IDA Ideas

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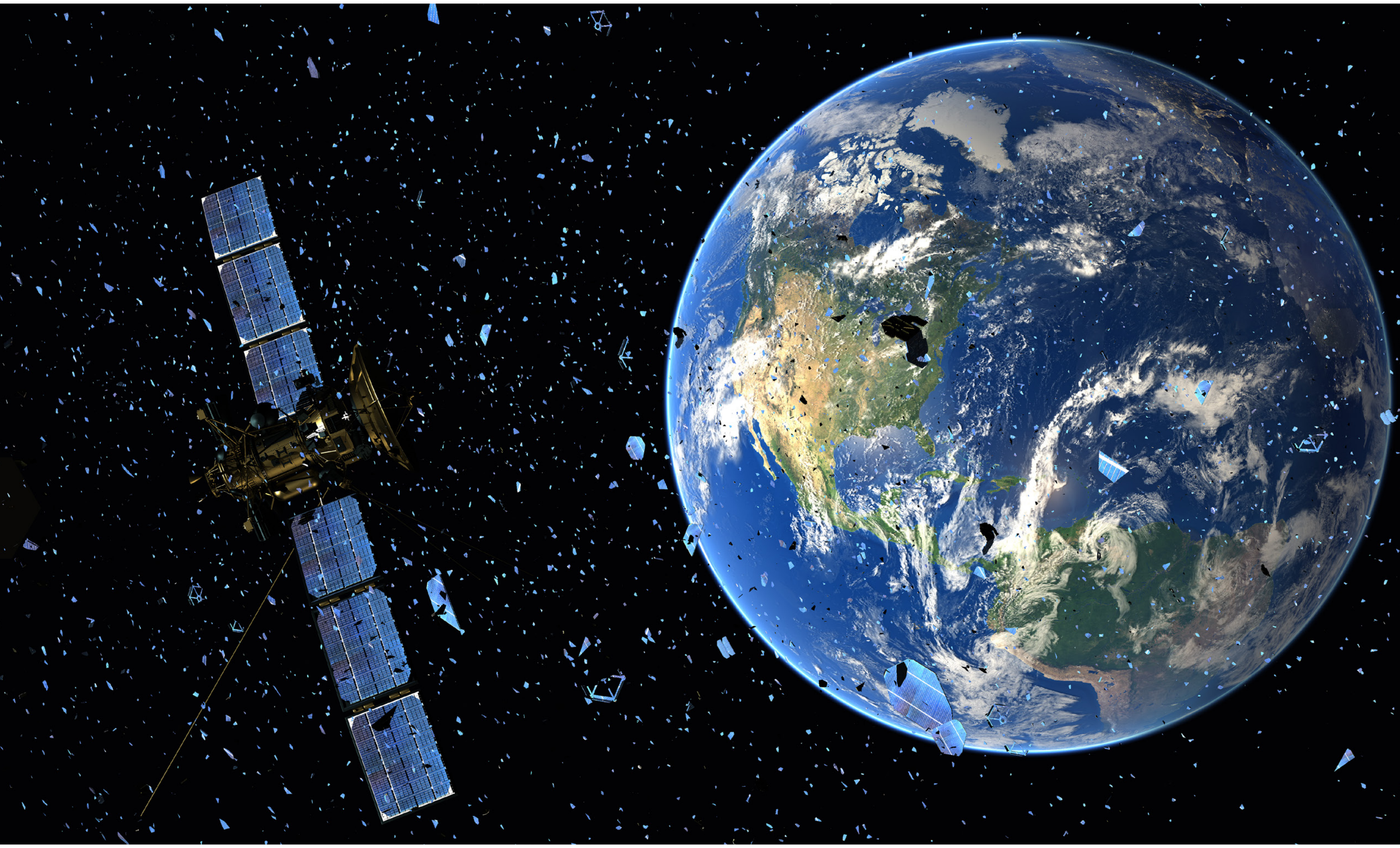
Episode 4

Orbital Debris Tracking: Improving Orbital Debris Environment Predictions Using Satellite Movement Data



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Orbital Debris Tracking: Improving Orbital Debris Environment Predictions Using Satellite Movement Data

IDA Ideas host Rhett Moeller spoke to IDA research staff members Daniel Pechkis and Jason Sheldon from the Operational Evaluation Division and Stephen Ouellette from the System Evaluation Division of IDA's Systems and Analyses Center about characterizing the orbital debris environment using satellite movement data. Much of the discussion in this podcast originally arose during the IDA Forum on Orbital Debris Risks and Challenges, held on October 8–9, 2020, and attended by researchers and decision makers from the Department of Defense, the Space Force, the Department of Commerce, NASA, the Federal Aviation Administration, the Federal Communications Commission, and IDA.

