Trash in the Skies III
Thursday, November 2, 2017
Russell Senate Office Building, Room 253
Washington, DC

Trash in the Skies III: Prospects for Active Removal of Space Debris

Speakers

- **Dr. Marshall Kaplan**, Chief Technology Officer and Co-Founder, Launchspace Technology Corporation
- **Mr. Jerome Pearson**, President, Star Technology and Research, Inc.
- **Dr. Siegfried Janson**, Senior Scientists, The Aerospace Corporation
- **Mr. James Dunstan**, Founder, Mobius Legal Group
- **Dr. Brian Weeden**, Director of Program Planning, Secure World Foundation
- Moderator: **Ms. Victoria Samson**, Washington Office Director, Secure World Foundation

Victoria Samson: My name is Victoria Samson. I'm the Washington office director of the Secure World Foundation. We're a private operating foundation that promotes cooperative solutions for space sustainability. Our vision is the secure, sustainable, and peaceful use of outer space that will contribute to global stability on Earth.

In order to create that mission, we work with governments, industry, international organizations, and civil society to develop and promote ideas and actions for international cooperation that will achieve the secure, sustainable, and peaceful use of outer space.

I wanted to give just a quick overview of the space debris topic in case there's any newbies in the audience and those of you who've been to on of our events before, you can go to your happy place while I talk for a minute.

Currently, there's about 1,500 functional satellites in orbit and that changes all the time. With the Indians putting up hundreds at a time, so that's going up. But currently, there's about 22,000 pieces of trackable space debris and these are things coming from dead satellites to rocket bodies, fragments from earlier satellites, that are bigger than 10 cm or the diameter of a softball.

There's an estimated half a million, that's 500,000 pieces of space debris between 1 and 10 cm that are not tracked but they are going very fast. Any kind of collision could be very damaging if not catastrophic. Particularly the collision with large pieces could create hundreds of thousands of new pieces of debris.

Collision with small pieces can either damage or even possibly destroy satellite components, or even the satellites themselves. When we're talking about dealing with space debris, there's four different parts of doing so. You have space situational awareness or knowledge of the space environment.

There's mitigation guidelines that are trying to reduce the creation of new debris. There's space traffic management and that's used in a variety of different ways. When we look at it, we consider close approach warnings and collision avoidance. Then, finally ADR, active debris removal, which you'll be hearing a lot today. That's removing the existing debris.

Space debris continues to be a significant feature of space activities. Although progress has been made over the last decade implementing voluntary guidelines to minimize the creation of the debris, it's still not enough. There's been many scientific studies by space agencies that show that collisions between objects can generate thousands of pieces of new debris.

Given that we are on the precipice of increasing the number of active satellites by an order of magnitude, if all the mega-satellite constellations that are filed with the FCC come to fruition, we will see an increase of 16,000 satellites over the next 10 years. Given that there are about 1,600 current active satellites, that's a huge increase.

One question to consider about the current space debris is, what about the growing risk of damage during launch? The potential for collision is greatest during launch and orbital raisingh. Has the impact or threat of access to space been thoroughly removed?

In 2010, the Obama Administration issued a new national space policy that included a directive to the administrator of NASA and the Secretary of Defense to jointly research and develop technology and techniques to do active removal. Seven years later, there's been very little progress and even NASA and the DOD show unwillingness to invest in ADR technologies.

Despite the threat space debris poses to their use of space. NASA has awarded a few small grants in the private sector for early concept studies of some ADR technologies but that support does include on-orbit demonstrations.

I'd like to take a moment to advertise an article my colleague Brian Weeden just wrote, on SpaceReview.com earlier this week, where he goes into a real interesting history and the background for this. He talks about [inaudible 11:06].

We'll be discussing some of that so I won't step on his toes any more but I highly recommend it. It's available. There's a link that's going to be up on my website. Again, SpaceReview.com. You can find it there as well.

This event is the third in a series organized by Secure World Foundation here on Capitol Hill. Our first one was in 2012. Trash in the Skies, the challenge of space debris. The impact of the growing amount of space debris is having on space activities and the importance for improving SSA for managing the risk posed by space debris and then looking at national and international efforts.

Our second one was in July of this year. Trash in the Skies two, interesting perspectives on dealing with space debris. We thought it was a good title. Providing the update, look at the progress made and perhaps more importantly, not made in the past five years. We included perspectives from satellite operators including insurers on risk to satellites posed by space debris.

Today's event, Trash in the Skies three, we'll be looking at active debris removal and we have a great panel that will be discussing various aspects of it. Our first three speakers are companies that have ideas about active debris removal.

We have Dr. Marshall Kaplan, the chief technology officer and co-founder of Launchspace Technology Corporation. We have Mr. Jerome Pearson, our President of STAR in technology and research. Dr. Siegfried Janson, senior scientist at the Aerospace Corporation.

Then our next speaker will be looking at some of the legal challenges for active removal. This is James Dunstan, the founder of Mobius Legal Group. Then finally, coming up the rear will be Brian Weeden to discuss the policy implications of active removal.

He's a director of program planning at Secure World Foundation. You should have received copies of their bios when you walked in and so, in order to make sure you have times for questions and conversation, I'll stop the bios right there.

Each speaker will have five to seven minutes opening remarks and then we'll open for questions from the audience. Just to let you guys know, this event is being recorded, they'll be an audio recording on our website publicly.

One of the things we like to do is we also like to provide a transcript of our events. If you're a person like me that needs to both read and listen to podcasts that like doing research and like reading transcripts, just so it's on the record. With that, our first speaker...Have you got the PowerPoint?

Marshall Kaplan: Yes.

[crosstalk]

Marshall: You might be wondering why I'm the first speaker. The answer is that they thought I'm the fastest talker with the least slides. Little did they know.

My approach and my presentation's a little different because I'm going to talk about a new approach to the overall problem of active debris removal. In fact, the title of my talk and my subject matter is, "A Commercial, Multi-mission Ecosystem for Near Space Control." The subtitle is, "Methods and Systems for Permanents, Affordable Debris Removal, Plus Enhanced Natural Security Capabilities."

It's a long title. In fact, it probably could be my whole slide. In any case, what I'm going to introduce today, in the next few minutes, is a new approach to the whole problem of space debris and the problem of maintaining space safety with added attributes, which are attractive for other missions related to national security, space traffic management and other applications.

Not only that, but we're taking a commercial approach. That means we have a business plan and an idea for creating enough revenue to pay for it, to sustain it. This is a new approach because previous approaches have had a problem with business plans but I think we have a good approach.

