Kelly (00:00):

Laura Villafañe is an assistant professor in the department of aerospace engineering at UIUC, or the University of Illinois at Urabana-Champaign. Prior to joining UIUC, she was postdoctoral fellow and research associate at the Center for Turbulence Research at Stanford University. She received her PhD from the von Karman Institute for Fluid Dynamics in Belgium in 2014 and her bachelor of science and master of science degrees in aerospace engineering from the Polytechnic University of Madrid, Spain. Her research group focuses on the use of experiments and data analysis tools to gain physical insights into complex turbulent flows, particle-laden flows, and flow-surface interactions, and on the development of new diagnostics to study these complex flows. Today, Laura Villafañe's topic is on dust, a planetary nuisance. You can go whenever you're ready.

Laura Villafañe Roca (01:12):

Thanks so much for the opportunity of being here. As Kelly introduced me, yeah, my name is Laura. I'm a professor at the University of Illinois Urbana-Champaign in their space department. Today, I want to talk to you about dust. Yes, about dust. Not from the point of view of your house or pollen outside. All of that is dust. But the point of view of Mars, the Moon, and space exploration.

Laura Villafañe Roca (01:39):

The picture that you are seeing here is actually a picture taken around June 2018 by Curiosity rover at [inaudible 00:01:51] crater in Mars. You can see that the visibility is quite low. This was in the middle of a dust storm, so it got much worse as this stage passed by. This was actually the dust storm that caused the end of the life, let's say that loss communication with Opportunity, after four years of being rolling in Mars. This type of view, actually, this picture is from Mars, but if you think about it, it could be a picture Texas or New Mexico. You probably experienced dust storm about a month ago, I believe. We have dust storms from Sahara. But actually, the view is not that different that you could see also when there are shoot grains from fires, like in the wildfires of California, or as from a volcanic eruption. You can see also a similar, similar picture.

Laura Villafañe Roca (02:44):

They also lead to same reduced visibility, and we actually call all those dust clouds. So, indeed, not all that we call dust is made of the same stuff, but it serves one characteristic, and is that it's tiny. It's small enough to be lifted and move around. With that general definition, dust is also aerosols, it's also pollen, tiny grains of ice. Dust fills our galaxies. It's what we see when we look to the Milky Way, actually. If you are thinking about cleaning the dust out on the universe, forget about it, that's not a possible task.

Laura Villafañe Roca (03:26):

Actually, tons of space dust are raining down on Earth every day alone. So, no, we cannot get rid of that. We have to learn how to live with it. Yet, to most of us, especially for planetary explorations, it's a real nuisance. If I show you here some pictures, in the top left, you can see a picture of, this one was Opportunity, I believe. Yes, it was Opportunity, with the panels completely clogged with dust, almost indistinguishable for the background. In the central one, this is actually a dust selfie of Curiosity around before the time of the 2018 dust storm, at the beginning of it. The right figure is actually something very different. Comes from the Moon. What you're seeing here is dust being lifted from the surface, being sped up very high velocity from the surface, as one of the Apollo missions, this was from the Apollo 15, was landing. That's another type of challenge that is not the visibility and the coating of the panels.

Laura Villafañe Roca (04:39):

Can all this be avoided? Well, difficult, but let me step one step back and see how do we get there. That's very different from the case of Mars and on the Moon. The Moon has about a sixth of the gravity of Earth, and it's a quarter of the size. It actually also doesn't have an atmosphere, so we do not really powerful heat shield and parachute to land in there. With retrorockets is sufficient. This is a picture of the Apollo 11 lander. You are seeing their [inaudible 00:05:16] in 1969. This is how we got to the surface. Those are the pictures that you saw belong actually from a view of the Apollo landing.

Laura Villafañe Roca (05:25):

Now, the case in Mars is very different because Mars does have an atmosphere. We enter at much higher velocity, and the descent phase is what we know as the entry, descent, and landing, or, for Mars, the seven [inaudible 00:05:42] of terror. It starts with the separation from the cruise states. Following an atmospheric re-entry, that starts at about 12,500 miles per hour. At this velocity, the atmosphere drastically slows down by drag the reentry capsule, but at the expense of very high temperatures. So we need to do research on a heat shield that is able to sustain those high temperatures. Then, after this, we detach a parachute. Is a supersonic parachute that farther decelerates the capsule down to the last phase of the descent, which is a powered descent. Dust is lifted on the last phase.

