Teresa Gomez (00:14):

Dr. William Schonberg is a professor in the Civil Architectural and Environmental Engineering Department at the Missouri University of Science and Technology. Dr. Schonberg is a registered professional engineer in the states of Missouri and Alabama, and has over 30 years of teaching and research experience in the areas of shock physics, spacecraft protection, hypervelocity impact and penetration mechanics. He received his bachelor of science in chemical engineering from the Princeton University in 1981, and his master's and doctorate degrees from Northwestern University in 1983 and 1986 respectively.

Teresa Gomez (00:53):

The results of his research have been applied to a wide variety of engineering problems, including the development of orbital debris protection systems for spacecraft in low Earth orbit, insight to resource utilization for lunar habitats, kinetic energy weapons, the collapse of buildings under explosive loads, insensitive munitions, and aging aircrafts.

Teresa Gomez (01:18):

Today, Dr. Schonberg's talk is about space debris.

Dr. William Schonberg (01:22):

Okay. Sounds good. Well, thank you for the kind introduction. I appreciate everybody being here. Yes, we're going to talk about stuff in space. I'm a simple kind of guy here. I look at stuff sometimes, maybe, as either being useful or not useful. So when it comes to stuff in orbit, we have useful stuff and we have not so useful stuff. Useful stuff are satellites that still work. The not so useful, that's the space junk. We're going to talk a little bit about useful stuff to set the stage, and then we'll talk about the not useful stuff.

Dr. William Schonberg (01:56):

So I'm a professor. I imagine my audience here is primarily students. You love pop quizzes, when your faculty come into the classroom and they give you a pop quiz. So here we go. Ready? What was the first Earth-orbiting satellite? Tick, tick, tick, tick. Okay, you got your answers in your head? Okay.

Dr. William Schonberg (02:18):

Who said the moon? If you said the moon, go to the top of the line. No, I'm just kidding, you get 1,000 points for whatever good those are. But that was kind of a tricky question. I didn't say man-made satellite, human-made satellite. I just said satellite. Of course, the first human-made satellite was Sputnik. Those of you who said Sputnik, yeah, yeah, yeah, that's fine. No problem. It was put up by the Russians. Shortly thereafter, the Americans put up the Explorer satellite. After that, it's just been open season on launching satellites for various reasons.

Dr. William Schonberg (02:53):

From this chart, if you do your numbers right you can probably see that about two thirds of the satellites that are up there have to do with communication as their main function, that means military, commercial, government, whatever. There's some science going on. There's some weather going on. There's some spying going on. But most of the satellites that are up there are basically what allow you to order pizza or to text your friend. That's what the satellites are up there for. That's what most of them do.

Dr. William Schonberg (03:28):

And this was fine, until about 10 years ago. A bunch of countries launched satellites and there were a few thousand satellites up there maybe. But about 10 years ago, along came New Kids on the Block. For those of you who are staring at this image and going, "What is this?" I understand. You're not old. For those of you who know who this is then, yeah, you're old.

Dr. William Schonberg (03:52):

But anyway. No. I mean, 10 years ago saw the birth of satellite. And a friend of mine said, "Don't call them mega constellations because they're not putting a million satellites up there" But large satellite constellations; many companies, for various reasons, putting up thousands of satellites. If you've been following SpaceX and Starlink, I think the latest statistic is SpaceX owns about a third of the stuff that's up there. So that's pretty amazing, when you think about it.

Dr. William Schonberg (04:23):

And these numbers, these plans, this is the original plans. I think I need to hire someone just to update this slide for me every other day because these numbers are changing. But if you do the math real quick here, you'll see that various companies ... and I think one of them already went bankrupt so that's probably not going to happen. But I think they're being bought out now ... we're talking 30,000, 40,000, 50,000 satellites in Earth orbit in the next five to 10 years. Which, if you work in the satellite business, if you work in the space business, whether you're an astronomer or a space technology user, it's scary.

Dr. William Schonberg (05:00):

I understand large satellite constellations have their use and their purpose; it brings the internet to where none exists, it's good with better disaster management because different satellites have different kinds of sensors ... eyes, as we call them ... and they can hear different things, see different things. But there is the serious consideration and concern that there's about a 3 to 5% failure rate on Starlink right now.