In any case, I'm giving you enough ideas that will raise a lot of questions and I'm not going to answer a lot of questions here, but as we go through the question and answer period, I think I'll be able to answer some of the questions. This should raise a significant number of questions.

First of the next two slides -- I only have three slides altogether -- is the problem. My approach to the problem is that there are three threat capabilities and three threat categories, which is the function, the size of the debris and the number of debris. The first category has been studied essentially the past 30 or 40 years. In fact, some studies are Penn State, 1970. That's a category, we look at recruiting big stuff.

That's where most of the research has taken place. However, more recently I realized that the real problems, the three real problems, one is the big stuff, the next one is the middle stuff, which is the one millimeter to five centimeters and then the third problem is what I call the small stuff, less than one millimeter in size.

You've got to remember, everything in LEO -- low earth orbit -- and I'm focusing I'm low earth orbit as opposed to GEO, because that's where most of the debris is, but everything in LEO is moving at over seven kilometers a second or about 17,000 miles an hour.

Every piece of stuff, no matter what it is, is moving at about 17,000 miles an hour in all directions. You can imagine the chaos, so to speak, if this thing gets more dense. In fact, it is going to get more dense the next few years. We're positioning ourselves to be the controllers of the debris in a way that we can actually create a business plan and make it a commercial business.

We have attacked all three problems. The second problem, the third problem, which is the middle debris and the small debris, we're going to attack directly. In other words, we're going to create a wholesale collection system in low earth orbit to pick up everything smaller than five centimeters and everything bigger than five centimeters, we're actually going to help with that too through our tracking system.

As you'll see, we'll have a complete tracking system or sensor system that will allow us to raise the accuracy of tracking and predictions way above what it is today because our sensors are space-borne and today's sensors are mostly on the ground. Ground sensors are limited, visibility-wise, field-of-view and recurring views of the same things. We're not going to have those problems. I'll explain in a second.

The system will accurately track near-earth, resident space objects, which means everything in low earth orbit. We'll collect debris of less than five centimeters in size, provide precision, low-latency space situational awareness data for dissemination and control.

What that means is our sensor constellation is going to be able to enhance space situational awareness and some other things that I don't have time to get into here. The point is we will be creating a revenue stream through the collection of debris and the selling of data.

Let's see…

My last slide. Our solution is patented. We have a basic patent on it. It involves two satellite constellations. One constellation is what we call the sensor constellation, which is, ideally or notionally, it's a circular orbit of sensor satellites with multi-sensor suites on them, looking at RSOs, which is resident space objects.

In other words, debris or satellites or upper bodies, wherever it happens to be, down to possibly as small as one centimeter, because we'll be in the environment, we'll be in the vicinity, so to speak, with the debris. Our tracking capabilities and our precision should be much higher than it is today. This constellation is in the equatorial plain.

Now, the other constellation is our debris collection constellation, which is in the range from 600 to 1,200 kilometers, maneuvering and changing shape of orbit all the time in order to collect the debris and avoid large objects. This constellation is also in the equator.

Everything we're doing is in the equatorial plain. Now, why is that? That is, because the equatorial plain allows us to reduce the problem to a two-dimensional problem. That means we have very small delta-Vs. We have very small propellant expenditure. We have great maneuverability, and everything is easy to get to, in terms of launching, of recovery, of the orbiting.

The equatorial plain turns out to be the ideal place to have our system. You might say, "Well, what about the debris?" Every hour or so in lower orbit, in fact, in any orbit, crosses the equator twice per orbit. Every 55 minutes, all 100 trillion pieces of RSO will go through the equator. We're waiting for them, so to speak. We have the ability of picking them up as they go through the equator.

That's the underlying approach to our collection process. All operations are in the equatorial plain, allow precise low latency RSO data collection. In other words, we can see objects much faster and more frequently than we can from the ground. We can track them and sense them better.

The equatorial debris collectors provide direct wholesale and selective removal of debris in the five centimeter and lower category. In other words, we'll be able to, not only collect small debris, but we'll be able to selectively collect it around the equator, which means that we'll be able to selectively remove debris from around constellations.

One of our services we're going to offer is protection, if you will, of satellite constellations, among the other services. That's a big revenue producer thing. Finally, the system provides a permanent safe environment for satellite constellations.

That's the end of my talk, but I'll be answering questions later. Thank you.

[applause]

Jerome Pearson: Yes. Do I have a controller?

Tech: You have it right there.

Jerome: Perfect.

[background conversation]

Jerome: Very good. We have a proposed solution for orbital debris removal. It's called EDDE, the electro dynamic debris eliminator. Now, I'll give you a few moments and the summary of what the EDDE space capsule is all about and how it works.

EDDE is a propellantless spacecraft that sails in the nearest magnetic field. Like a sailboat in the wind, it uses solar power to drive a current through a conductor, and that conductor fields a force from the magnetic field. By adjusting the direction of that conductor, we get a force any way we want to. We can control all six elements of the orbit.

Anyway, EDDE is a very small satellite. It's only 80 kilograms, yet fits in half of an ESPA secondary payload slot. It can even carry a few extra satellites while it's at it. In the upper-right, it shows EDDE in an ESPA slot here. Then, once it's gets on orbit, it spreads out and has a long conductor to operate in the magnetic field.

We think EDDE can master LEO, like the clipper ships mastered the oceans in the 18th century. There is a video from the movie, "Gravity," about debris, which I'd like to play for you. It's narrated by Ed Harris.

[video starts]

Ed Harris: [inaudible 22:35] active debris removal are ones that take advantage of the natural phenomenon and record it. One idea rides earth's electromagnetic field like a sailboat and catches debris in nets, like a trawler. This device is known as EDDE.

EDDE can be packed into four cubic feet, but once in space, it unfolds over a mile long. The main body is a thin tape conductor, which receives its current from solar array. The earth's electromagnetic force pushes against the current in this tether, like wind against the sail, or a bustier from space.

At each end of the EDDE are nets that can be fired at derelict satellites. The EDDE rendezvous with objects, catches them, and tows them to a lower altitude where atmospheric drag can help pull them back down to earth. It will cut the net free and find the next satellite to deal with.

[video ends]

Jerome: There's our 60 seconds of fame from the movie, Gravity. EDDE is a secondary payload. It's very easy to carry in orbit. It doesn't even have to have a dedicated launch vehicle.

Here's an example of it being in one of the ESPA secondary payload slots. It's deployed, it opens up, and pulls out this full length. At the bottom, you see a diagram of how it works with solar arrays distributed along the length and along the conductor.