IDA has supported nearly 20 years of sponsored and independent research into the effects of orbital debris, a concern which has intensified in recent years due to the phenomenal growth of satellite constellations in low Earth orbit (LEO), and the Defense Department's expected use of such constellations for national defense. Much of IDA's contributions over the years have centered on predicting the risks of spacecraft mission loss due to orbital debris impact, for both debris created promptly by satellite collisions or antisatellite tests, and over the longer term, as the background orbital debris population continues to grow. As discussed in a previous *IDA Ideas* episode, this growth has led to what many researchers believe to be the beginning stages of a *Kessler Syndrome*, which is a self-sustaining growth of the orbital debris population wherein existing debris creates more debris when it hits operating and non-operating satellites.

In this episode, we talk about how the United States tracks Earth-orbiting objects and discuss IDA research published in *Journal of Spacecraft and Rockets*, "Improving Orbital Debris Environment Predictions through Examining Satellite Movement Data." Two of our guests are coauthors of that article.

[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. 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 continue our discussion about our work on the topic of orbital debris going on at the Institute for Defense Analyses. If you want to catch up on part one of this discussion, make sure you listen to the previous episode, which covers some ideas foundational to this topic. 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.

Today I'm joined by three researchers from IDA's Systems and Analyses Center: Dr. Daniel Pechkis, Dr. Jason Sheldon, and Dr. Stephen Ouellette. Can our researchers each take a moment to introduce yourselves?

Dan Pechkis: Sure, thanks, Rhett. My name is Dan Pechkis. I did my undergraduate work at Southern Connecticut State University, and I got my PhD in physics from the College of William & Mary. Since graduation, for the last 10 years, I've worked at IDA, working with an interdisciplinary team of academics, industry professionals, and former military personnel on operational testing of various space systems, with a strong focus on space situational awareness. The systems I work include the JSpOC [*Joint Space Operations Center*] Mission System, Space Fence, and I do a lot of space command and control, and I've also participated on numerous independent review panels that have informed DOD [*Department of Defense*] leadership on acquisition decisions of various space programs.

Jason Sheldon: Thanks, Rhett. I'm Jason Sheldon. I did my undergraduate work at Rowan University, and then got my PhD in mechanical engineering at Penn State. Since joining IDA in 2016, I've primarily been worked with Dan on the test and evaluation of space surveillance systems. My bread and butter at IDA has been an upcoming weather satellite and the Air Force—now the Space Force now that some of that work is transitioning—multiple mission systems in space situational awareness and space domain awareness.

Stephen Ouellette: Thank you, Rhett. My name is Stephen Ouellette. I did my undergraduate work at the University of Maine, and got my doctorate in physics at California Institute of Technology, or Caltech for short. Over the last 20 years at IDA, I've been involved in assessments of planned military systems, exploration of new mission concepts, and evaluation of technologies with military potential. That work has mostly been related to military surveillance and reconnaissance, air warfare, missile defense, and more recently has emphasized modernizing U.S. space capabilities.

Rhett: Well, thank you all for joining us, and welcome to *IDA Ideas*! You each obviously bring a lot of expertise to this discussion, so let's talk space!

Stephen, can you start things off by giving our audience a sense of how many objects there are in orbit and perhaps how many of them are debris?

Stephen: Absolutely, it would be my pleasure! Right now, the United States tracks more than 20 thousand objects that are 10 centimeters across or larger. Of those, almost 15 thousand are debris.

There are millions and millions more that are too small to be tracked, but still large enough to be dangerous.

Rhett: Wow, 20 thousand sounds like a lot, but three quarters of that number being debris sounds especially worth being worried about. That works out to, what, three times as many pieces of debris as there are functional satellites?

Stephen: Yeah. The big question everyone wants to know is how much debris can be on orbit before we have a serious problem with collisions affecting the mission of operational satellites. The scary thing is that every collision that does happen generates more debris, expanding that problem.

Rhett: Okay, so if one object hits another one that breaks up into smaller fragments that then all spin out in their own directions, right? Can you give us an example?

