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Episode 3

## **Orbital Debris and Kinetic Anti-satellite Concerns: How a “Kessler Syndrome” Threatens U.S. Use of Space Assets**



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### **About This Publication**

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# Orbital Debris and Kinetic Anti-satellite Concerns: How a “Kessler Syndrome” Threatens U.S. Use of Space Assets

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*IDA Ideas* host Rhett Moeller spoke to IDA President Norton Schwartz, Joel Williamsen of the IDA Systems and Analyses Center’s Operational Evaluation Division, and James Heagy of the IDA Systems and Analyses Center’s Science and Technology Division about the threat of orbital debris and kinetic anti-satellite (ASAT) weapons to the economic and military value of satellites in low Earth orbit (LEO), especially satellite constellations. Many of the comments in this podcast arose during the IDA Forum on Orbital Debris Risks and Challenges, held on October 8–9, 2020, and attended by IDA researchers and decision makers from the Department of Defense (DoD), U.S. Air Force, Department of Commerce, NASA, Federal Aviation Administration (FAA), and Federal Communications Commission (FCC).

IDA has supported nearly 20 years of sponsored and independent research into the effects of orbital debris and ASAT weapons on satellite systems. This research has intensified in recent years due to the phenomenal growth in satellite constellations in LEO, and the DoD’s expected use of such constellations for national defense. Much of IDA’s work has centered on predicting the effect of orbital debris on spacecraft mission loss, both in the short term from collateral damage due to satellite collisions or ASAT tests and in the long term as the background orbital debris population continues to grow. This growth has led to what many researchers believe to be the beginning stages of a *Kessler Syndrome*, named after the original NASA researcher who predicted the onset of a self-sustaining debris growth environment as existing debris hits operating and nonoperating satellites, creating more debris. Such a debris environment increases the risk of losing reliable and safe access to affected regions of space.

## [Begin transcript]

**Rhett Moeller:** Hello, listeners, I’m Rhett Moeller, and I’m the host of *IDA Ideas*, a podcast hosted by the Institute for Defense Analyses. You can find out more about us at [www.ida.org](http://www.ida.org). We also have a social media presence on Twitter and Instagram, so there are plenty of ways to keep up with the exciting work we’re doing. Welcome to another episode of *IDA Ideas*.

Because of the ongoing COVID situation, we are conducting this episode by video conference, so there may be a slight difference in our quality. In this episode, we’re going to take some time to talk about the interesting work on the topic of orbital debris going on at the Institute for Defense Analyses. Our research staff is driven by curiosity, a desire to better know and understand the world around us, and to find ways to use what we discover to help improve the safety of our Nation. Sometimes that work is directly tied to sponsor-driven requests, and

sometimes IDA *anticipates* sponsor interest. Our topic today deals with both of these areas. There's a lot to cover, so let's get into it.

I'm joined by the president of IDA, Gen. Norton Schwartz [USAF, retired], and two of our researchers from IDA's Systems and Analysis Center: Dr. Joel Williamsen and Dr. Jim Heagy. Can our researchers each take a moment to introduce yourselves please?

**Joel Williamsen:** Sure. Thanks, Rhett. I'm Joel Williamsen. I did my undergraduate work at the University of Nebraska, and I got my PhD in systems engineering at the University of Alabama in Huntsville. While I was there in Huntsville at NASA's Marshall Space Flight Center, I helped design the orbital debris shielding used on the International Space Station, along with predicting the effects on the astronauts should something get through those shields and developing potential repair techniques. Here at IDA, I'm still focused on those efforts: the effects of meteoroid and orbital debris impacts on spacecraft.

**Jim Heagy:** Thanks, Rhett, I'm Jim Heagy. I did my undergraduate work at Gannon University, and I got my PhD in physics at Drexel University in Philly. After post-doctoral positions at the Naval Surface Warfare Center and the Naval Research Lab, where I did basic research in nonlinear dynamics and chaos, I began my space science career as a satellite maneuver analyst at the Goddard Space Flight Center in Greenbelt, Maryland. There, I supported various NASA and NOAA missions. Here at IDA, I've led several space surveillance studies for the Under Secretary of Defense for Research and Engineering. Most recently I've focused on the orbital debris environment produced by on-orbit collisions and kinetic energy anti-satellite, or ASAT, weapons.