At the ends, we have electron collectors and emitters so that we can pick up electrons, conduct them through the conductor, and emit them at the other end. That's what allows us to have the force.

EDDE is an affordable way of removing debris. If you look at the job of removing all 2,600 large objects from the lowest orbit, over two kilograms, that's about 2,200 tons. What you need to worry about is getting that propulsion to go from orbit to orbit to do that, if you want to grab each one individually.

If you try to do it with conventional chemical rockets, you're going to have to launch about 3,500 metric tons, and it's going to cost scores of billions. If you did it with ion rockets, you're going to have to launch probably 50 metric tons. It's still going to take billions of dollars to do it.

EDDE, with its propellantless propulsion system, you only have to launch one ton total to get rid of all 2,200 tons of debris in the lowest orbit, and the cost per kilogram is much, much lower, an order of magnitude lower.

Our status is that EDDE's been funded by Air Force, NASA, and DARPA. We've done laboratory tests, vacuum tests, and a few things like that to develop the technology. There are areas of technical challenges. The technical challenge is, we have to deploy and control that in space. That's something that's a key technical limitation.

As far as operations are concerned, EDDE is like a UAV in controlled airspace. We're going to be moving from orbit to orbit by other satellites, and we've got to be very careful in our control. We're going to have to file flight plans, have an agency that will clear our flight plans, and approve what we're doing and keep track of us.

Fortunately, EDDE can actively avoid all tracked objects. We're not going to endanger any other satellites or large tracked debris. Finally, we got to have some kind of policy to handle debris removal.

If an international agency wants to remove debris, and they work out some way of funding that, then perhaps there can be a bounty system where they pay commercial operators to remove certain amounts of debris, and so forth. EDDE would bid on those kinds of removals.

Our plan is, in three years, we can build and fly EDDE to demonstrate it in space. As soon as we get EDDE up, we can start removing dead satellites from constellations, like OneWeb or Iridium. That will provide some revenue. Then we can remove all the LEO debris over two kilograms in less than 10 years. That, of course, will stop the Kessler syndrome.

I have a simulation of the removal process. This shows the orbital debris accumulation since the late '50s. On the left, there is the altitude from 300 to 2,100 kilometers. At the bottom is the inclination orbit from equatorial to past polar.

What you do is you launch 12 EDDEs, one secondary payload slot. Then, the EDDEs move out, each selecting different inclination of orbit to move things. These are the 2,600 objects that we have plotted there. This simulation shows how fast the things come down. EDDE wants to come down slowly. Light ones come down pretty fast.

The other thing is that this simulation shows them taking them down at 350 kilometers, and then letting them re-enter, or we can do a control re-enter. It would be quicker and easier to put them into storage orbits at various altitudes, like 600 kilometers, and then collect them there, control their orbit so they don't endanger any other satellites.

Then, that gives us about a thousand tons of extra high-grade aluminum to build things out of it, like space structures, and so forth.

When they're done here, you'll see off to the right there, one of them goes over to the retrograde orbits, like the Israeli satellites that were launched westward cross in the Mediterranean. This simulation, in less than seven years, 12 EDDEs, one ton of launch can actually get rid of all those debris objects. That's our plan.

[applause]

Siegfried Janson: Good afternoon, everyone. I'm Siegfried Janson. I'm with the Aerospace Corporation, a federally funded research and development center for the Air Force's Space & Missile System Center, and for national security space in general.

Today, I'll be talking about Brane Craft, which is short for membrane spacecraft. This is a project funded by NASA's Innovative Advanced Concepts group. It's currently in a Phase II effort, which means I spent nine months and $100,000 doing a lot of paperwork to show that the concept is feasible.

The Phase II is a two-year, $500,000 total effort to try to invent some of the technologies. For those of you that understand NASA TRLs, I'm now taking it from, a technology rating is level of one to, maybe, two. Things apply are more like technology rating is level seven and eight.

This concept we're working on is a radical concept. It'll probably take about 10 years before you'll see a mission being done by this kind of a satellite in the future, but we'll try to fly parts of it earlier to test out different systems and subsystems.

I'd like to start out by saying this is from NASA's chart of the growth of orbital debris. I believe the five centimeter and up range is a function of time. Starting from the left, you see, in 1957 we didn't have anything to worry about.

Then, they invented these things called satellites, and the lines are then creeping up there with time. It's a growing problem. The brown line, they are the total number of objects, and the purple line are fragmentation debris the trash in space. The other lines below for satellites in the upper stages.

The one I'm concentrating on is the total number, and again, these are 5 to 10 centimeters. That top line is 18,000 objects. That's about what we officially track. If you go smaller, you're going to have a one-centimeter-sized objects. There are hundreds of thousands of those in orbit. A one-centimeter-sized object, if it hit you, it would have about 10 times the energy of a 0.357 Magnum bullet.

It may not kill you, but it's going to hurt. Same thing for a satellite. This large 5 to 10-centimeter objects, if they hit you, they're going to take out the satellite. That's what I'm concentrating on in this project. You see the numbers are growing, and things grow, they level out, then you have things like the Chinese anti-satellite test, which increases that number by a factor of 5,000 collision between the Iridium/Cosmos.

If you threw another couple thousand objects into the mix, imagine this progressing with time. That's what we're fighting. As long as everybody is level-headed and we go do stupid things, we have a chance of keeping that the grow rate is slow enough so that we can live with it.

When I'm looking at this active debris removal using a radically new spacecraft design that's a membrane spacecraft, the bottom line is I'm reducing this spacecraft mass from kilograms down to below a hundred grams. The reason I'm doing that is because it's expensive to put things into space.

If you will order a laptop on Amazon, and you got to the checkout page, there is no Amazon Prime for space yet, but if you did, they charge you, probably, $5,000 a pound or so to deliver it to your house. Well, you're going to order the lightest laptop you can. Same thing for space. We have to be aware of how much it costs to put things in the space.

Here, to eliminate say a kilogram class object using today's technology, I'd use what's called a 3U CubeSat, about a five-kilogram spacecraft. Right now, that cost about $250,000 to put into orbit. This chart shows the cost in billions as the function of spacecraft mass to 5,000 kilogram objects. You can see, if I use current technology, it's billions of dollars.

Take these numbers plus or minus 50 percent or more. This is just an estimate. You see, that's why people don't want to go after this. This is a multi-billion dollar problem. By reducing the mass significantly, I can reduce it down to $100 million or so, and that's the draw here.