Stephen: Yeah, in 2009, an inactive Russian Kosmos military satellite collided with an active U.S. Iridium commercial satellite, destroying both and generating over 2,000 pieces of detectable debris.

Rhett: Then that makes it immediately clear why it's so important to track everything, especially when I think about the Kessler Syndrome, which we talked about in the last *IDA Ideas* podcast. Jason, can you please remind us of what the Kessler Syndrome is and why we should be concerned about it?

Jason: Sure. Kessler Syndrome, or Kessler effect, is a theory named after NASA scientist Don Kessler, and it—basically just what we've been talking about—once the density of debris in an orbital region or range of altitudes in space is above some critical threshold, this chain reaction of collisions can occur, cascading creation of more and more debris and more and more collisions. And that's why tracking the large debris is so important, because collisions of large trackable debris can make huge amounts of both trackable and untrackable debris, which would increase the [*probability*] of the Kessler Syndrome; it just perpetuates down the line.

Rhett: Very important, indeed! Knowing this, then, Dan, can you explain to us how the United States tracks and monitors all of this orbital debris?

Dan: I'd be happy to, Rhett. The United States and its allies run a world-wide collection of radars and telescopes that monitor objects in Earth orbit, whose altitudes range roughly from about 200 to 40,000 kilometers, that's about 125 to 25,000 miles above the earth's surface. And there are two organizations that have the responsibility for understanding orbital debris environment, one is NASA's Orbital Debris Office and the second is the United States Space Command's 18th Space Control Squadron.

Rhett: So NASA and Space Command are involved. That makes me wonder: Is one responsible for tracking civilian interests and the other military?

Dan: They actually both have both a civil and military—they both supply information to both those sectors. Their responsibilities are segmented somewhat differently. The two main differences between the NASA and the DOD mission are, one, the United States Space Command's 18th Space

Control Squadron primarily focuses on larger debris. That's roughly objects of the size of about 10 centimeters and larger. Where NASA is really interested in trying to look at and capture what is going on with the smaller debris, and that is from around the 10 centimeter size and longer and down to about 10 microns. The second difference is that the 18th Space Control [*Squadron*]'s main focus with the larger debris is to really identify with each object it can track, where the object currently is, and identify where it's going to be going in the future. So they're trying to maintain custody—that's kind of the technical term that is used. NASA, since a lot of that smaller debris is harder to track—they can't look at individual objects they're just trying to understand and estimate sort of statistical distributions of different debris populations and different orbits.

Jason: Yeah, and it's probably worth pointing out that NASA uses observation data also to improve their debris model estimation of the current and future debris environment.

Dan: Thanks Jason, that's a really great point!

Jason: Sure! NASA created multiple models that estimate the population of space debris, since we don't have complete knowledge of how much debris is up there in different sizes. These models are useful for a bunch of things. NASA uses the models themselves to provide guidance for government satellite design features, such as how much spacecraft shielding is needed to protect against small debris and to prevent satellites from becoming pieces of debris themselves. NASA also gives their models to private companies so that they can do similar things. The companies can use the debris models to estimate the orbital debris environment that they'll be flying in and how much debris their satellites are likely to encounter. This helps ensure the satellites' designs will meet with FCC [*Federal Communications Commission*] regulations for safe satellite lifetime, and allows the companies to develop appropriate risk mitigation strategies for themselves and for their investors.

Rhett: You bring up an interesting point about shielding. It's easy to wonder how to decide how much shielding is enough. If you overshield it, that's going to be just as problematic as undershielding it, since it affects things like cost, maneuverability, and probably a whole lot more. Before we move on, I do want to go back to a point Dan made. Dan, when you say knowing where objects are and where they are going in the future, are you referring to something like space situational awareness?

Dan: That's absolutely correct.

Rhett: Okay, so how is that different from space domain awareness?

Dan: That's a really good question because it is a new term. Space domain awareness is a term coined by U.S. Space Command that encompasses space situational awareness, but also captures the capabilities of active satellites and the intent of their owner-operators.

Rhett: Okay, so it sounds like maybe space domain awareness is the larger picture, and then space situational awareness is a part of that.

Dan: Right. So, if you are looking for a formal definition, I'd say that space domain awareness is knowledge of where objects are now, where they are going to be in the future, and whether their intentions are benign or hostile.

Rhett: That sounds like a big job! So once Space Command collects all this data, what happens to it?