**Rhett:** Thank you, and welcome to *IDA Ideas*!

General Schwartz, "Norty", in October IDA hosted a virtual forum on orbital debris risks and challenges that I understand was attended by researchers and decision makers from the Pentagon, the Air Force, the Department of Commerce, NASA, the FAA, the FCC, a whole bunch of different organizations. Can you share with us why the issue of orbital debris is so important to all of these organizations and the DoD's operations in space?

**Norty:** Good question, Rhett. Orbital debris has been a known threat for decades actually, but recently we've learned that private industry could place more than 100,000 new spacecraft in low Earth orbit over the next 10 years—five times as many as now are operating there. The Starlink constellation alone has mentioned launching some 42,000 satellites and has already put up nearly 1,000 in the last year.

**Rhett:** Starlink—that's the SpaceX-led endeavor that is working toward satellite-based internet access, right?

**Norty:** Right; that's correct. That 100,000 number, by the way, comes from counting up licensing and launch requests. Now, they may not all be launched, but just the act of launching a satellite also creates orbital debris, for instance upper rocket stages and components that get

expelled when releasing a satellite. The numbers add up pretty quickly, especially when compared to the number of tracked items in orbit, currently around 30,000. The military is expected to increase its use of commercial and military satellites in low Earth orbit to support national defense, so sustained orbital debris growth will put our future space assets at risk, which, in turn, can place our national defense and economy at some degree of risk. This growth is happening so rapidly that all these arms of the government are scurrying around to react to it. That's probably the driver for this increased interest.

**Rhett:** Hmm, 100,000 satellites in 10 years—that's not a lot of time.

**Norty:** That's right, Rhett. And on top of that, the International Space Station has maneuvered three times this year due to potential collisions with space debris. The last one was just a couple of months ago, because a remnant of a Japanese rocket that broke up into 77 different pieces last year. There have been 25 similar maneuvers between 1999 and 2018, so it seems to be accelerating. So that events like this don't overcome our ability to mitigate them, we set up our forum in October to start a dialogue with our sponsors, and the space community at large. In fact, we invited Don Kessler, the NASA scientist that pioneered the first work in orbital debris, as a speaker and shared our own thoughts and approaches, such as Joel's and Jim's work over the years.

**Rhett:** Now, let's get a little flavor for that work. Joel, you mentioned that you worked as a NASA shield designer on the International Space Station before you came to IDA.

**Joel:** That's right.

**Rhett:** How has orbital debris environment changed over the years and the ways that we cope with it today?

**Joel:** Well, it's changed a lot. When NASA started designing satellites in the sixties and seventies, the natural meteoroid environment was really at the top of everyone's mind. Those particles are made of rock or iron from comet tails or other naturally occurring sources, and they hit the spacecraft at tremendous speed—up to 70 kilometers per second. That's over 157,000 miles an hour or a hundred times faster than a bullet. A large satellite called Pegasus with these large unfolding wings was launched to count the numbers of particles in that meteoroid environment, and for a time, they thought that even the Apollo 13 failure might have been caused by a meteoroid impact, although it was later proven that it wasn't. Skylab, our first space station, had a large deployable meteoroid shield, and that was ripped off when it was launched, and they had to place a new one on-orbit with the astronauts. Both the Space Shuttle and my first project at NASA, the Hubble Space Telescope, had meteoroid protection requirements—meteoroids only—naturally occurring particles. They had a 95 percent chance of no penetration over their lifetime.

But by the time that 1990 rolled around, we started to realize at NASA that the man-made orbital debris environment was really increasing, and that in fact had overtaken meteoroids as the real

spacecraft risk driver. The man-made debris hits at very high speeds, not quite as high as meteoroids, but up to about 15 kilometers per second—that's still 35,000 miles an hour—and now outnumbers meteoroids in the 1 millimeter size range by far. Now a millimeter is about the thickness of a credit card so you wouldn't think that would do much, but it does at those sorts of speeds.