As a technologist, my argument is, "Hey I can save, at least, one and a half billion dollars. Why don't you give me a billion for R&D because that's thousands of many years of technology development, something our country could use?" That's what I'm going after. I'm trying to drastically reduce the mass of spacecraft for active debris removal. This just goes through some of the members for that.

It's an electrically-propelled vehicle which means it has electric thrusters, which are very good. They are high-mileage automobiles. They generate thrust while using the smallest amount of propellant possible, but the idea is to take a spacecraft and crush it down in one dimension. You need the area for things like solar power and for resolution if you have sensors.

I'm shrinking it down into something that's on the order of 50 microns thick. That's thinner than a human hair. The reason I do that, I have a spacecraft that's about a square meter in size, I can process, I can produce about 200 watts of solar power with thin film solar cells. They're actually available today. Seven percent of the world's solar cell production are thin film solar cells.

I can produce 200 watts, drive my electric thrusters, and drive the electronics and everything else needed to make this thin spacecraft function. That's a radically different spacecraft. There also need things like the curvature control, which you don't have in a normal spacecraft, but I don't need gimbles and other things.

The idea is start off from a common orbit and throw up about 100 degrees. The International Space Station orbit looks like a reasonable starting orbit, and they maneuver out to individual pieces of debris that you've identified that you want to get rid of.

That takes a lot of delta-V because typically, the orbit inclination is different from your starting orbit, but once you get out there, you rendezvous with the target, and then you wrap around it, and then you just keep firing in the anti-flight directions to slow it down, and that brings it down quickly to reentry.

There's a video of this online in YouTube. Look up Brane Craft and the aerospace corporation. There's also another video on RatedRed.com, which is more amusing than factual. That's the basic idea. We maneuver up, we rendezvous, wrap around and then drag it down to its fiery death.

If propellant is still available, you can go after other objects. One of the other applications for this that people have mentioned to me is upper stages. I can go up, rendezvous with an upper stage and just perturb its velocity a little so that I can prevent a potential collision that's going to occur three weeks later. There are other applications for this. It's a revolutionary design.

I'm shrinking the mass of the spacecraft by more than an order of magnitude, typically about two orders of magnitude. What that does for me is it gives me an electrically-propelled vehicle that accelerates two or three orders of magnitude faster than any other electric spacecraft that's been put into orbit before.

The thing maneuver is more like a chemical spacecraft than an electric, but it has the fuel efficiency of an electric thruster. What does that mean? It means that you can get a huge delta-V at one of these things. It only weighs about 80 grams as delta-V of 16 kilometers per second. Now, remember the orbital velocity in space is on the order of seven kilometers per second.

That's 16 kilometers allows me to go up to anywhere I'm allowed to orbit, and that's up to 2,000 kilometers, any inclination rendezvous with an object up to 0.9 kilograms in mass and bring it down, and that's on the worst case. Typically, you can take down a piece of debris that's about two kilograms in mass.

On the left is a cross-section of the basic design. The idea is to get rid of all the boxes, all wiring, and make it more like the way we make televisions today. On the right, it's a cross section of a flat screen television.

Tech: One minute Dr. Janson.

Siegfried: You normally have two glass sheets, you have liquid crystals sandwiched in between, and there are transistors that are printed on one side of those glass panels. On the left, we replaced the glass panels with 10-micron of the Kapton, and instead of liquid crystal, we filled with an ionic liquid. That's the propellant for the electric thrusters.

We bound them all together and again, in a current 4k television, there are about 25 million transistors. Those are enough transistors to drive the spacecraft. We're going to shrink those down and use them, print them in a Brane Craft.

I'll go through...Skip through some of these...

Victoria: You have 30 seconds, typically.

Siegfried: It turns out the two biggest problems are radiation because it has no radiation shielding. It has to be rather hard. We'll figure out how to do that. In terms of orbital debris, now we got to worry about things that are four microns in diameter. The bottom line is a one square meter Brane Craft will get hit about 40 times over its one month lifetime.

That's all it takes to go from lower Earth orbit, grab something and bring it down for re-entry. Literally, it has to be bulletproof. That's a challenge I accept because we can build, distribute an electronic systems on the surface of the Brane Craft.

Finally, again, this is a new technology. We're pitching it for active debris removal, but it can also be used in a lot of applications. The high delta-V allows it to go just about anywhere in the solar system. On the bottom right, I have a solar system subway map, a lot bigger than the LA subway or the Washington DC subway map, and the numbers are delta-V.

It's not cost, but it's the cost in propellant essentially. If you add the numbers, basically, a Brane Craft can go from the space station to orbit the moon, come back twice. It can go to any of the two moons of Mars and come back. They can visit a lot of the asteroids in the main belt.

It's an interesting new capability that NASA and the rest of the world could utilize for things other than active debris removal. I'm going to stop it there.

Victoria: Thank you.

James Dunstan: Good. Asking a space lawyer to give you a talk in seven minutes is like asking an orchestra to play Beethoven's Ninth in seven minutes. You can do it, but you're going to lose a lot in translation. Just to give you a very, very high level, pun intended, talk about the legal implications of orbital debris and debris remediation.

Before we start talking about it, we got to put a fence around it. Orbital debris is an international tragedy of the commons. To give you a perspective, they are now nearly 50 countries who are registered with the UN as exclusively or jointly in controlling objects in orbit. That's about 25 percent of the world's country.

We think about orbital debris in terms of three major powers, but in fact, everybody's got skin in the game in this way. It's just not the United States, Russia and China.

The first fundamental question under international space law, is there a duty to do anything about space debris, space junk? The simple answer is no. None of the treaty language talk about space debris. They talk generally about not contaminating space and celestial bodies, but there isn't anything specific about it.

We do have a number of international guidelines, and we have domestic guidelines. One could argue that at some point, they either have become or could become what is known as customary international law, which is an international law, which binds all countries because all countries have essentially agreed to it.

The problem is, I don't think we're there yet, and I don't think we're anywhere close to being there yet. How is this played out? I'm going to give you three scenarios here where we've had to deal with orbital debris and what we've done. The poster child, probably, is Envisat, the ESA base satellite.

This thing is huge. It's about, boom, half the size of this room. It's one of the largest objects ever put into space. I think it is the largest single object put as one piece. It was 8,000 kilograms, launched in 2002, had a design life of five years. ESA decided to basically run the thing dry.