Laura Villafañe Roca (06:27):

Now, before getting to that, let me tell you bit about parachutes because it's also something we are working on in here, at UIUC. It's quite, quite crucial, not only for landing on Mars, for the Moon we don't need them, but actually the heat shield, the dynamic heating, and parachute shares common characteristics with how we will reenter, how do we reenter on Earth. The parachute inflation and dynamic descent is actually one of the least understood problems in entry, descent, and landing. The current approach is experimental. Is actually very costly and prone to large uncertainties, and we do really need good models and good numerical methods to be able to predict what is going to happen with our parachutes.

Laura Villafañe Roca (07:14):

Now, there are many factors that enter in here. Parachutes are porous materials, they are subject to very high loads that can tear the parachutes, and all of this enters into the difficulty of designing parachute. In the top left, you can actually see a picture of a test, a flight drop test, in which one of those para is completely teared down. In the bottom, you see a picture of the Mars [inaudible 00:07:44] parachute actually be tested on the largest wind tunnel on Earth, at NASA Ames. The top right picture corresponds to the parachutes that actually the Apollo capsule used to reenter before the splash-down on the ocean. As you see, one of them failed, actually, but it was sufficiently robust that they landed with two parachute.

Laura Villafañe Roca (08:07):

So we need to actually add a lot of safety on the design of these parachutes. Here, you have a sketch of what the nominal design for ORION parachute system to be launched in the future. It will be consist actually on 11 parachutes. Different [inaudible 00:08:23] decelerate to different amount.

Laura Villafañe Roca (08:24):

Let's come back now here to our main issue of dust. The last phase of the descent after we get rid of the parachute is a powered descent. There are retrorockets in there, and approach the rover up to a altitude of around 20 meters, which is about 66 feet. From there, what we do in Mars, actually, is to use a sky crane. We use cables to deposit the launcher. The [inaudible 00:08:56] rockets do not approach more the surface than this 20 meters, and then we descend the rover to the surface of Mars with a crane, until, at which point, when there is contact, there is a flyaway. So the cables are cut, and the capsule flies far away not to intercede with the rover.

Laura Villafañe Roca (09:15):

Probably, you have seen this video. If you didn't, [inaudible 00:09:18] here.

Speaker 3 (09:18):

Ground speed is about 38 meters per second, [inaudible 00:09:22] speed of about 300 meters.

Laura Villafañe Roca (09:23):

You're seeing cameras at the bottom of the rover.

Speaker 3 (09:28):

We started at a constant velocity [inaudible 00:09:31], which means we are about to conduct the sky crane maneuver.

Laura Villafañe Roca (09:36):

All of dust. Now you see the pictures in the left from the bottom of the sky crane.

Speaker 3 (09:43):

[inaudible 00:09:43]. About 20 meters off the surface.

Laura Villafañe Roca (09:44):

Look to the dust, the amount of dust that is lifted around in here.

Speaker 4 (09:51):

We're getting signals from MRL. Tango, delta.

Speaker 3 (09:55):

Catch-on confirmed.

Laura Villafañe Roca (09:57):

Okay. So this was a messy, very successful, and actually very smooth landing, but the dust cloud that is around does not go unnoticed. The dust was lifted by the retrorockets even though they stayed at about 66 feet from the floor. What the rockets have to sustain is actually the weight of the spacecraft, the weight of the rover. You have to realize also that the gravity in Mars is lower than the gravity on Earth. That means that this rover was about 100 kilograms. The weight of this rover on Mars was about the fourth of what will be the weight on Earth. That's the power that the Earth rockets needs to do the descent.

Laura Villafañe Roca (10:48):

If this mission was to carry humans, now the weight will be much higher, the mission will be much larger, and we will have even a much larger problem with dust being lifted. Actually, if you think about how do we approach the landing to the Moon just with a retrorocket that gets to the surface, what we believe will happen in a Mars environment is that we will be digging a crater, a hole, under this exhaust rocket that [inaudible 00:11:15] deep into the soil.