On the Space Station, we had to add thousands of pounds of shielding just to protect the astronauts, plus patch kits and training and ways to find leaks and close hatches during potential emergency depressurization. So, it's really important to remember that every pound of shielding is a pound lost for payload, and so it wasn't done very lightly. It's still the top risk considered for human spaceflight and a big risk for commercial spaceflight.

**Rhett:** Got it, and I know Norty discussed this a little bit in his opening comments, but where did all these little pieces of debris come from?

**Joel:** Jim, you want to take that one?

**Jim:** Sure, Joel. Well, mostly, from *big* pieces of debris. Most of the things we put in space are launched with rockets that have multiple stages, which are the separate sections of the rocket that contain the engines and fuel. A few decades ago, explosions of upper rocket stages that were left on-orbit were to blame for creating much of this small debris, but thankfully international agreements have led to the practice of depressurizing those stages and dumping the extra fuel, so even when they are left in orbit, they are less likely to blow up and make small untrackable debris items. Today, the debris items result mostly made from on-orbit collisions between satellites and other satellites or existing pieces of debris—by the way, some of those collisions were intentional. Also, as Gen. Schwartz pointed out, every launch is accompanied with some debris, associated with the deployment of the launch payload.

**Rhett:** Okay. You mentioned that you did some work recently on kinetic energy weapons, Jim. Is that the sort of intentional collision you're talking about?

**Jim:** There are all sorts of anti-satellite, or ASAT, weapons that have been conceived and developed over the years, to include missiles equipped with conventional explosives and even nuclear warheads. Adversaries continue to pursue ASAT technologies, such as satellite-deployed mines and ground-based lasers; however, by far the most employed and tested ASATs to date have been so-called kinetic kill ASATs. These are launched from Earth and are designed to collide directly with satellites to destroy them. The first successful kinetic-kill ASAT test was carried out in 1985 by the United States, using the ASM-135 missile launched from an F-15 fighter jet. The target was a U.S. Department of Energy [DOE] satellite called Solwind. As an aside, I understand that the DOE scientists were not particularly thrilled with that decision, since some of the experiments onboard that satellite were still going and giving back good data. That weapon has since been retired.

While the U.S. did use the Navy's SM-3 missile interceptor to destroy a disabled satellite in a special operation in 2008, the DoD does not currently have an operational kinetic ASAT weapon. The most spectacular—if that is the correct word—deployment of this sort of weapon is the 2007 Chinese ASAT test against their own Fengyun 1C weather satellite. That event generated over 3,400 tracked debris objects, and single-handedly raised the number of tracked LEO debris objects by 25 percent. It is important to note that this only includes the tracked objects—they are far outnumbered by the untracked objects, generally taken to be less than 10 centimeters in size, about the size of a softball. Another problematic aspect of the Chinese ASAT test is that it was conducted at a pretty high altitude—about 860 kilometers, or 535 miles, above the Earth. Because of that, there are still over 2,500 tracked objects in orbit from that test, and they're going to be there for a *long time* to come.

**Rhett:** Okay. Well, Joel, you mentioned that you still have to worry about those untracked objects, right?

**Joel:** Yeah, Rhett. We've analyzed many spacecraft for their vulnerability to untracked orbital debris impacts over the last couple of decades at IDA, and their likelihood of failure really depends on the energy of the impactor, where they're hit, and what's critical. The longer that a satellite is exposed, and the larger its exposed area is, the more likely that it will be hit by a particle large enough to cause its loss. That means that huge satellite constellations have a large area-time product, and that makes losing one or more of their satellites very likely. Orbital debris particles generally impact spacecraft between about 8 and 16 kilometers per second relative to the spacecraft, with an average of about 14 kilometers per second, and that's, again, about 31,000 miles an hour, in the most cluttered polar debris orbits that are near an altitude of about 800 kilometers or about 500 miles up. And at 14 kilometers per second, a 1 millimeter aluminum particle carries roughly the same impact energy as a .22 caliber bullet. And a 2 millimeter particle is like a .357 magnum bullet, a 3 millimeter particle is like a 30-06 rifle bullet, etc., etc. But you get up to a 1 centimeter particle—and that's about the width of your pinky—it has the energy of a Mark 2 grenade.