They were getting such good data out of it, such important data out of it, they just kept working it, and then lo and behold, in 2012, boom! They lost contact with it, lost the ability to control it, lost the ability to de-orbit it. Now, one of the claims put out was that in 2002, ESA adopted orbital debris mitigation guidelines, which included a guideline that said, "You need to de-orbit at the end of life."

One of the arguments made was, since Envisat was designed and partially built prior to the adoption of those guidelines, the guidelines didn't apply. [laughs] Second one, in 2014, Iridium went to the FCC and said, "OK, we got his orbital debris mitigation plan."

FCC has pretty strict rules, which we have to do and they said, "But we really need to operate some of these satellites beyond their design life. In fact we need to run some of them dry, but that's OK because they'll de-orbit just under the 25-year rule."

The FCC said, "OK, that sounds OK to us," but you went from a debris mitigation plan that was, originally, at end of design life, we'll get them down within a few months to they're going to be hanging around there in 25 years.

Quick thing on the 25-year, I don't believe that the 25-year equations have been updated. Those of you familiar with solar cycles, we're in our third since Maunder Minimum solar cycle. That's important because that doesn't raise the atmosphere of the earth, and so, both that 25-year equation may actually be a lot longer than that now.

I don't know. I'm not an engineer or scientist, but it needs to be looked at again as Senator Peters said.

Finally, just recently, EchoStar III. You probably all heard all about it. It was sitting as non-orbit sphere for EchoStar, and they ask FCC for authority to move it from 61 degree, 0.86, 0.85, and operate for a few months as a stop deck measure for a European group, and then they were going to de-orbit it. The problem is, they've been sitting.

Engineers will tell you what they're most concerned about, state changes. Going from on to off, off to on, you all have experienced this. You turn on that light bulb, it pops, or you turn off that light bulb. It's when you change the state from on and off.

I don't know if there was actual discussions about the fact that EchoStar was, at least, eight years past its design life when it was allowed to be moved, and they turned it on, started to move it, lost contact. Fortunately, they got contact back with it and they were then able to take it up into a graveyard orbit above the geostationary orbit.

My point is that is discussion needs to be had. If you're going to do something like this with a satellite that's well beyond its design life, the hard questions need to be asked, "Should we really be doing this because what if something happens?" If they haven't been able to regain that, that was moving at 0.1 degree a day across the geostationary orbit, and folks would had to get out of the way of it.

Moral of the story is, how can we get serious about debris removal when we're really not serious about the debris problem itself? I would say that we really aren't that serious about debris problem. We get serious every couple of years when we have something like the Iridium/Cosmos or the Chinese ASAT test, but generally, we go back to sleep because, gee, it's a big sky, it's a big place up there.

Let's just let these guys go get the bad stuff, right? Right? Not so fast. Problem is, we've got Article VII in our space treaty, and that basically says, "Anything launched into space always remains within the jurisdiction of the launching state."

Even if it's no longer viable, even if it's debris, it's still is the property of the launching state, which means, I can't just go up there and grab all those Soviet and Russian upper body stages that people talk about as being the worst actors of them. Under international law, I'm just not allowed to do that. What do we have to do to overcome this legal challenge?

I agree, there's a couple things we need to do. We need start thinking of space more in terms of maritime law than other types of law. Because under maritime law, it's exactly the opposite. You have a duty under international maritime law to get rid of your debris.

There's even an international court justice case the Corfu Channel, a case that all the law students in international law have read many times, I'm sure. We said that you just can't leave your mines after World War I sitting there. You got to get rid of them and you're liable if somebody crashes into one-year old derelict mines.

The same thing could be applied in outer space to say, you have an actual duty to get rid of this stuff, and more importantly, if you don't get rid of it, then somebody else can. Under maritime law, there's concepts of fines and salvage in which you can go get rid of that derelict barge, and then get paid for it because the owner of the barge didn't get rid of it.

He had an obligation to do it and now you can charge him to do it. We be thinking about this. We also need to make it easier to be able transfer the ownership of objects so that you could go to Russia and say, "Hey give me the right to take down one of your upper stages. Now, you need to pay a little bit to do it."

Finally, overall, we just got to get this notion of big sky out of our heads. We keep falling back on it, and we've got to get rid of it. We should start bilateral discussions without other countries, with China and especially with Russia, who's, again, has a lot of those upper stage sitting in polar orbits 600 kilometers that we'd like to get rid of.

We need to pass additional legislation to cover some of the financial liabilities for doing this. Then Congress needs to designate a single agency as Senator Peters talked about. There's five different agencies that have five separate sets of orbital debris mitigation. They're splattered all across the role code of federal regulations.

Finally, the United States government needs to invest in orbital debris removal technology such as these folks, and then turn it over to private sector to let them commercialize. With that, I thank you.

[applause]

Brian Weeden: Thank you. The last one we're going to talk about today is the public policy element of some of this, and as Victoria hinted at, I wanted to start talking a brief tour of the evolution of US policy on space debris, what we have done, haven't done. I'm going to close and echo some of the things that Jim just mentioned about steps we can take now in my mind addresses issues from a policy standpoint.

The evolution of US policy on this, space debris is the part of national space policy statements since the Reagan administration in 1988. Along the years, the present administration that had published updates in '88 have generally included everything the previous administration said, and it added a little bit of new stuff.

In some cases, they reworded a work here, there, but generally, it's been pretty consistent from administration to administration. The driver for this, initially, was human space life, where they put these astronauts up in orbit on the earth and sent into moon.

How do we keep them safe while the space environment is a problem there? That's where they start the original massive studies on this. What's fascinating is you read Don Kessler and Burton Cour-Palais originally paper in 1978, the paper that have since coined the Kessler syndrome.

They're concern was that at some point in the future, the human-generated space debris will be more of a threat than the natural space debris. Don't even think about the natural space debris in the orbit. The bits of asteroids that are floating around space. All we think about is the human space debris. That is the original concern when we think of the Kessler Syndrome.

What's also interesting is that in most cases, these statements in national policy have followed actions. In other words, the policy statements most often didn't come first and then drove actions. In most cases, they basically codified things we were already doing.

In 1988 which is the first time it appeared in National Space Policy of Reagan administration, the focus was, basically, on reducing debris through tests and experiments to be done in space. And that reflected some things that were going on, where they were doing test on the FDI program, and trying to figure out ways to test on-orbit intercepts without generating huge amount of space debris.

Just a year later, the first Bush administration published their updated, and they added in, by the way the US should also be pushing other countries to do more about space debris.

