Michelle Munk (00:15):

Welcome, everyone, to the Innovation and Opportunity Conference. I'm Michelle Munk, the assistant capability leader for Entry, Descent, and Landing and Precision Landing. Within the STMD Strategic Framework, Entry, Descent, and Landing and Precision Landing fall within the Land Thrust.

Some of our main outcomes there are to enable lunar and Mars global access with 20-ton payloads to support human missions and to land payloads within 50 meters accuracy while also avoiding local landing hazards, which can mean either natural terrain or pre-deployed assets. Within that Land Thrust is where all of our content resides.

This graphic shows you some of the main things we're working on within Entry, Descent, and Landing and Precision Landing. This will sort of serve as the outline for this presentation. Within the Artemis missions of NASA, we are moving from lunar capabilities forward and looking to Mars capabilities. Within the lunar capabilities, two of our main areas are precision landing and hazard avoidance, and also plume surface interaction, how the rocket thrusters interact with the surface of the Moon and may cause damage to the lander or things around the lander.

As we move towards Mars, we're going to be looking at larger hypersonic deceleration systems, as well as supersonic retropropulsion to help get large payloads down to the surface. I'll talk about that a bit more later.

Then across both of these initiatives and capabilities, we need to keep our eyes focused on improving our models within the EDL disciplines and validating those models through the return of data from ground and flight testing. For Entry, Descent, and Landing, in particular, it's nearly impossible to test our systems end-to-end on earth, and so we rely heavily on simulations. That's what this area is all about.

To put this into words for you, I've listed some of the main challenges within this thrust area that we can see coming for the next 20 years. As I've explained, we're trying to land precisely on the Moon, first, with small, commercially provided landers, and then human-scale by 2024 as part of the Artemis mission. Some of our challenges are lightweight, cost-effective sensors for precision landing, plume surface interaction modeling, and integrated simulations for assessing the lander performance all the way down to the safe landing.

Some of the other challenges that we have within the EDL community focus on science missions. A major thrust of this decade and into the next decade is returning a sample from Mars for study by scientists on Earth in their laboratories. Some of our challenges here are to land over a metric ton of payload precisely, the next lander with a rover on it to fetch the samples that Mars 2020 is going to cache when it gets to the surface in 2021.

Also, we need to autonomously launch a rocket from Mars to a target orbit, and so there are aerodynamic issues associated with that, as well as plume issues. Then we're returning the samples to Earth via a capsule very low probability of failure. This high-reliability system is really driving our modeling challenges for the coming decade.

In addition, we have challenging science missions to Venus, ice giants, ocean worlds, and outer planets. Those encompass rugged terrain, unknown atmospheres, high entry speeds, and the potential for using aerocapture for enabling lower-mass systems to get out to the outer planets and establish orbit.

We're trying to, across the board, lower the cost of exploration by improving launch stage return using aerodynamic deceleration systems. We want to enable entry, descent, and landing and orbit insertion for small spacecraft.

Then, of course, as our far-term goal, we want to land humans on Mars. This is going to be a huge challenge because of the high mass of the payloads we have to land reliably and the precision landing, of course, at Mars, as well as at the Moon.

Next, I'll go through each of the challenge areas in a little more depth. First is precision landing and hazard avoidance. As I showed earlier, that pertains to the Moon, and it also goes forward to Mars. For the status quo of precision landing, we come in and do a blind soft landing. We've done this pretty successfully many times at Mars, and we did this at the Moon with Apollo, of course. We're trying to improve the capabilities here and land precisely, either next to scientifically interesting or areas where there are resources or next to predeployed assets that we've put there to support missions and infrastructure.

Right now, we've come in using an initial measuring unit, and an altimeter, and sometimes a radar velocimeter as Mars Science Laboratory did and Mars 2020 will do. We get within a landing ellipse that's defined by the uncertainties that we have when we reach the surface.