Laura Villafañe Roca (11:16):

There are many different characteristics be between landing in the Moon and landing in Mars. The reason for those difference are actually twofold. One is that the atmosphere is very different, so how the dust behaves is very different. The second is that the characteristics of the dust in the Mars and in Moon are also very different. If we go forward to what happened in the first image we saw today, the image that we saw at beginning from the Apollo, the video I'm going to play in here belongs to the Apollo 15. Very similar images were obtained for all the Apollo landings. Remember, all those landings happened between the '69 and the '72. Since then, we have not been back. A human has not been back on the Moon. And there were, at that time, between those three years, actually 12 astronauts that really walked on the Moon.

Laura Villafañe Roca (12:10):

As I already mentioned, because of the low gravity and the fact that there is no atmosphere, we don't need a heat shield or we don't need parachutes. For comparison, in this case, the vehicle dry mass without the propellant and the oxidizer was about 2,000 kilograms, so twice than the Perseverance rover. But, if we compare the gravity of the Moon with the gravity of Mars, is even lower. So the weight is actually lower. That is in our favor. The weight on the Moon is about a sixth of that on Earth, and if you compare it with Mars, a bit less than half to that of Mars. So for equal kilograms of load, actually, in the Moon, you need less thrust from the nozzle to approach to descent.

Laura Villafañe Roca (12:59):

I'm going to now play the video [inaudible 00:13:04] here. You're going to see that you first have a clear view of the surface.

Speaker 8 (13:12):

[inaudible 00:13:12] three.

Laura Villafañe Roca (13:15):

In around 70 feet, you will start losing visibility.

Speaker 3 (13:17):

53. Trap pointers look good. 43.

Laura Villafañe Roca (13:22):

We have streaks in there, particles flying away at very high velocities.

Speaker 3 (13:26):

33.

Laura Villafañe Roca (13:27):
Modification of the terrain, all those phases are going on in here.

Speaker 3 (13:30):
7% fuel. 20 and one.

Laura Villafañe Roca (13:38):
[inaudible 00:13:38] lower.

Speaker 3 (13:38):
15 and one. Minus one. Minus one. 6% fuel. 10 feet minus one.

Laura Villafañe Roca (13:52):
[inaudible 00:13:52] reason.

Speaker 3 (13:52):
Contact.

Laura Villafañe Roca (13:52):
Okay.

Speaker 3 (13:59):
Okay, Houston. The falcon is on the plain at Hadley.

Laura Villafañe Roca (14:03):
We made it. As you see, actually, on the image on the left, there is no crater that has been formed under the nozzle. As I mentioned, that is expected in Mars. The loose gravel is actually swept away by exposing layers of more compacted terrain, but there is no deep hole that we are making. Why? Because of the reasons that I mentioned before: atmosphere, how the dust travels away, but, very importantly, the properties of the soil. The soil or [inaudible 00:14:37] in the Mars and Moon are extremely different. In Mars, dust is looser, [inaudible 00:14:42], more eroded. It's actually similar to what people think about the Earth dust. It's sorted. It's fine particles on top. However, in the Moon, the soil is [inaudible 00:14:55], it's way more regular, and it's more compacted.

Laura Villafañe Roca (14:58):
Why is that? Is because the Moon does not have an atmosphere, so its exposed to the thermal cycles of the galaxy. So it's actually been exposed to micrometeoroid bombardment and direct sunlight through billions of years. Let's say, in the Mars, the soil is protected by this atmosphere. Same thing as happens on Earth.

Laura Villafañe Roca (15:20):

With these two main difference, actually approaching with a retrorocket in Mars and in the Moon is totally, completely different. We know very little about it, to say the truth. So you might still be wondering, "Okay, very nice, very phenomenological, but what is the big deal with dusting?" Yeah. One problem, there are many concerns. One problem that we might arrive to is visibility. Dust is the number one concern that we have right now in returning safely to the Moon. This was said by Apollo 16 astronaut John Young, but it was actually shared by all the crew that travel during those years to the Moon.