The next update came in '96 in the Clinton administration, and they talked about there should be design guidelines to minimize debris creation and include safety of spacecraft, and we should do more to foster international adoption.

What's interesting is that it came two years after the formation of the Inter-Agency Space Debris Committee, which is where all of the space agencies get together to discuss the technical aspects of space debris, and a year after NASA had finalized its first set of draft guidelines on debris mitigation. Again, the Clinton policy was defined by what's already have been done rather than pushing.

2006, the second Bush administration released their National Space Policy and they talked about implementing national standards on space debris for both public and private actors. By that, they meant in 2001, US Government had approved a set of standard space debris mitigation guidelines.

The Bush administration said, we're going to put those as requirements for government satellite programs and through licensing for commercial satellite programs.

Now there are waivers, and Jim talked about a couple of examples where government actors and ESA is not the only example, NASA, the DoD have also requested waivers to the debris mitigation requirements, have gone and said, "Hey, we'd like a little bit of a leeway on this."

But in general, if you license a satellite, if you're a commercial actor and you're launching a satellite or if you're a government program launching a satellite, you have to comply with these standard debris mitigation guidelines.

Then in 2010 the Obama space policy added yet another update. They added two new things. This is where the trend changes because these were not quite leading but they're on the edge between leading and codifying what exists. The Obama Administration added that there should be more done to do collision warnings and there should be this research into debris-removal technology by NASA and the DoD.

The collision warning measures have largely been implemented. Later that same year in 2010 USSTRATCOM officially started its SSA sharing program where they provide every satellite operated in the world warnings of close approaches between their satellites and other things in space. That's been going on ever since 2010.

The last numbers I saw were there were on the order of 150 or so maneuvers done in an average year to reduce the risk of a collision as a result of those warnings. That I think is a success in terms of implementation of what the policy directive was. It was hinted at by Victoria a little bit less so I think on the ADR side of it.

There was early interest 2009 to '10, 2011 and '12 by both NASA and the DoD in debris removal. I remember going to a conference in Chantilly in 2009 co-sponsored by DARPA and NASA on debris removal. We talked about legal issues, talked about policy issues, talked about technology.

DARPA had a research project called “Catcher’s Mit” that I know Marshall was involved in that talked about the importance of doing it. But that focus and study hasn't really translated into a lot of action. NASA has funded some initial research into this. Both Jerome and Siegfried, they've talked about, they've gotten some funding from NASA to do early-stage studies on some of these technologies.

NASA released a memo in 2014 that said they're going to limit their investment to things tier L3 and lower. Which means they're going to invest in the R&D up to a certain point but not invest in on-orbit demonstrations and further.

That creates what we know in the technology world as a Valley of Death. We have a little bit of funding in the beginning to do some basic R&D and there may be somebody who might actually purchase it or use it if it gets there, but there's nothing in the middle that gets it beyond that initial stage where it's actually being useful.

Next slide. Sorry. If I was to go through and give a grade in terms of implementation, I would say most of this were implemented -- now it's easy because most of it lagged -- but the Obama 2010 policy ideas...my daughter has a term, her thumb's middle when she has a food that she doesn't really like but we're going to eat anyways.

[laughter]

Brian: That's where I would say for the 2010 policy. Some of it was implemented. Like I said, the collision warning measures implemented. But the develop-the-ADR technology was not. What I want to finish with is this question of why not.

Victoria: One minute.

Brian: I think there it has to do a lot with incentives. It is not NASA's mission, it's not DoD's mission, to manage the space environment. They have other missions to do. When it comes down to budgets and priorities, they're very unlikely, it seems rational for them not to put money against things that are not in their actual mission area, particularly when they have not enough money for the things they're actually being told to do.

I would largely agree with Jim in that I think we solve this from the government side by making it someone's mission to think about the space environment. That could be one of the existing entities. NASA, NOAA, the FCC, it could be a new entity that combines some of the regulatory, let's say, functions that Jim talked about.

That's part of the discussion going on right now with changing the way we do oversight of private-sector activities. I don't think that entity should go off and have a multi-billion-dollar budget to go do this. What I think is more the case, that they're in charge of...basically I said a bureaucratic champion.

They're in charge of shepherding the technologies. Figuring out which one of these technologies that are being discussed here, and there's others out there, is the best to push forward. Doing that early-stage R&D, maybe doing an X Prize program, maybe doing some sort of a commercial cargo and crew-like program that then the government can purchase its service or private can purchase service down the road.

That, I think, would go a long ways towards fostering some of the private-sector development we're already starting to see and take it to something we can actually make use of. I went in there, and I'm happy to take any questions.

[applause]

Victoria: My first question's actually for the technology guys. One of the things I hear a lot of in industry is they like a light regulatory touch and that you want enough regulations so your investment is secure and safe and you have a stable demand to work in but you don't want it so heavy that you're unduly hindered by regulations.

My question to you is currently is the regulatory environment a good environment for your technologies to work in, or is there something that could change to make it more beneficial for your programs to proceed? This is for any of you guys. Can the legal policy guys answer this?

Marshall: I'll try and amend here a couple things. We'd like to have an indemnification with the government for liability in case something runs into us or we run into something that we shouldn't have run into. I think we need to limit our liability through a government legislation. That's a pretty big factor for everybody I think.

Secondly, we're trying to do a public/private partnership to start our program with that we'll want to convert ourselves into a commercial entity. There will be a certain regulatory impact there, but I'm not sure what at this point.

Jerome: We're concerned a little bit about EDDE being a maneuverable spacecraft that moves around among other satellites. We're going to have to be protected from liability as well. We expect to have a NASA or Air Force contract to cover us for things like that. Also, we have to have somebody agree on approving what orbits we can go to and how we can do it.

That's like flight plans for aircraft. The other thing is the Air Force would like us to avoid certain assets they have, but they don't want to tell us what those assets are or where they are.

[laughter]

What they have suggested to us is that we file a series of flight plans to go from orbit A to orbit B, and they'll pick the one that avoids their assets.

[laughter]

That's OK with us.

Jim: Technically speaking, if any of these technologies work here, eight or nine ready to fly, there's no government agency that has the authority to actually say, "Yes, you can go do this." The one thing we always have to keep it in mind is one person's orbital debris-removal system is another person's ASAT because that same technology can be used.

Jerome, I think just hit it right on the head. We've got to find a way to make everybody both domestically and internationally comfortable with these types of technologies flying around taking bits and pieces out of the orbit because you don't want your bit or piece taken out if it's an asset of yours.