Dr. William Schonberg (05:25):

If you do the math and multiplied the mass of each satellite and number of satellites that might fail, if the failure rate is 3 to 5%, you are putting a lot of useless junk in space. In addition to all the 95% stuff that works, there's 3 to 5% stuff that can't communicate, can't deorbit. It's just going to sit up there for a little while. If you're an astronomer, you're going to be really worried about the fact that these things are going to come across your telescope, radio or visual telescope, and mess up your hours and months of preparation. So there is serious concern that the not so useful stuff, the orbital debris, is going to mess things up for a lot of people.

Dr. William Schonberg (06:07):

Why do we have space debris? We have space debris because we've been living, working, playing, in outer space for our over 60 years now. We've launched about 9,000 satellites, and about 3,000 of them, roughly, are still active.

Dr. William Schonberg (06:23):

So where did these other 6,000 satellites go? Some of them are still out there. Some of them have pieces from them still out there. Some of them have been brought down to Earth. But for the most part, they've hit things, they've corroded, they've exploded, atomic oxygen erosion, degradation, unspent fuel, collisions; that instead of being gentle nudges become full-blown conflagration events. I guess, part of living and working in outer space, we leave a little trace of ourselves behind us, no matter where we go or what we do. So space is no different. There is rocket boosters, there's breakup fragments, mission-related debris. There aren't any softballs up there, but I put this baseball up there and this marble on the image, and this grain of sand on the image, between the two fingers, or this pebble, so that you can see the relative scale, that there are things up there that are the size of sand grains but there are also things up there the size of school buses, and everything in-between.

Dr. William Schonberg (07:34):

This is a chart that shows the growth of the debris population. LEO, low Earth orbit, is where the bulk of the debris is. If you look at this, you'll see distinct jumps. That's when you've had either deliberate anti-satellite tests by countries that should have known better, or you have accidental collisions by a defunct satellite with a live satellite.

Dr. William Schonberg (08:05):

When I started in this business in the 1990s, we were right around 6,000 to 8,000. And we thought, "Oh, well ... then in the mid '90s and early 2000s, it was kind of flat ... "It's probably not going to go above 8,000." And then bad things happened. So here we are, we're upwards of 14,000, 15,000, 16,000 pieces of objects in Earth orbit. That's a lot of stuff.

Dr. William Schonberg (08:33):

What can happen if something from Earth orbit hits you? Well, if it's small it could ruin your telescope or it could put a hole in your space suit and kill you. Or it could maybe do nothing, if you're in a big module. If you get hit by something the size of a softball or a baseball, no matter who you are or where you are or what you're doing, it's a bad day. So a lot of what happens to you depends on what hits you. So if you're up there doing a space walk, an EVA, something the size of a grain of sand can penetrate, can puncture, your space suit, which would also be a really bad day.

Dr. William Schonberg (09:15):

What do we do to protect our spacecraft? Well, it depends on what's in there. If it's a satellite in geosynch, then there's not that much debris up there so we're probably not going to put a lot of protection on it. If it's the International Space Station, where our friends, colleagues, relatives, parents, uncles, aunts, nieces, nephews, are up there, then we're going to want to protect that as much as we possibly can.

Dr. William Schonberg (09:42):

How do we protect that? Well, there's three different basic schools of thought, philosophies of protection. Active protection ... the name Buck Rogers comes to mind ... you blast the heck out of it as you see it. If you've been paying attention to the problems of space debris and how space debris happens, you could probably figure out: what is the problem with blasting something out of your way?

Dr. William Schonberg (10:07):

So for the most part, we've done what are called spacecraft avoidance maneuvers. This chart illustrates, for example, how often the Space Station has had to make avoidance maneuvers. And the orange is a year by year histogram of those maneuvers. And they range anywhere from five in one year, in 2014. 2005, 2006, 2007, they didn't have to do any. But in 2010 to 2015 they did about 10 avoidance maneuvers. So they were warned. They traveled with a shoebox around themselves, so to speak. And if there's a debris whose path is going to cross within that shoebox then they have to make an avoidance maneuver.

