Shannah Withrow-Maser (00:00):

I want to thank you guys so much. I'm so excited to be here with you, and specifically to be here with you on the eve of Ingenuity and Perseverance landing on Mars tomorrow. The team is just so excited, and hopefully you guys will see some of that in the presentation today.

Like was said in the introduction, this is part two of a talk that my colleague Haley Cummings began a couple weeks ago about how to fly on Mars. So I'll start by giving a quick recap of some of the information, in case some you weren't able to attend that talk, and then we'll get into the new stuff about the future of Mars rotorcraft. Okay, here we go.

So like what was said, I graduated from Missouri S&T, with aerospace engineering in 2017, and then completed my master's with an emphasis in project management in 2019.

During that time at S&T, I got to participate in a lot of research groups, such as Micro Gravity Research Group. And I especially spent a lot of time working on CubeSats. You can see my team here in the center of the screen.

Additionally, during that time, I was privileged enough to get to be a NASA rotorcraft aeromechanics intern for 2014, 2015, which meant I had the really unique experience of getting to do research in both the space and the aeronautics side of aerospace engineering.

In 2018, I became a Pathways intern and that led me to my current position. So what I do now is I work at NASA Ames research center where I'm part of the vehicle design and controls group. That means that basically I get to play in all of our awesome facilities, including the large wind tunnels that you'll see here, which are the largest in the world, as well as the vertical motion simulator. And I do research specifically related to urban air mobility. And I'm the vehicle systems lead for the Mars Science Helicopter Project. The second one is what we'll be discussing today.

So before we get too much further in, I just want to take a second and give a shout out. One of my favorite quotes is this one here on the screen, "Be the person you needed when you were younger." These pictures are of MiMi Aung and she is the program and project manager for Ingenuity. She'll make history tomorrow when it lands on the surface.

But it's really, really important for you to find these types of people in your career to be role models. Mimi is really important to me, not because she has done all of these major feats, which she has, but because of the way she leads her team. Anytime you pass her in the hallway, she makes sure to smile and say, "I'm so excited that you're here. And thank you so much for the work that you're doing."

And she's also really hands on and with the technical side of things. And I just really admire that. So just something to keep in mind, even if you don't listen to the technical part of what I'm about to talk about is that it'll really help you in your career. If you find those role models and mentors to look up to as well as looking back and reaching out to students or other professionals who are younger than you.

I know I specifically was really hesitant to do that in college because I didn't think I had that much knowledge to share, but there's always somebody who's coming up just right behind you. So in summary, basically find that person and be that person for someone else.

Cool. So let's get into the material. So as I mentioned, Haley, one of my team members, came and she talked about basically 2015 to 2018 on this timeline. So she talked about where did the Mars helicopter idea come from? How was ingenuity built? And then she talked about some of the rotor calculations and performance measurements we've done since then. I'm going to kind of pick up there and talk about what we're planning next and how we plan to transition this from Ingenuity to future missions that are doing real science.

So just for a quick review, Ingenuity is a coax configuration. It's a small coax, which means that it's actually less than two kilograms. And it has a rotor diameter of 1.2, which is relatively small. Think about your arms kind of outstretched. And then it's nestled into the belly of the rover. So you can see the rover flipped upside down here and them integrating the helicopter.

And tomorrow, both of them are going to land on the surface. It's going to be super exciting to watch. I put the link here in case you want to join in, whatever happens in the supplements of terror will learn a lot. And so I would definitely encourage you to join that.

So Ingenuity is a big deal because it will be the first ever powered flight attempt on another planet. The goal is to try to do about five flights over 30 Martian days or sols. And those will last about 90 seconds each and go about 180 meters on average.

So while flight is obviously the long term goal, there's a lot of milestones that we've already met in an effort to get Ingenuity there. One of those is to go from concept to vehicle on planet. And that process has actually been just six years for Ingenuity, which is extremely fast for a spacecraft.

Ingenuity has already survived launch, which is a big deal because we're using a lot of materials and components that are thinner than what we would normally send. It's shown it can charge its COTS or commercial off the shelves batteries while in deep-space crews. And then also before it can actually fly, it still has to land, deploy, charge and survive the Martian night. So as we achieve each one of those, we're checking things off the list and those are all considered successes. So just something to keep in mind with tech demonstrations.

Something else that's really interesting is not only is this the first attempt of powered flight on another planet, but it will also be completely solar charged and it'll be the first aircraft to try to survive autonomously on another planet. So why does this all matter? Why do you all care? Why would we want to fly on Mars? Well, as Haley shared previously, we figured out that we can increase the performance of the vehicle compared to more traditional land or orbit based vehicles.

Landers are great. Rovers are great, but when we're using the helicopter, we can get a lot higher resolution because we can get a lot closer and we have more sensor options than when we're working with the orbiters. And we can also go over a much larger range of diverse terrain and move a lot faster than we can with the landers or rovers.