Brian: I would add onto that yes. There's no one that could say yes. There's no license you can get for one of these guys to operate a removal vehicle. The Department of Defense currently has the data to monitor what's going on in space, just space data, but they don't have any regulatory powers.

The civil agencies that have that regulatory power always had function in some cases. They don't have a lot of the same amounts of data that we have. I think there's also a link there between access to the data to know what's going on and the oversight licensing mechanism. In my mind that needs to be closely linked, so then that leaves a question.

If you think about if there's going to be a civil agency that takes over some of the collision warning as a safe function, do we pair that up with whoever is doing the alarm-orbit oversight? That's something I think to consider.

Victoria: My next question, then we'll go to the audience. Who's going to pay for this? Do you guys anticipate the customers having the money to pay for this? Are you more likely to find people to pay for it in one orbit than another? What kind of cost will come from that? Any insights you guys can combine on this?

Siegfried: Well, I'm from California. When you buy a television, they charge you an extra $10, $15 disposal fee for when you get rid of your television finally. That's one option.

Victoria: You have a solid disposal fee.

Siegfried: Whenever you launch it, there's some fraction. You pay a fee or some fraction of the total vehicle cost for eventual disposal.

Victoria: I don't know, but there's mega constellations that might be more worried about that.

[laughter]

Marshall: I have some ideas. We're designing a whole system to be commercial. In other words, we're designing it around a business plan that makes money. In fact, we're already profitable. I can't give you the details but we're already profitable.

We've only been in business a year. The fact is that we're positioning ourselves to be there when the debris gets worse, a lot worse -- that's probably going to happen in another 10 or 15 years -- and people start losing satellites very rapidly.

We'll have the capability of removing the debris around these satellite constellations. Of course, the insurance companies will require us to do it. Anybody that wants insurance on a constellation about 10 or 15 years has to come to us. We're going to charge them enough to pay for our services. That's only one of our services.

We're also going to collect and send data, data for big debris removal, data for SSA, data for space travel management. We'll have the accurate data nobody else will. That's another revenue stream that's pretty large. There are others, too, that I can't talk about here.

Jim: I want to respond to the insurance question, because I've always thought that that was eventually the holy grail for all of this. Once on-orbit insurance rates started to bump up because of potential collisions, that would flood money into it. I've talked to quite a number of the insurance industry people over the years. They're still saying it's still in the noise level.

There isn't a single orbit now where they target it and they're on-orbit insurance, which itself is about five percent of the total insurance budget. Most of it goes to launch and deployment. There's not a single orbit that they've looked at that they've said, "We're going to bump your rate because of potential orbital debris and collisions."

It's horrible to say we may have to wait a little while for the insurance folks to get on board on this. They're actuarials. Essentially it's licensed gambling. Right now they're playing with house money. They don't have to put anything into this.

Brian: The business model is looking to the commercial operators to chip in. I think that makes sense going forward, especially as there's is more commercial development, more commercial something in space.

I find it difficult to ask the commercial operators to pay to clean up the mess the governments have made, which is largely what the existing debris population is. It's mostly government payloads, government fragments and government rocket bodies in the last 15 years.

In the many cases, they're in orbits where there's not a lot of money being made, so it's hard to find an economic incentive. I like the ideas of a company that may have hired someone to remove their stuff as a service, so then they don't have to guestimate how much fuel is remaining. I like that. That's part of the solution. I don't see that's going to help solve the existing catalog.

I think there's going to have to be a time where the governments cough up money to clean up some of the stuff they made. Doesn't have to be right away, doesn't mean all in one chunk. At the moment, the US spends roughly $40 billion a year on investing in space and launching government satellites. They say that that's a huge thing that is critical to national security.

I don't see it as a huge leap to say there should be some extra money or some of that money towards helping clean up some of the mess.

Jim: Brian, I want to get back to the end of life. That actually could work. If our orbital debris mitigation rules across the agency have real teeth in them, that there's fining ability if you ran your satellite dry. The flip side of that would be, you run your satellite dry, you want to get two or three extra years of revenue off of a GEO satellite, that's tens of millions of dollars.

Now you contract with one of these guys. You can't do EDDE, because that doesn't go up to GEO, but what if you could contract with somebody and say, "I will run my satellite dry and I'll make an extra $30, $40, or $50 million, but then I'll pay $10 million to these guys to come de-orbit my satellite when it really is at the end of life, not just at end of design life."

Right now, there isn't that incentive. There's absolutely no stick. There's absolutely no penalty for running dry right now.

Victoria: With that, I'll open up to the audience. If you have a question, please wait for the mic to get to you and identify yourself

Audience Member: I have a question. There's lots of different models, but let's take the government's page four model. The extent to which the government is looking for a cost benefit trade, what's the right metric for determining how valuable any given orbital debris activity is?

Is it the pure number of objects? Is it some sort of density function? Is it some sort of probability function that deals with the probability that something in some orbit is going to get hit with? What's the right metric to make a value judgment? You guys were all dealing in different size regimes, different orbital regimes maybe. What's that like? The cost part is pretty easy, but the benefit part, what's the right metric?

Marshall: What's it worth to get into space?

Audience Member: Like I said, the cost part I get. What is the right metric? Is it the number of objects removed?

[crosstalk]

Marshall: The benefit to going to space is about $40 billion a year, I guess, what we're spending now. We can't get to space, we can't spend the $40 billion, we can't have the service we're having today, including communication, navigation, etc. We do nothing, in about 15 years, I figure, we won't be able to get to space. There will be too much debris.

What's it worth to keep the lanes open, so to speak? It's worth about $40 billion a year. I'm not going to charge that.

Audience Member: That's not my question.

Marshall: I know. I don't have a good answer for you on metric exactly.

Brian: I've had very similar discussions with the scientists at NASA and ESA, who are studying this. In some ways, it's a choice of what's your biggest concern. If you remove the big stuff, that slows the rate of growth over time, but it doesn't do anything to address the threat right now. Satellites right now are suddenly hit by all the stuff that's up there right now.

Removing the littler stuff that's up there right now, the kind of things we're talking about, the small debris we can't track, that is right now an unmitigated hazard that exists. We can't dodge it. We don't know where it is. That would probably have a better impact over the short to medium term in terms of reducing failure to spacecraft.

I think the sense of your question is, we don't really have a great answer. I agree with that in large part because there has not been a lot of studies put into answering is after that question. The IADC is looking at it a little bit, but my understanding is they have not really had enough time or enough motivation yet to answer that specific questions you're asking.

