sample return campaign. We quickly realized that the sites that we wanted to go to for this type of mission, where we're trying to see the signs of past life, it's one of those situations where we really want to go to a place that has the best potential for having that evidence of past life. We quickly realized that the sites we wanted to go to were not reachable with the Curiosity system we built.

Then the challenge became for us about eight years ago, how to add to that system new capability to allow us to go to sites like Jezero that are really rugged. More rugged than we had ever intended to go to with the Curiosity landing system. How do we add to our landing system without breaking all the heritage we had built up with Curiosity? We had a system that worked. Now we want to add some more capability, but we don't want to break what we'd already built. That was one of the central challenges here for us on the Perseverance mission.

And we did that by adding a couple of new technologies in landing, one being that terrain relative navigation system, and the second being a range trigger. A smarter way of deploying the parachute in the right place in ways that were as independent from what we had done in the past as possible to keep the hard earned heritage. The blood, sweat, and tears, we had put into Curiosity to make that work and try to isolate these two new technologies and make them play together. That was a big part of our success at Jezero in February.

Trey Powers: Allen, some of our listeners may be aware that there's a hidden message in Perseverance's parachute. The red and white panels on the chute look pretty random to an ex-biologist like me, but the panels actually spell out dare mighty things in binary code in concentric rings. The internet figured that out. Were you the one who authorized that Easter egg?

Allen Chen: I think I should officially say “no comment.” But there were a handful of us, and not much more than a handful of us, that knew about the code in the parachute there. It was fun to talk a little bit about in that parachute what it takes to be successful in designing and landing things on Mars, that you have to put yourself out there. We did that this time as well.

Trey Powers: Yes, sir. Are there any aspects of your many innovations on the Perseverance EDL team that you think are particularly cool and groundbreaking? I mean, what stands out in your mind as a triumph there?

Allen Chen: I think the big, new piece of technology that's going to play itself out and be used throughout the rest of things that we do at NASA, is really this new terrain relative navigation system that we've added. Again, this is the ability to take pictures on the way down, which we've done before. We've taken pictures under a parachute of that ground rushing up towards us, but we'd never really done anything with it before. In this case here, we took pictures of the ground and then asked and put it in a whole another computer on our landing system, to be able to process those images and compare them to orbital imagery. Images that we'd taken from the Mars Reconnaissance orbiter and gave it a map and these images that it was taking on the way down and asked to figure out where it was.

That's a pretty big deal for us. We expect to be able to use that capability, both in Mars again, and then also on the moon to help land people and things more precisely in those places. This is a situation where the ability to land exactly where you want to go or to know exactly where you are, so that you can land exactly where you want to go, is going to repeat itself over and over again in all our exploration of other planetary bodies. Whether it's the moon, Mars or other planets. I think it's a key piece of how we're going to do things.

Second, we actually added something that didn't help us land, but I think has that helped capture the imagination and helped us do a little bit of engineering after we landed, which is the EDL camera system that we added. In addition to images of the ground that we were using to actually help us land, we took a whole bunch of high-speed video of all sorts of things that we had never done on Mars before. I guess you could argue, this is 2021 now that everything has cameras on it and Perseverance is no different. And the landing system this time is no different. But we've been landing on Mars for a few decades now, but have never seen a parachute inflate on Mars until February. We had these three cameras looking out from the parachute so that you could see that code that we embedded in the parachute. But also so that you could see that parachute inflate in the blink of an eye. The parachute itself inflates in about 0.7 seconds. It's a very violent inflation that we'd really never seen before. We just know that they'd worked.

On top of that, we had video of the heat shield dropping away and could see how well the heat shield performed. As it flew away from the vehicle, we could see the ground rushing up towards us. We could see the flume disturbance of the ground and all the dust that was kicked up when we landed. We also had a video of that sky crane for the first time. This is literally stuff we'd only been able to imagine before or see in our simulations, but now we have actual pictures and video of the descent stage lowering the rover toward the ground and the mobility deploying that landing gear for touchdown.

Then even the rover looking back up at the descent stage, dropping it off and then flying away. That's all stuff that we'd never seen before and now we have. I think that's been essential for allowing other people to ride along with us, understand what it's like to land on Mars. And it's been helpful for us. Even after landing now, we've been taking a look at all those videos, trying to glean anything we can about how well our system worked and if there's anything we need to fix going forward.

Trey Powers: I think my kids and I have seen all that footage that you've released. Yeah, it's pretty amazing and impressive. I love watching those videos.

Allen Chen: Yeah, there's all sorts of stuff that you find. I mean, I've spent a lot of my hours since February staring at them and you could still see new things each time if you look carefully. It's a very rich dataset for us to get even better about how we can land on other places.

Trey Powers: Allen, where can our listeners find those Perseverance images and videos you mentioned?

Allen Chen: You can find videos and images every day. Images from Perseverance rover every day. Come down to mars.nasa.gov/mars2020. A lot of people on the internet see images before the operations team often sees them because they're piped right to the raw images page right there.

Trey Powers: What is the EDL team up to now that the EDL is over? Do you get to just hang out and go on extended vacation or what's next?

Allen Chen: I did take a vacation for the first time in a long time. But that being said, different people have moved on to different things. It's one of the joys and the sad parts of being part of the landing team, is that you get become a tight knit family. Then at the end of it, you move on to other things. Some folks are working the surface mission. A lot of folks have moved on to working other parts of the sample return campaign. We need to land a big rocket to be able to get our samples off the ground into Mars orbit. So people are working on how to both land on Mars and to launch them back up into space. Other other folks are working on how to get those samples back from Mars orbit all the way to Earth, to safely here on Earth. So we have folks working on all sorts of different things. Some folks have moved on to other missions, to other places. Folks are working on our Europa Clipper mission. Other folks are working on missions to asteroids. There's all sorts of stuff that's fun out there that people are moving on to.

Trey Powers: That's great. Al, finally, our last question. Something that we ask all of our guests here on Innovation Conversations. Could you tell us something about you or your background or maybe a hobby or an interest that might surprise people?

Allen Chen: I don't know if I have too much that's surprising. I have three boys that are keeping me pretty busy, even in quarantine and all that. They certainly eat up a bunch of my time. But I'd say, I'm from the Philadelphia area so I'm a big sports fan. Even if I try to stay calm at work with high pressure situations, you'll find me screaming at sports teams all the time in real life. Especially the Phillies and Eagles.

Trey Powers: Thanks to Allen Chen and all of our listeners for joining us today.

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