And so I'm sure like, but Shannah, you just said that you're only flying for 90 seconds. How are you doing all of that? Well, so like I said, Ingenuity is just supposed to be a tech demonstrator. So it doesn't actually have a dedicated science payload. And for context, this is pretty traditional in the development of aircraft.

So, for example, several people have called this a Wright brothers moment in the media and the Wright brothers actually only flew the first day for 59 seconds and 260 meters. So actually kind of a fun fact is that on the fourth flight of Kittyhawk is when they recorded that these numbers. And if Ingenuity survives to its fourth flight, it will actually be going for a really similar range value. So that'll be really cool to see the two missions mirrored.

So kind of back to the timeline. Now I'm going to talk about specifically what we did from late 2018 to now to get this technology to the place where I'm saying we can make this big leap from the technology demonstration, which will be really, really cool, to then using it in the future to expand into exploration.

So that leads me to something called the Mars Science Helicopter project, which was established around 2018, right around the time that ingenuity was finishing its final testing and starting to get packaged up. And Mars Science Helicopter project is a joint effort between Ames and JPL to develop the technology that's needed for future rotorcraft on Mars.

So as you can see, we've already been able to significantly increase the performance of the rotorcraft. What this graph here is if we were to remake Ingenuity today. You can see in the red what the current hover time and range capabilities of Ingenuity is versus what we can do with the design now.

So basically what I'm saying is that you can see with the blown up red piece that ingenuity can basically hover for one and a half minutes or it can go for 0.18 kilometers. It's a trade off, either hover time or range. But with the bigger blade area, the advanced airfoils, as well as a larger motor and battery, we could actually now, if we were to send it in the exact same form factor, hover for up to 16 minutes or go all the way out to 30 kilometers range.

With that in mind, you can also trade hover time and range for carrying additional science payload. So that means that we could actually carry a range of payloads with the heaviest being 1.3 kilograms with the current form factor while still increasing with this bottom line the hover time and range capability of Ingenuity. And that's pretty cool.

So with the Mar Science Helicopter project, we're concerned with developing all technology related to future Mars rotorcraft we don't want to just look at the current form factor of Ingenuity. So you can kind of see at the bottom of the slide here where we went from our original ingenuity design on the left to optimizing those rotors and adding the additional batteries and such to get this new and improved version of Ingenuity that we call the Advanced Mars Helicopter.

But in addition to that, we also looked at, okay, what can we do if we make the vehicles bigger? So for Ingenuity it was more designed as a piece of science instrumentation and it was meant to go as a payload with the rover rather than being the center of the mission. So we were kind of constrained in how big of a space we could put it in, which is kind of what determined its size.

So we scaled it up to say, okay, what do we need to do so that it can carry, let's start with two kilograms of payload, a range of two kilometers, increase the speed to 30 meters per second and hover for four and a half minutes? And that led us initially to the scaled coax design. And you'll see that the radius of the rotor here is about twice that of Ingenuity and the weight increases to about 20 kilograms total in order to be able to carry this payload.

So we looked at that, but we had to stop increasing it because we started running into really excessive blade flapping when we increased the rotor. That's because air is only 1% as dense on Mars as it is here. And so the air wasn't being able to help with the dampening. So because of that, we looked and said, "Okay, well, what if we leave the rotors approximately the same size, but we put them in a different configuration?"

And that led us to this hexacopter design. That's actually about the same weight, but again can enable us to carry the two kilograms and go two kilometers of range. And with that in mind, we were like, "Okay, well with the hexacopter design, we're actually not maxing out our capabilities. So what else can we do?" So we added additional batteries and sized up the motor and went to this variation that's this 31 kilogram helicopter, which has even more capability, which I'll talk about in just a second.

So here you'll see the same graph of range versus hover time to show the performance trade off for the Mars Science Hexacopter. So this is a conceptual vehicle that shows the type of science capability that we could potentially have on Mars. So here you can see again, if we carry no science payload like Ingenuity has, we can increase the range to 20 kilometers or the hover time to 10 minutes. Or if we want to add payload, we can carry up to eight kilograms while again, still increasing the range in hover time. And again, remember that these values are in the context of that Ingenuity overall is less than two kilograms. So that's a pretty significant change in just over two years.

So that's all great, but what kind of science are we interested in? Why are we going to all the trouble to make the vehicles more capable? So there's kind of three main groups that we're interested in and that's life, climate, and geology. The reason that we pick those three is based on things like the decadal survey that come out of the science community every 10 years or so that kind of align what the priorities are.