**Rhett:** Wow.

**Joel:** And none of those sizes are trackable from the ground.

**Rhett:** I can imagine that's definitely not what you'd want to hit your multimillion-dollar spacecraft with.

**Joel:** No way. It gets worse as the impactor grows—in fact, the impact energy grows roughly with the cube of the impactor size. So a 1 centimeter particle has about 1,000 times more impact energy than a 1 millimeter particle, and a 10 centimeter object has 1,000 times the impact energy of a 1 centimeter object, etc., etc. It's something like a 1,000 Mark 2 grenades if a solid, chunky 10 centimeter particle hits. So, at that size, you get the catastrophic exchange of energy that Jim referred to in those ASAT tests, and the creation of these vast amounts of tracked and untracked debris. That's why spacecraft operators try so hard to avoid these impacts with tracked objects—

not just for losing their own spacecraft, but for creating so much collateral debris that every other spacecraft in nearby altitudes is in danger.

**Rhett:** We keep coming back to this term ASAT, anti-satellite. Jim, earlier you mentioned other experiments related to this—can you tell us more about these?

**Jim:** Sure, no problem. India comes to mind, which tested an ASAT against one of its own satellites in March of 2019. That test created about 250 pieces of trackable debris items at first, of which 5 still remain—the rest of the debris has already reentered.

**Rhett:** So the debris threat can go away over time?

**Jim:** In this case, yes, but some of it can remain for a while. While that Indian ASAT test was performed at a pretty low altitude, about 260 kilometers, and the Indian officials claimed that the ASAT approach was directly head-on, both of which would tend to limit the altitudes of the target and the ASAT fragments, some debris was still lofted to very high apogee altitudes, that's the highest point of an orbit, and those pieces take a long time to reenter. It's all about the altitude; the lower the altitude where the debris starts out, the more likely that it will eventually reenter. In this case most of the debris reentered within a few months, but the highly lofted pieces are still up there well over a year later.

**Rhett:** Okay, I understand.

**Joel:** Norty mentioned the Starlink constellation earlier, which claims to want to add 42,000 satellites over the next decade to provide broadband services. That satellite constellation is actually a very good example of how to reduce the potential for creating debris with a long orbital life because they picked a low operating altitude. Their plan is to operate at a fairly low altitude—and that's about 550 kilometers or only 340 miles up—and leave enough fuel aboard so they can reenter their satellites at the end of their life. The lower altitude allows any created debris to have a lower life expectancy than their originally planned altitude, which was up at about 850 kilometers, or 500 miles. Iridium is another example of a satellite constellation that thought ahead about debris removal, so their satellites wouldn't be a target for debris. They left enough maneuvering fuel, and they were able to remove all of their first generation of satellites safely within the last couple of years.

**Jim:** That's right, Joel, except for one, which was lost in 2009.

**Joel:** That's right.

**Jim:** Unfortunately, Iridium is also an example of what can happen when one satellite hits another by accident. In 2009, a dead Russian Kosmos satellite hit an Iridium satellite, creating thousands of pieces of trackable debris at an altitude of around 800 kilometers, much of which is still there. Most satellites, in fact, most debris, travel on circular orbits, so collisions are most likely to happen between satellites at roughly the same orbital altitude. Constellations of satellites contain many rings of satellites, with each ring of satellites following other satellites at the same altitude, separated by a distance that allows continuous communication with the



ground. When a collision with a big piece of debris or another satellite occurs, other satellites in the same ring or adjacent rings are in immediate danger of suffering a collision from the debris of that collision—the more satellites, the greater the chance of collision. And that collision debris can cascade to make other collision debris.

**Rhett:** Okay, that sounds familiar, isn't there a movie about that?

**Jim:** Yes, the movie is called *Gravity*. A pretty good movie, but it has some things that a lot of people don't necessarily agree with. In the movie, Sandra Bullock's character is a Space Shuttle astronaut who first watches her shuttle, then the International Space Station, suffer catastrophic losses. Those losses stem from an orbital debris cascade, triggered by—yeah—a Russian ASAT test. There's a lot of Hollywood special effects going on in that movie which aren't very believable, not the least of which is seeing George Clooney's character call out debris approaching the station at 7 kilometers per second or so.