Dr. William Schonberg (10:56):

Operational procedure is sort of the middle ground. You can get out of the way of something if you can see it, you can protect yourself against it if you can't. But if there's there's stuff in there in-between, that you can't really see but it's big enough that if it hits you it can cause really big damage ... and if it's too big to protect against, because then you'll never launch ... operational protection means flying with the engines, of what used to be the space shuttle, forward, in the ram direction. Protect the valuable cargo, expose the heat shield, if now, they're outer space, unless needed. So it's basically working smart, living smart, in outer space.

Dr. William Schonberg (11:37):

Passive protection is kind of like the bumper on your car, it's kind of like insurance. You don't need a bumper until you need a bumper. You don't need your insurance until you need your insurance. But you carry it around with you every single day just in case you might need it. So a bumper is basically a piece of material, a wall that's put in front of this spacecraft to protect it, to make sure that if something hits it it will disintegrate it, and what eventually travels in towards the spacecraft is diffuse enough so that it's not going to do a lot of damage.

Dr. William Schonberg (12:08):

How do we protect the Space Station? Here are all the hotspots on the Space Station. And these are all the parts of the Space Station that have the most shielding because they're the ones that are facing the ram direction as the Space Station travels. So these are the really shielded elements.

Dr. William Schonberg (12:24):

Does the Space Station get hit? All the time. Is there damage? Everywhere. Yeah. Everywhere. Is the damage severe? Thankfully, not yet. But there are little holes. There are pings. There are dings. There is damage to the stuff that's on the Space Station.

Dr. William Schonberg (12:46):

Sometimes we identify parts of the Space Station that are weak, in terms of protection, they give rise to a large probability of possible damage. So we enhance those shields. And those gray squares that you see there are shield enhancements that were put on a Russian module to increase the protection of that particularly sensitive area.

Dr. William Schonberg (13:08):

So that gives you an introduction into what space debris is all about. Some recent studies that I've been involved in ... I just thought I'd touch on a couple of things here that we worked on to give you a sense of what's cooking in the space debris world ... one of the studies looked at whether or not a composite overwrapped pressure vessel will just have a hole in it after rupture, or could it possibly explode? Conventional wisdom says, "Oh, once you get a hole in, it's going to explode." That was the wisdom that was currently used in the design process. We found that that is not the case.

Dr. William Schonberg (13:46):

The work was funded by NASA, lots of different folks, lots of different agencies being involved. The idea was that you have, in every spacecraft, whether it's robotic or human, pressurized vessels; whether they are fuel tanks, whether they are living quarters. Either way, you have to protect your spacecraft against possible damage due to space debris. We've been looking at thousands and thousands of test shots against flat unpressurized plates but, because it is scary, very few tests against highly pressurized metallic or composite overwrapped pressure vessels.

Dr. William Schonberg (14:23):

So we decided to work to see if we could rectify that problem. Here is an example of an early drawing, an early sketch of a JPSS satellite, where that black dome in the middle, that was a composite overwrapped pressure vessel fuel tank exposed to outer space. So it was right out there, ready to get hit. Now they buried it and covered it and wrapped it ever since the design, and will continue. But until you think about it, you don't know that this is a possibility.

Dr. William Schonberg (14:57):

So to understand what we mean by rupture, as opposed to a small hole or crack: here's a tank. And I've put a little gray dot in where the hole is. You can see it on the left if you look real close, if you need to ... It's basically a hole. That's a small hole. This is a rupture. Under the right impact conditions this thing will explode into many pieces. So this is what we wanted to be able to predict: when it would happen. So we developed an equation that would be able to, without being too convoluted, thread in-between regions of rupture and regions of non-rupture, depending on the operating conditions and the impact conditions.

Dr. William Schonberg (15:45):

So this is what we got, which you kind of need a magnifying glass to see what's going on in there. But basically, in the closeup, all the orange are ruptures, all the greens and blues are non-ruptures. And this is what we wanted, we wanted to come up with a line, the black line ... the dash lines are the plus minus one, plus minus two signal lines ... but we wanted a line that would go right in-between all the rupture and non-rupture points. And we were able to manipulate the data, be clever about how we nondimensionalize things, and come up with an equation. The data floated for a while, but eventually then separated out and we were able to draw a line right in-between the data.