Jason: The data from different radars and telescopes all gets packaged up and shipped off digitally to the 18th Space Control Squadron out at Vandenberg Air Force Base, and they fuse that data together and use it for object identification, orbit prediction, object cataloging, and threat assessment.

Rhett: That all sounds really important. I think what's really going to capture everyone's attention is that last one really. Jason, can you give us an example of a threat assessment?

Jason: Sure. One of the most common things the 18th Space Control Squadron does is called a conjunction assessment. Basically, they check if two objects are possible to collide with each other. If they say two objects heading toward the same space at the same time, they'll develop courses of action. This can entail saying, "Okay, let's gather some more data, more observations from radars and telescopes, to have a better estimate of where those objects would be." Or it could mean sending warnings out to the satellite owner-operators and letting them know that they might need to prepare for a maneuver to avoid a collision. All this conjunction assessment analysis and data gets sent out to a variety of users, including the radars and telescopes Dan mentioned earlier, military and U.S. government satellites, commercial entities, foreign partners, and others, such as research groups in academia.

Rhett: That sounds like it's incredibly important work. Seems like there's a lot of moving parts to keep track of, and obviously that needs a robust communications channel to keep threat warnings moving out smoothly and effectively. What I would like to do is change gears a little and talk about a paper IDA published on characterizing the orbital debris environment using satellite perturbation data that was just published in the *Journal of Spacecraft and Rockets*. First, Dan, can you explain what a perturbation is?

Dan: Yeah, that's not a term you really find in a newspaper column, is it? A perturbation technically is a disturbance or a deviation from normal brought on by an external force. So just to give you an analogy or a picture to have in your head, if you're familiar with ever watching auto racing, you know, such as the Daytona 500 or the Indianapolis 500, where the cars are going in an oval. If you follow that, you'll notice that the race car drivers really try to follow the exact same path along the track every time. And you can think of a perturbation as a bump or a tap that one car receives from another. Now depending on how fast the car is moving and where that tap occurs or how hard it is hit, the car can swivel a little bit after being hit, it can get pushed out of the way, it can even spin out of control, but at the very least its path along the track will get slightly changed. Scientifically speaking, we'd call that little bump and change in path a perturbation.

Rhett: Okay, that's an excellent analogy, and I think it makes perfect sense. So tell me, how does someone characterize the orbital debris environments using satellite movements or perturbation data?

Stephen: Well, if you think about Dan's auto racing example, replacing the first car with an operational satellite and the second with a piece of debris, you can get a sense of what will happen when a small piece of debris hits a satellite. The really small pieces won't destroy the satellite on impact, but instead, will nudge it off course, resulting in a slightly different orbit than what the satellite had before the collision. If large enough, the satellite perturbations, or unexpected orbital changes, can be observed by watching changes in the satellite's reported GPS position, temporary breaks in communication links between satellites, and other indicators on orbit, which are also known as in situ observations. By looking for and observing these slight orbital changes, people can estimate the mass of the impacting piece of debris. And if we keep track of perturbations for hundreds, or even thousands, of satellites, and estimate the size of the impacting particles, we can get a sense for how many debris particles there are on orbit and how much mass they have.

Rhett: Great, thanks so much, Steve. So, in other words, you're using the satellites, or maybe more accurately, their sudden unexpected movements as a way of detecting orbital debris that are too small to be tracked?

Stephen: You got it, that is absolutely correct!

Rhett: Great, so has this been done before?

Stephen: In a manner of speaking, yes. Up to 2011 or so, NASA did a good job at collecting data for debris impacts on space shuttle services, like windows; however, the shuttle data has an area-at-a time problem; even though the shuttle was big, with missions that only lasted a few weeks, we just didn't get a lot of collection time on orbit. The key to gathering data on the debris population is getting a lot of time with a large total area impact collection. With our proposed approach, we're not suggesting just collecting perturbation or movement data for a single satellite, but instead from multiple constellations, each with hundreds or thousands of satellites. And since those satellites will be on orbit for years, our approach would provide orders and orders of magnitude more data than the space shuttle program would.

Rhett: Great, thanks Stephen, that's pretty cool, but it does make me wonder why this type of debris-detecting approach is necessary when NASA and U.S. Space Command have a network of radars and telescopes tracking these objects.