**Joel:** I don't know if anybody has seen a *bullet* whiz past them, much less something going 10 times *faster* than a bullet...[laughter].

**Jim:** Absolutely, Joel. But the basic idea is still correct—debris can impact, cascade to make more impacts, and become self-sustaining, unfortunately. That effect is called the Kessler Syndrome, named after your colleague Don Kessler, the NASA scientist that speculated on the phenomenon of debris producing self-sustaining and increasing debris through collisions. As we mentioned earlier, many folks who study the orbital debris problem believe that the Kessler Syndrome is already happening, but none of those folks would claim it's happening as portrayed in the movie *Gravity*. Most likely the time scale for the collisional cascade is measured in years to decades, not hours or days—but the addition of all of those new satellites and constellations make studying that possibility extremely important.

**Rhett:** Norty, I think you mentioned that Don Kessler was a speaker at the IDA forum on orbital debris.

**Norty:** That's right. He gave a couple of great lectures on the origins and dangers of debris, and he was worried about the effect of the growth of these constellations on the debris population. The constellations make very good targets for the debris that's still up there. Even though our debris growth rate is low today, that syndrome is likely already with us, and he was fearful that it could continue to grow rapidly.

**Joel:** That's right, and that's the problem. We really don't have a good general model for how fast debris can grow, from one collision to another, and considering the existing satellite population, and now we have to consider this projected growth, which is huge. The same is true for ASATs—we don't have the tools to predict how use of an ASAT, or many ASATs, can affect other satellites in orbit, both in the short term and in the longer term. We also need handier tools to predict how often these smaller, untracked debris particles can disable a satellite, because the DoD and our economy are so dependent on them.

**Norty:** Developing models for predicting those collateral effects of collisions and mission loss in satellites are the focus of an internally funded project that Jim and Joel hope to start at IDA within the next year. It was an idea that came out of discussions with the attendees at the forum.

**Rhett:** Sounds like it was a fruitful time at that forum. Did any other good ideas come out of it?

**Norty:** One suggestion was to encourage an exchange of personnel between NASA's Orbital Debris Program Office—that helps predict the orbital debris environment—and the new Space Force that is now being stood up—which is responsible for protecting the DoD assets in space. The Department of Defense exchanges officers all the time to improve the collective understanding of needs and capabilities and to fight better together as an integrated team.

**Jim:** Another idea was to use the commercial satellite population as a measure for how often small debris is impacting the constellation by monitoring their changes in position through GPS and other means. Getting that data could be part of DoD's contract for using those services and help everyone to monitor the small debris population.

**Rhett:** Sounds like the time spent in the forum was very productive, very valuable.

**Norty:** We sure think so, Rhett. We wanted to take time to listen to what all the organizations thought was important so we could better prepare ourselves to help solve the orbital debris challenges that so clearly, *clearly* lie ahead of us.

**Rhett:** This is a very pressing problem it sounds like, and it sounds like IDA has a lot of experience in every area involved. We are definitely interested in doing more work in this area, and we have a lot to contribute to national security when it comes to this sort of analysis.

Norty, Jim, Joel, thank you *very* much for taking the time to discuss this intriguing project with us.

**Jim:** My pleasure.

**Joel:** Sure thing.

**Norty:** Pleasure.

**Rhett:** And for giving us more insight into an interesting yet very serious topic. It has been most illuminating!

As always, if you want more information on IDA and its ongoing work, please do check us out at [www.ida.org](http://www.ida.org) and also at our social media presences that we mentioned at the beginning.

This show is hosted by the Institute for Defense Analyses, a nonprofit organization based in the Washington, DC, area. Once more, you can find out more about us and the work we do at [www.ida.org](http://www.ida.org). Thanks for tuning in, and we hope you'll join us again next time as we discuss another big idea here at *IDA Ideas*.

## Show Notes

*Learn more about the topics discussed in this episode via the links below.*

Balakrishnan, A., S. M. Ouellette, D. L. Pechkis, and J. E. Williamsen. 2020. "IDA Forum on Orbital Debris Risks and Challenges." *IDA Research Summary*. IDA Document NS D-18426. <http://idalink.org/d-18426>.

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