So here you'll see a couple specific science tasks including geological mapping and stratigraphy, volatiles and climate astrobiology, atmospheric science, aeolian and slope processes, and geophysics. And while some of those things can be done with a rover lander, you'll see here on the left with the green being range, the purple being access to hazardous terrain, and the blue being access to the planetary boundary layer, each one of these are enabled either for the first time or to a greater degree by using a helicopter for those reasons.

The other thing besides the type of science that we can do is where we can do the science. So with our current vehicles we're kind of limited to valleys and planes and areas that are relatively easy to move across. But with rotorcraft we can go to things like canyons, poles, caves, skylights, and also land at higher altitudes. And that is where we suspect that a lot of the really interesting planetary science is.

So one other thing that I want to specify is that there's kind of two classes of missions here. There's independent rotorcraft missions and there's cooperative rotorcraft missions. Independent missions are going to be things where it needs to go a really long distance and it needs to be able to carry its own science payload and have its own calm system, things like that, be completely capable, but it would be somewhere that a rover or lander couldn't get to.

A cooperative mission is more what Ingenuity is right now, where it's tagging along with a lander or a Rover. And it's able to assist it either as a scout or by providing additional coms or by providing things like sample transportation. And eventually either of these designs could actually also assist humans, rather that be that they are trying to avoid a specifically high risk task for the astronauts or just that it's a lot of work and the astronauts only have so much time in the day.

So when we're talking about the independent missions we're usually talking about either the larger scaled coax, if we're able to develop a material to dampen out some of that flapping, or this helicopter design. And if we're talking about the cooperative missions, we're more likely talking about an improved version of Ingenuity.

So just as an example of that, this is an example of one of those independent missions, which is an ice and climate type mission at the Marian poles. This concept was put together by one of my colleagues at JPL, and the goal here would to be to see what kind of history is frozen in the polls of Mars and also to see if there's any near surface water ice that we might be able to use responsibly, of course, when we go to do human exploration.

Here's another example of one of those more cooperative type missions, which is a clay and organics mission at Mawrth Valis to see if there are potentially biosignatures there. This is kind of along the same concept of something that insight would do where normally you would put a lander down in that location and they would have whatever range that their arm could extend to, to collect samples.

But here the proposition is that if you take and you package an Ingenuity size helicopter in a lander here, which happens to be a Heritage Pathfinder lander, then you can actually use the helicopter itself to be a little bit more picky and selective about which samples it wants to collect as well as travel a further range to collect those samples and then leave the heavier equipment for some of the processing instrumentation, as well as the comms to go back to earth on the lander itself. So basically the rotorcraft acts as a ferry back and forth.

So like with any vehicle design, there's also external constraints. So one of the big ones for our mission is, again, how do we get there? Just like I said, that Ingenuity was limited by how we could fit on the rover. We have to make sure that we have the technology to launch our rotorcraft.

For that reason, we had to do a trade study basically. And we started with the looking at Heritage systems and narrowed in on the Pathfinder aeroshell. We chose that from the three Heritage EDL or entry descent and landing systems here because it's the smallest and least expensive. So our thought process was kind of, if we're not spending money on the EDL system, we can spend it on the helicopter. And also if we can show that it can be in the smallest one, then we can easily make it larger if needed. So our first job was just to make sure that we could fit it relatively in the volumetric space. And that looks something a little bit like this.

There were many packaging concepts we looked at. This is one of the areas that I work in and kind of a throwback to my CubeSat days of trying to figure out how to integrate everything and package it and make it work. But this is the one that allowed us to have the most room for the rotorcraft.

However, it's not quite that easy. You can see here with this graphic of the Pathfinder EDL system that the aeroshell is what we considered to be comprised of the back shell and the heat shield. But there's also this additional lander in the middle, which is tetrahedral and not exactly a convenient shape for a rotorcraft. That means that we kind of have two options. And this is actually a process that's ongoing. So sorry to leave you with a cliffhanger, but you'll have to stay tuned to see what we decide.

The first is to continue to fold the rotorcraft. Pros for that is that we can use the Heritage system. We know it works. It reduces risk. Con is that the lander itself is pretty expensive. And we also have to slightly reduce the rotor radius to get it to fit, which means we don't have as much performance.

Another option is to do mid-air deployment. So mid-air deployment is basically when you don't have the lander in a aeroshell and after the heat shield comes off, the rotorcraft drops off and then goes ahead and uses its rotors and landing system to separate, fly out from underneath the aeroshell, and then fly away. This is what Dragonfly will be doing on Titan. However, it's a little more challenging on Mars again, because of that 1% density that I was talking about earlier.

So we're currently working on these two concepts and we'll see which one's the winner pros for that are obviously that it reduces a lot of costs that would have to go into the lander, but cons would be that we we haven't tested it before so we would add risk.