Laura Villafañe Roca (16:03):

From the landing perspective, you have this sheet of soil blown away during the landing. It's so thick that it blocks the view of the boulders of craters. At the end, what you're doing is landing blind. Naturally, here, you can see a picture of the Apollo 15. Apollo 15 landed at about 12 degrees, 11 point something. It was actually very close to the design limit. A bit more and the astronauts could not have descended from the lander and could have not launched back again to Earth. So it was a very lot of luck, what happened in Apollo 15 landing.

Laura Villafañe Roca (16:44):

The amount of soil that is expelled is actually not the same. Depends where you are landing, which part of the Moon. Not all of them have the same amount of loose [inaudible 00:16:53] on top of that. Particularly bad was the situation for the Apollo 12, actually. Commander Pete Conrad reported in Apollo 12 that 300 feet, not 70, as mentioned before, there was a tremendous amount of dust. They couldn't really see anything, so they prayed that they were not landing on top of a rock or a crater. Actually, the dust expelled is not only a problem of the Moon. Is of Mars. It behaves totally different. There is much more [inaudible 00:17:26] around the vehicle on Mars, but it's the same. Here, you can actually see a picture of the inside camera lens after it remove the cover. It's totally full with clumps of dust.

Laura Villafañe Roca (17:41):

What other problem we have? We have the problem of ejecta. This ejecta that we are expelling out as we are landing is composed of fine and not-so-fine particles. It might even lift rocks. Whatever is on the surface is expelled out, and it's ejected at actually a very high speed, hypersonic speed. In the Moon, because of the lack of atmosphere and the lack of rock, actually, the fine particles get higher speed and reach farther away. Some of these particles shown in this picture, this simulation, can actually reach to orbit. Bad luck if you have an orbiter around the Moon at the wrong time, in the wrong place. You will be sandblasting it with particles that have been ejected during landing.

Laura Villafañe Roca (18:26):

The picture that we see in the right is actually something that was [inaudible 00:18:30] proposed. The image that you're seeing is the Surveyor 3. The far field vehicle that is in there is actually the Apollo 12 Lunar Module. It landed on purpose about 116 meters away from the Surveyor 3. It was done to actually check what is the effect of sandblasting while you are landing. They went there, they cut pieces of the Surveyor 3, and they took them back to Earth to review them in the laboratory.

Laura Villafañe Roca (19:02):

This is a picture of a portion cut out of the Surveyor 3. It was found that it was cracked, it was full of little holes. It actually even had lunar [inaudible 00:19:15] inserted into the cracks that was created on that.

So it was seriously damaged. This is actually particularly bad if you think about going and traveling often to the Moon. If you want to do a lunar outpost, because of repeatedly landing nearby, will cumulatively degraded and sandblast everything that you have on the surface.

Laura Villafañe Roca (19:36):

Another problem is cratering or erosion. There is actually very much affected by the soil properties, as we mentioned. In the Moon and in Mars, it's something completely different. How do we study this? We cannot just do this in situ in Mars or in the Moon, we have to do it on Earth. There are many parameters that cannot be replicated. For example, any test on Earth will never get rid of the gravitational field that we have here. So we'll never be able to simulate... I should not say never be able to. We're very creative in here, but normal test, we do not do reduced gravity,

Laura Villafañe Roca (20:16):

Here, you will see two pictures of what the NASA researchers actually usually do. They do experiments on Earth in ambient conditions, like the image in the right, or in the vacuum chamber, which is the image on the left, but they are done usually in [inaudible 00:20:35] experiments. What is that? Is that you put, at the central plane of your nozzle, you put clear Plexiglas or glass window so that you see the central part of the crater. It's not exactly the same thing, but it allows you to see the penetration.

Laura Villafañe Roca (20:51):

The problem is that the phenomena that is happening while the crater is being formed, it's very dynamic. You are [inaudible 00:21:01] air, digging a hole. The crater might collapse. Think about when you are digging on a sand, On the wet sand, on a dry sand, it's not going to be the same. You have crater collapsing through [inaudible 00:21:15] of the grains. On the bottom, everything's happening during the process. Actually, erosion is one of the least understood processes for landers. We know very little about these dynamics.