Dr. William Schonberg (16:30):

The next topic that's a hot topic right now is passivation of spacecraft, and especially spacecraft pressure vessels. Again, thanks to the NASA Safety Center for providing the support. Basically, all spacefaring nations' agencies have requirements to make sure that your spacecraft ... if you're going to build a spacecraft and launch a spacecraft, you have to prove, certify, confirm, that your spacecraft will not create more debris. And what that means is ... the phrase is stored energy devices. It doesn't just have to be batteries. It doesn't have to be fuel tanks ... but all stored energy devices have to be passivated at the end of this spacecraft's mission or useful life, or whatever.

Dr. William Schonberg (17:20):

Not everybody can do that. That costs money. That's the reality. The engineering is there. The physics is there. We know how to do this. But to actually do it is a bit of an effort. So what spacecraft designers do is they file for waivers with NASA. They say, "Yeah, we're not going to be able to do what's called a full passivation or a hard passivation, but we're pretty sure that the odds of bad things happening are really, really small." So NASA ends up either asking them to go revisit their calculations, fix these calculations, or grant a waiver.

Dr. William Schonberg (18:07):

This is the NASA standard that addresses passivation, which basically consists of two parts ... these are the rules ... you have to make sure that all sources are depleted, all energy sources disconnected when they're no longer required. Which is pretty harsh, because those of you who are involved in spacecraft design probably are thinking to yourselves, "Well, wait a minute, most spacecraft design is written to the effect that I have to show that there's a 99.95% probability of things not happening." That language is not here. The language here is all, all; everything has to be passivated. Which is a very odd requirement.

Dr. William Schonberg (18:51):

And then if you can't do that, then you have to show: this is a possibility that's true, that whatever is left cannot cause an explosion large enough to release debris. Not won't cause, to a certainty of 99%, but cannot cause. This is an absolute requirement. If you cannot meet either part one or part two, strictly speaking, you shouldn't launch. But waivers are given, launches take place; based on experience, based on analysis. We decided then, to come up with a process that would help with that analysis process.

Dr. William Schonberg (19:27):

What if you were able to calculate how many rupture-causing projectiles you might encounter at the end of your lifetime? And then you can say, "Well, that number is big. That number is small." The smaller that number is, the more sure you are that your spacecraft won't result in a problem. And the process is actually pretty straightforward, but it was fun to work on this and get it all together.

Dr. William Schonberg (19:53):

Given where your spacecraft is, what's the angle of impact that you're most likely to see? That's step number one.

Dr. William Schonberg (20:03):

Step number two is: okay, at that angle and velocity, what's the diameter of the particle that's going to cause your tank to rupture?

Dr. William Schonberg (20:16):

Next question, step three: how many of those rupturing particles are you going to expect to see in the remaining 25 years of your passivated lifespan? Well, first you calculate flux per meter squared per year, and then you calculate the total number. And then, bottom line, you look at the total number. Is it a big number? Is it a small number?

Dr. William Schonberg (20:38):

We looked at two satellites, two different pressure tanks. For both of these satellites, the orbital debris environment predicted about 15 kilometer per second impact, straight on. So given these tanks and their configurations, what sizes of projectiles will cause rupture?

Dr. William Schonberg (21:00):

So this is another rupture limit equation that I developed for metallic tanks in these particular cases. So you can use this equation to calculate the size of the particle that will cause a rupture.

Dr. William Schonberg (21:14):

Next question: how many of these particles are going to be out there? Should we be [inaudible 00:21:19] about that? In those orbits, how many of these particles are going to be out there?

Dr. William Schonberg (21:23):

So for these two satellites, you find out that the flux is really, really small, per meter squared of exposed surface area per year. And when you roughly guesstimate the meter squared and multiply by 25 years, you find that the number of particles, over 25 years, that's going to hit the tank, that's going to cause it to rupture, is really, really, really, really, really, really small.

Dr. William Schonberg (21:46):

So this kind of calculation is meant to increase confidence in your ability, in your statement, in your claim, that even though you may not be able to fully passivate and totally satisfy the requirement, however, that your calculations show that: look, even if we get hit by something that's going to rupture this, look at the odds of that ever happening. How many particles? I would need to be out there 25,000 years before I would see three particles. So I would see my first particle in 8,000 years, probabilistically speaking, statistically speaking. So there's a very slim chance that I will rupture and cause more debris.