Wrapping up here. What's next? For the Mar Science Helicopter team. We're working on things like the controls design right now. We are also adapting these reference vehicles that I've shown you for more specific missions as we get closer and closer to our proposal date. JPL is leading a test flight of an earth based demonstrator to show our new navigation and avionic software, which lets us fly at higher speeds.

You all have already heard about the ROAMX project at Ames that is validating and verifying the rotor. And then also tomorrow when we land, we'll be gathering data the whole time. And that data will go directly into this as lessons learned.

Additionally, the community is working on things like Dragonfly, which will go to Titan here in 2027. There's a lot of groups working on human presence and rotorcraft can be a big part of that.

Additionally, both we are developing technologies that benefit other things in day to day life, as well as things that are developed for day to day life benefit the helicopter. Examples of that are batteries, swarm technology, processing power, and solar cells. A lot of Ingenuity's brain is based off of a cell phone. And then additionally, because the region we're flying in there's application to high altitude flight and micro UAVs.

What you can see on the right is that we're also looking at alternate configurations with things like lifting surfaces and stuff to fit more specific missions. And one of my students put this together and I thought it was really cool.

The other really neat thing about this project is that it's not something that you have to wait 5 or 10 or 15 years to work on. I just listed. There's a lot of areas and I didn't even come close to identifying them all where there's information gaps right now. So if there's something that you're excited about, just jump in and go for it. There's so much room for students and for the communities to be a part of this new field.

This is just a display of a bunch of the students I've worked with. And every one of these students was at Ames while we were working on the rotorcraft and many of them have contributed to the current design. So with that in mind, go for it. And maybe your idea will be on the next Mars rotorcraft. With that, any questions?

Josh Rovey (20:23):

Hi, Shannah. This is Josh Rovey. Thank you very much for your presentation today. Really appreciate it. I do have a question. You mentioned Titan and, of course, Mars, are there any other planetary or satellites of planets bodies that are being explored for rotorcraft like this?

Shannah Withrow-Maser (20:46):

Yeah, that's a great question. So one of the other common locations that I've heard that's of interest is Venus and obviously Venus is challenging because of the thermal issues, but it does have a really good atmosphere as far as flight is concerned. So those are kind of the big three that I typically hear, but basically Mars atmosphere is not very dense, so it's kind of an extreme example of showing where we can fly. So basically anywhere that has an atmosphere and we can reasonably get to, it's not out of the question, just maybe not in as much of the near term.

Speaker 3 (21:29):

And Shannah, August Beck had a question from the chat. "Does it have the ability to recover from flipping over?"

Shannah Withrow-Maser (21:37):

That is a great question and actually a question I get a lot. So Ingenuity again, because it's only trying to do five flights and fly over 30 days, they're just going to wait to set it down until they feel fairly confident that the conditions for flight are good. And because again, we're talking for Ingenuity more of an opportunity to right along as a piece of science instrumentation, it wasn't able to be made that robust yet.

For the science helicopter designs, again, obviously the intention would be for them to be a lot more robust and to be able to participate in longer missions. So right now that's not currently something that we have in the design, but it's definitely something we're considering, if there's additional things we can put in the landing gear or things like that to be able to assist it if that were to happen. But of course, that's always the challenge of anything that you do like that is going to add weight and decrease your performance. So you have to do a really careful trade off there.

Speaker 3 (22:47):

Okay, we do have another question. August says, "Thank you." And Chloe Bens asked, "Does ingenuity only rely on solar charged batteries?"

Shannah Withrow-Maser (22:57):

Yes, that is correct. Basically it flies and then it takes a day to charge, and then it can fly again.

Speaker 3 (23:04):

Okay. And then we have another question and, I'm sorry, I don't want to mispronounce your name, but it's, "How do you verify stability and sustainability of the Rover in the Mars weather and turbulence?"

Shannah Withrow-Maser (23:16):

Yeah, so we'll have a lot more data to go off of after the next month. To test Ingenuity we created a wind wall in the JPL space simulator, which is basically a giant vacuum chamber. And we did a lot of system ID and control tests within that environment. So to the extent that we could, we replicated that here on earth, but we won't be sure until it actually flies. And then from here on out, we'll use the Ingenuity data.

Speaker 3 (23:51):

Okay. And Anish has another question. "Is Ingenuity better at absorbing energy than solar panels that you could find on houses?" So, I guess, are Ingenuity's solar panels better?

Shannah Withrow-Maser (24:09):

I'm not as familiar with the specifics of the solar panels. That's a little outside of my area, but based on the time that it takes to charge and the fact that Mars is further away then I think they would be more comparable to spacecraft grade, but you should fact check me on that.

Teresa Gomez (24:30):

I hope everyone enjoyed the talks today. Thank you, Dr. Schonberg and Shanna Withrow for sharing with us today. Please join us for future talks each Wednesday at 4:00 PM for the spring semester.