In our new paradigm of precision landing and hazard avoidance, we add sensors and information into the navigation state such as terrain-relative navigation, which will be done on Mars 2020, hazard detection, and hazard-relative navigation. All this improves our velocimeter and ranging so that we know our position and velocity relative to our target much better, and we can navigate relative to known surface features. All these things at the bottom allow us to shrink our landing ellipse as well as avoid local hazards such as craters, slopes, and rocks, and boulders.

Next, let me talk about plume surface interaction. This is a main challenge for us as we start to land landers more frequently on the surface of the Moon and next to predeployed assets. We're really concerned in three main areas, understanding the plume physics, understanding the site alteration physics or what we're doing the surface as we come down, either in cratering or scouring, and then what are the ejecta dynamics? Where does all that [inaudible 00:07:49] go? How big is it, and at velocity is it traveling when close to our neighbors? We are looking into all of these areas as a main focus for our near-term lunar missions.

Let me turn my attention to Mars for a second. Landing 20 tons on Mars is going to be a major challenge for us, especially the entry, descent, and landing. As you see on this graphic down here, the entry vehicles we've sent to Mars to date have been limited by the size of the launch shroud of the rocket that we launched them in, and so they're restricted to about 4.5 meters in diameter. This limits the amount of hypersonic deceleration we can do because of the thin Mars atmosphere.

With the low masses that we've landed so far, up to one metric ton, we're able to use parachutes or retropropulsion in the way of sky crane or airbags or propulsion under the lander to slow us down and land us softly enough. For humans, we'll need a larger decelerator to take more advantage of the thin Mars atmosphere.

We're talking about decelerators that might be on the order of 16 to 18 meters in diameter, and then we're going to have to turn on our engines a lot sooner in the atmosphere because parachutes will be ineffective at these large scales and for these large masses. And so these large decelerators and the use of supersonic retropropulsion will mean that we have a new EDL paradigm and new systems to certify for landing humans and the payloads, which are going to be up to 20 metric tons.

Diving in a little bit on the supersonic retropropulsion part of this, we're looking to conduct ground testing. Right now, we're conducting some wind tunnel testing in the supersonic regime, and we're doing computational fluid dynamics analysis to see how well our models can predict what we see in the testing. This will help establish the aerodynamic databases that will be used in our end-to-end simulations of these vehicles.

We found though that running our CFD codes on just CPUs is not adequate and won't allow us to do the number and types of analysis we'll need to do to really design these vehicles. We're going to have to convert our codes to GPU base and other architectures to get the throughput we really need to get these systems designed in time for a human Mars mission.

Then, finally, let me talk about the bottom part of that graphic chart I showed you about data return and model improvement. We have a portfolio of projects within STMD called entry systems modeling, and we are tackling all of the most challenging modeling problems within our system capability. We have an area focused on predictive materials modeling from the micro to macro scale, and looking at the robustness and reliability of materials. As I mentioned, for Mars sample return, this is a major challenge of high reliability.

We're looking at guidance, navigation, and control, particularly for hypersonic entry, and then all the way down through the descent portion of the trajector, so the end-to-end performance simulation, and how to make that more efficient, and quantify the uncertainties.

Then we have aerosciences. This is all about understanding the aerodynamics of vehicles and deceleration systems, such as parachutes. Wake flows behind vehicles are a big challenge for us, as well as stability characteristics. We have a lot of testing in ground facilities here as well.

Then shock layer kinetics and radiation applies to really all the destinations, especially those where we're coming in at high entry velocity. What does that shock layer do? What are the constituent products in that shock layer, and how do they react with the materials on the vehicle? Again, lots of modeling and lots of ground testing. So we have many ground test diagnostic needs in these areas, as well as uncertainty quantification needs.

Last, let me give you a snapshot of some of the capability gaps in simple terms that we've established to address all of these challenge areas that I've talked about. We have lunar-focused gaps, Mars-focused gaps, science-mission-focused gaps, and then I made an area called cost-cutting, which really contains all the modeling gaps, and knowledge return, and testing platforms and capabilities that we'll need in the future.

I hope that this has been informative for you and shown you a little bit about the Entry, Descent, and Landing and Precision Landing capabilities, challenges. Thank you.