Laura Villafañe Roca (21:29):

Let me tell you a bit about what we are doing here at UIUC to study these problems. We are actually funded by NASA. We are actually studying plume surface interactions in the lab, in a small vacuum chamber. You can see a picture of the vacuum chamber there in the bottom, in the left. We have modified the front door to have very good visibility. For now, we are attempting to visualize, since we have a very wide field of viewing here, with cameras in different positions, we are trying to visualize what happens 360 degrees without modifying the dynamics of erosion and the cratering.

Laura Villafañe Roca (22:06):

You can see in the right picture in the bottom that we have our nozzle in there. All the [inaudible 00:22:13] is scaled down. We have our thruster that really replicates the Mach number and the conditions of a real thruster. Here, you have a transparent Plexiglas box, which is empty right now, but is the one that we filled with particles. What we are actually doing in here, what we are already doing, is actually studying the effect of these supersonic jet engine on a bed of particles that we can change. Can be less particles, can be lunar simulant, can be sand. How are the different types of cratering under different atmospheres and different conditions, and which is the velocity that the particle reach, and actually improve a lot of diagnostics that we have to visualize this problem. Optical accessibility is one of the issues.

Laura Villafañe Roca (22:59):

Let me show you. I mentioned that the crater, the [inaudible 00:23:02], was much more concentrated and collimated on Mars. That's why it penetrates farther, and on the Moon, it opens much more. That's what you can see actually in these two images here on the left. The left picture is [inaudible 00:23:16] actually a flow visualization. If you think of a supersonic jet, same Mach number, same everything, but at the lunar pressure, which is around 100,000 times more than in Earth, that on Mars on the right, which is 100 times larger than in the Moon, let's say. If I play this video, you see what happens in our vacuum chamber. This is for Mars conditions. This is very slow motion video. All of this happens within eight milliseconds. You have this wide explosion of particles covering all the field of view.

Laura Villafañe Roca (23:57):

Another problem with dust, let me pick up here a bit, is that it gets everywhere. It's very adhesive. It's actually electrostatically charged, and this is the same in Mars and in the Moon. What Apollo 15 astronauts actually observed is that, as soon as you're out there, dust covers you completely. When they were trying to clean themselves to return to the Lunar Module, it was really not possible to remove all this debris. You can see here in these pictures how the spacesuit of an Apollo 16 astronaut is when he's already inside the Lunar Module and has done the cleaning. It's full of this gray matter. This actually is very toxic too, so inhalation is a real problem. This dust is extremely sharp and glassy-like due to the environment it's exposed to, so it's actually clanking into all terms of instruments and causing instruments to fail, into the wheels of the rovers, into everything. It's actually a very difficult problem to deal with. It actually also covers solar panels, so, as we have seen, is a concern for surviving long times relying on solar panels.

Laura Villafañe Roca (25:16):

Let me change a bit quickly, something about global dust storms and dust evils. Dust is lifted from the ground when we landed. That's the first time it is; everything starts there. We actually cover our rovers with dust as soon as we start approaching the surface. But then, over the time, there are other phenomenon that bring dust on our surfaces. The first is global dust storms. You are seeing there a picture in the left of a changing sol. A sol is actually approximately the same duration of a day here on Earth. You see that visibility goes very, very, very worse and worse as days progress. Global dust storms, as said before, happen on Earth. This is a picture of a Sahara sandstorm traveling to the US in here. We have actually also dust evils. You can see a dust devil here in the bottom picture. Dusts events are not actually bad. In events, there are soft winds, and they have removed the dust from the solar panels of rovers. They can also deposit dust.

Laura Villafañe Roca (26:33):

This just came out 18 hours ago, something like that, so I couldn't refrain from showing it in here. Ingenuity did its first flight on Monday, as you probably know. Did it lift dust? Yes, it did. Here, there is an [inaudible 00:26:50]. In the left, you see an [inaudible 00:26:51] picture. It's very difficult to see on the real picture on the right, on the real video on the right. On the left, you have seen the dust announce by obstructing images. You can see that, when it lifted, there was some dust. It touches bottom but goes on again. You will see another dust cloud being lifted. There it goes, down. So yeah, everything generates dust.