Dan: That's a fair point. What Jason and I were alluding to before is that there is a gap in orbital debris knowledge. In a nutshell, we have little information about objects ranging in size from 1 to 3 millimeters, because radars and telescopes have difficulty seeing debris much below the 3 millimeter in size, especially over a wide area of space. So we just don't know how many particles exist in that size range. Now, most people would think the sizes of these particles as being very small, but given the relative velocities they are traveling, they could seriously damage or even kill a spacecraft. Just to give you some context, a 2 millimeter size particle, which is roughly the size of a grain of sand, traveling at a typical orbital velocity of over 14 kilometers per second, which is equivalent to about 31,000 miles per hour, would impact a satellite with the same amount of energy as a bullet fired from a .357 Magnum.

Jason: On top of that, getting data from the 1 to 3 millimeter size particles is important because we're going to be adding a lot of constellations over the next few years. If all the mega-constellations like SpaceX's Starlink launch—they currently have plans to—we're expecting over 100,000 satellites on orbit in the next 10 years. At the time the IDA paper was written that we've been discussing, there were only about 22,000 satellites that we used in that analysis. Dan, Stephen, and their coauthors saw that in the year 2030, assuming all those satellites were still on orbit, they could risk collision with more than 16,000 pieces of orbital debris of 1 millimeter size or larger each year. Many of those satellites will be in orbits where small debris under 1 centimeter is both untrackable and dangerous. We've done some preliminary calculations that indicate there should have already been an impact of a 1 millimeter particle on the new Starlink satellite constellation, which over the last year or so has placed over a thousand satellites in low Earth orbit at an altitude of about 550 kilometers, or 350 miles.

Stephen: Now the cool part is that if these perturbations are systematically reported and cataloged in a database, NASA can use that information statistically to update their orbital debris models. Then, companies can use the improved NASA debris models to estimate the 1 millimeter to 3 millimeter orbital debris population that their spacecraft may encounter and develop more appropriate strategies to mitigate debris impacts. Companies may save money if in fact the amount of 1 to 3 millimeter orbital debris population or the mass of individual debris particles is found to be less than current debris models estimate.

Jason: Recent NASA studies have also compared the number of observed satellite perturbations to the number predicted from orbital debris models. We've found that the number of actual perturbations may be far fewer than what the debris models predict. This suggests that there might be an overestimation of mass distribution of small orbital debris particles. So if future satellite perturbation data confirms that the overprediction is real, spacecraft might need less shielding and therefore weigh less. That would reduce their costs for debris shielding and for launch and could potentially give them a longer life, given the reduced risk of encountering debris.

Rhett: Excellent, I really appreciate it Stephen, Dan, Jason, thank you very much for taking the time to discuss this intriguing project with us and for giving us more insight into an interesting yet obviously very serious topic. It's really 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—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. Thanks for tuning in, and we hope you'll join us again next time as we discuss another big idea here at *IDA Ideas*.

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Rhett: Hello listeners, this is Rhett again. As a postscript, we found out about a relevant event related to the topics we covered in this episode. I reconnected with Dan Pechkis to go over it. Dan, recently something happened up in space that really highlights the danger of the things that we've dealing with in this episode. Could you give us a little more information about what happened?

Dan: It would be my pleasure, Rhett. So, recently, in May of 2021, the International Space Station was struck by a piece of debris. The debris impacted the—there's an arm that comes off of the station that is operated by the Canadian Space Agency, and the arm I believe is called Canadarm2. It was recently discovered that there was a debris strike that left a 5 millimeter hole. Thankfully, no one on board the station was ever in danger or had any incident, and the arm is actually fully functional. So it was, I guess, a lucky hit in the sense that there was an impact from debris but it didn't cause any serious harm or challenges to the mission of the International Space Station.

Rhett: Well that is encouraging that we could have something like that happen and not have any danger to human life. Obviously, with the recent surge in commercial space tourism, you know, Richard Branson going up and Jeff Bezos, we're going to see, I think, an uptick in the number of people and even more objects in space, so obviously this becomes more and more important to think about and try and find ways to mitigate.

Dan: Yeah, it's definitely worth studying. I know there's some naysayers out there because people think space is really big, and it really is, so even if you have a lot of particles up there, intuitively you would think that, this isn't an issue, but it does happen. Satellites get struck by debris, the International Space Station getting struck…yeah, with everything going on, it's something that we feel should be looked at.

Rhett: Well, thanks for connecting with me Dan, and filling in a little bit more current events on this. This is obviously an ongoing discussion about a very serious topic. There's plenty more to talk about, and, of course, we do have one more episode coming up in this series, so listeners if you are interested in following this topic, please do join us again for the next *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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