Dr. William Schonberg (22:38):

So that is your brief introduction to the wherefores and the whys of orbital debris, and a brief introduction to a couple of recent projects, recent problems that have been worked on, that I was able to work on with NASA, to use this information and to hopefully make space travel safer and to protect those who we send up there into space in our spacecraft, now and in the future.

Dr. William Schonberg (23:09):

So that concludes my presentation. And if anybody has any questions, I will try to answer them.

Teresa Gomez (23:16):

Thank you so much, Dr. Schonberg. If anyone has questions, you should be able to unmute yourself now.

Josh Rovey (23:22):

Dr. Schonberg, this is Josh Rovey, University of Illinois. At the very beginning your talk here mentioned constellations, where we're talking about maybe 1,000 or thousands of spacecraft. Your number of particles here is 0.03. But if I have 1,000 spacecraft in my constellation, isn't there now a strong probability that one of them will encounter a particle and catastrophically fail?

Dr. William Schonberg (23:56):

Right now, the calculations that these companies have been doing ... and they're all very reassuring calculations ... indicate that they have sufficient knowledge and sufficient engineering design to avoid hitting each other, to avoid failing, and to avoid causing more debris on their own. So in a sense, they are working that end of the problem.

Dr. William Schonberg (24:26):

This end of the problem, about the passivation, I don't think has been looked at yet. But the gut instinct, that perhaps you share, is that this is something that needs to get looked at. Because this is one satellite in one orbit, it's maybe a highly conservative number, but if you multiply it by 1,000 then all of a sudden you're within the range of: it can happen. So yeah, this is something that needs to be revisited for the constellations, I think. Yeah.

Matthew Wallace (25:00):

Dr. Schonberg, my name is Matthew Wallace. I'm a sophomore at Parkland College right now. Actually, I've been working in the automotive industry as a safety engineer for Volvo Group. I just want to go back to ... is there a point where there's going to be so much debris in space that we're no longer going to be able to operate in space or even launch missions to Mars and beyond?

Dr. William Schonberg (25:27):

If I could answer that question with the [inaudible 00:25:32] certainty, then I would indeed be a very clever man. Let me just put it this way. I guess the answer is yes, there is that possibility. However, there are a lot of really smart people and a lot of different countries working to keep that from happening.

Dr. William Schonberg (25:52):

And those of you who've heard this or read about this phenomenon called the Kessler Syndrome that was proposed by Don Kessler several decades ago, about that very possibility, that, yes, if we are not careful, we will put so much debris up there that basically it will have the same effect as nuclear fission, where it's a chain reaction. I mean, you've seen the cartoons about nuclear fission. One particle hits, two particles created. Then they told two friends and they told two friends and pretty soon you have a nuclear reaction going on.

Dr. William Schonberg (26:38):

It is a possibility, that you have enough debris that it doesn't ever have a chance to clear itself and there's so much stuff out there that it's basically setting up a chain reaction. And you could have that. But there are a lot of people working really hard to keep that from happening.

Josh Rovey (26:55):

I'll go again, if that's all right?

Dr. William Schonberg (26:57):

Go for it.

Josh Rovey (26:58):

This is Josh Rovey, University of Illinois. Dr. Schonberg, could you say a little bit about the materials that are used to protect spacecraft? So one of your slides, I think you called out aluminum, maybe corrugated aluminum, Kevlar. Are these typical materials that are used for protection?

Dr. William Schonberg (27:19):

The response of materials to incredibly high speed impact is way different than anything we have in our experience database. Whether we hit something with our head, or our fist, or a baseball, or a rifle, or whatever, I mean these are all relatively low velocity events.

Dr. William Schonberg (27:41):

When you get into incredibly high velocity events, like being hit by orbital debris ... which can go as fast as 15 kilometers a second in Earth orbit. That's closing velocity ... typically you have to balance density and weight. It's no longer putting up the strongest material, the material with the highest strength. These events are basically hydrodynamic at those velocities, at those really high velocities. And strength is really a secondary feature that comes into play, only in the cooling down stage of the impact event.

Dr. William Schonberg (28:32):

There was an optimization study done by NASA about 30 years ago where aluminum was right on target, in terms of density, strength, corrosiveness; all that. So aluminum is a really good bumper, if you will, to protect your spacecraft against debris impact.

Josh Rovey (28:56):

Great. Thank you. And thank you very much.