Laura Villafañe Roca (27:23):

Very quickly, dust is everywhere. Yes, it's also on Earth. Actually, very similar images of the mini robot, mini helicopter, Ingenuity flying. It's what we see on a helicopter in Earth. This is a dusty helicopter. This is a problem for military aircraft operating in sand regions. We have dust on fires, combustion. We have dust in volcanic eruptions, on engines. Dust is actually sometimes used on our benefit. For instance, dust in here will be small [inaudible 00:27:59] fuel that we ignite in a combustion system.

Laura Villafañe Roca (28:02):

So we're studying all these sorts of dust and interaction of [inaudible 00:28:08] dust with fluids to understand how they behave at UIUC. Also, in this very long facility that is in here, which is actually the longest of this kind in the US, it's as long as a four-story building. So, if you've been in UIUC campus, this is the Talbot Building. It's as tall as the building.

Laura Villafañe Roca (28:28):

Not everything is bad. Dust also leave us very beautiful images. What you're seeing in here is a sunset in Mars. This is a blue sunset. Sunsets on Earth, when there is dust on the air, are red. Sunsets on Mars are actually blue. This fine dust is actually of the right side to scatter the blue light in the direction of the sunlight, so it actually appears to human eye blue. Also, [inaudible 00:29:00], this is the team that makes all this interesting research possible, and I have to mention that all the image credits for this presentations were directly taken from the NASA website and the GPL. If you are curious about it, there are thousands of very interesting pictures out there. Thank you, and if you have any question, I'll answer it happily.

Kelly (29:22):

Yes. As she said, if you do have any questions, unmute yourselves now, or submit your questions into the chat. Thank you so much for your presentation.

Heidi (29:31):

I actually have a question. This is Heidi from, from Illinois Space Grant. I was wondering if they are concerned about Mars dust being similar to the Moon dust with the fragments and of course all the problems it can cause and things. Do they think it's very similar? I guess that's what I wanted to know, is do they think it's very similar to that and going to cause a lot of the same issues.

Laura Villafañe Roca (29:57):

That's a really good question. It's not super known. We don't have yet in our power Mars dust. Right?

Heidi (30:04):

Right.

Laura Villafañe Roca (30:04):

We have Moon dust but not Mars dust, but there are certain characteristics that make it very different. One that is very important. Both of them are electrostatically charged and, because of that, they are there everywhere. That's going to be a problem. Now, moon dust is very sharpy and is very abrasive. It destroys space suits, it destroys everything. Durability out in the Moon environment, due to the characteristics of the particles, is very low. On the other hand, Mars dust, in a sense, is a bit more benign. It's eroded, is more grain, more loose. So it's not abrasive. Both of them are toxic. Lunar dust is more toxic than Mars dust due to the composition. Mars dust is mostly ferrous iron at the end of the day, while Moon dust contains [inaudible 00:31:05] that are really poisonous. It's innate.

Laura Villafañe Roca (31:08):

So there are similarities and differences. The fact that it is accelerated at high velocity and it becomes like a bullet is a problem in any environment. Yeah. We can learn something, but we cannot extrapolate results totally from one atmosphere to the other one.

Heidi (31:28):

Thank you.

Kelly (31:30):

[inaudible 00:31:30] as well. You mentioned the vacuum chambers on the lunar [inaudible 00:31:34] and dust. Are the experiments in the vacuum chamber strictly for visibility, or are they using different items, like the space suit? Are they testing dust effects on those?

Laura Villafañe Roca (31:49):

NASA is doing all sorts of testings with that. So, yes, the vacuum chambers is actually to reproduce the pressures. On the Moon, the pressure is about a 100,000 times lower. So a jet behaves very, very different than it does on Earth. On Mars's, it's about 800 pascals, so it's about 1,000 times smaller. So behaves, also, again, differently. The dynamics, anything that has to do with the dynamics of particles and of the jet need to be tested on a vacuum chamber. Erosion too.

Laura Villafañe Roca (32:29):

Now, the resistance of a spacesuit, the rover components, and the instrument to vacuum, those are also things that are tested in vacuum chambers. But that's relatively easier. We have that more under control because, for other applications, we do many tests on Earth, on vacuum. So it's not such a problem. The vacuum environment, just resistance to vacuum, let's say, for suits and components. It's more of the problem, actually, of the [inaudible 00:32:57] to very, very low temperatures and very, very high temperatures that poses a challenge for that.