Jim: Actually, one of Jerome's associates, Joe Carroll, who's done a lot of study on this and has done some probabilistic analysis. The problem is the probability of any particular object colliding with any other particular object is 17 points to the right of the decimal point. It's really hard to do it.

Nonetheless, there are some good analyses Joe and a couple of other people have done that basically look at size, density, and most importantly, the overall congestion in the orbit. There are a couple of particular orbits, 600-kilometer polar is generally regarded as the most crowded.

Chances are, if you wanted to go somewhere and take some stuff out and have the greatest benefit, that's where you would look because that's got the highest density and probability overall of something happening. Which of those 2,000 objects in that orbit you take down of the greater benefit? That's a tougher call. I think we can make some difference between different orbits as to where you would want to go after.

Victoria: Right. Just to clarify, I'm going to jump in real quickly, as a policy person. I think a lot of people think the movie "Wall-E," you can cast your mind after that, where there's planet completely sounded by debris, virtual debris.

I don't think anyone here is saying that's what's going to happen. The concern is more it's going to be economically unfeasible to operate things at a particular orbit until the debris situation is taken care of.

[crosstalk]

Marshall: Let me jump in here. We are about to start a cost benefit study and evaluate the various propositions for the whole system. We're a commercial company. We need that for our business plan. Hopefully, within six months or so, we'll have some good ideas.

Siegfried: How many collisions have occurred in the last decade? Three? Four?

Male Panelist: Define collision.

Male Panelist: That we know of.

Male Panelist: That's right.

Male Panelist: Define collision.

Siegfried: That's part of the problem. I think there's three or four collisions we really know. There could be 10 that we don't know, because we just see it as a system failure. It occurs to me that the probability of a collision is probably proportional to the square of the local density. If you double the density, that number goes up by a factor of four.

If you have one per year, is that acceptable? Maybe not. That tells us, OK, we probably don't want to quadruple the density of objects in orbit at any given location. It is a lot more complicated. It depends, do you have concentrations of density? Does it spread out? Right now, we're at a point where I think we're still trying to figure out, is it worth it?

Marshall: One of the reasons we haven't done anything so far is because we haven't had to. That's obvious. We've accepted the occasional collision or damage. However, the problem is growing exponentially. It's not growing linearly. It's growing exponentially. Sometime in the next decade or two, it's going to be a lot worse.

Siegfried: Is it exponentially? The official tracked objects is going like...that's not an exponential growth. I don't know about all the other objects.

Marshall: They don't account for the 16,000 new satellites that are projected to go up, for example.

Siegfried: That doubles it.

Victoria: It also raises the question that Hannah was talking about. Is our situational awareness up to the task?

Male Panelist: No.

Male Panelist: No.

[laughter]

Victoria: Next question.

Siegfried: I've been on the receiving end of a call from JSpOC. "Your satellite's about to collide with something else." Ironically, it was a piece of debris from a Russian anti-satellite. The problem is, the arrow bars are so big, I had to call him back and say, "I don't have altitude. I don't have propulsion. I can't do anything."

The bottom line was, they call you, but there's really a very small probability that there will be a collision. That arrow bar has to be reduced to the point where we know within a factor of four or so if there is going to be a collision.

Marshall: You just gave a sales pitch for our satellite constellation. [laughs]

Siegfried: As a satellite operator, that's what I'd love to see. I want to know. Will it collide? It's very important because a lot of satellites don't have propulsion, but they have attitude control.

If you tell me two weeks from now, "There's a high probability you're going to hit something else," and I'm below 700-kilometer altitude, I can change my spacecraft orientation and avoid that collision just through air drag. That's another tool in our pocket.

Marshall: You'll know which way to change the drag.

Siegfried: Right.

Victoria: Since our mic is no longer working, just stand up, speak, enunciate, yell. We want to be able to record this best, please.

Audience Member: Just a quick question.

Victoria: If you could identify yourself, please.

Audience Member: My name's Roger Cochetti, I'm the author, or rather the publisher, of "A History of Space." Question I had, for lots of good reasons, all of the conversation has been about lower orbit. That's where the action is. That's where the risks are. I wonder if any of you could just offer any comments or observations about geostationary or elliptical orbit.

Is there anything in the next 100 years to even think about in that category, or should you just confine all of the LEO information available?

Brian: I'll start. Historically, we've said there's a lot of stuff in GEO, but it's all going the same direction. The relative loss is much lower. The density of the objects are might higher in LEO, particularly 600-700 kilometers, so a lot of the things have focused on LEO. There's been some research and analysis in the last year or so that suggest we probably should think about GEO a bit more.

There had been two or three anomalies that have happened in the last year with GEO satellites. The one you mentioned was one of them. There was a couple others. They're all toward the end of their life, so it's hard to tell whether it was because it reached the end of life and it exploded, or whether they got hit by something, particularly something small enough that we're not tracking it.

That's a really difficult problem to figure out.

Audience Member: It could have been a natural one.

Brian: Absolutely. Absolutely. My sense, we have a lot worse data and understanding of the GEO orbit regime from a debris perspective than we do for low Earth orbit because it's 36,000 miles away. It's much harder to track stuff. I think the historical conclusions then, we don't have to worry about GEO yet, but that may be changing.

The flip side is, that's where all the commercial value is right now. There's $120 billion or so or more a year in revenues in broadcast and television. It's all in the GEO belt. I think that's something that's starting to change. We probably should pay attention to that.

Jim: Let's not forget the medium orbits, where GPS lives. If something were to happen to multiple GPS satellites, we all would drive off the road, literally. We couldn't get around. I posited a thought experiment one time, what if we would merely charge a dollar tax on every GPS chip that went into every phone?

That would in fact fund orbital remediation across the entire world and nobody would know the difference of it, since you essentially don't pay for your phones anyway, you wrap it into your service plan. As Brian points out, are you then going to take that money and bring it down the LEO where the problem seems to be the greatest? It's an interesting thought experiment. Brian's absolutely right.

Take ISS out of the equation. The most valuable objects we have in space sit in GEO or they sit in MEO, not in LEO. Yet, LEO is where the most congestion is right now because it's the easiest place to get to.

Brian: I was about to say, the most commercially valuable things are in GEO.

Jim: Yes. Yes. Yes.

Brian: That's true. The National Security community have some stuff in LEO, you don't put a price tag on it.

[laughter]

[chatter]

Victoria: Other questions? Yes.

Audience Member: Hi, my name is Eliza Boggs. I'm a recent law school graduate. I had a people question for you. Following up on the suggestion that governments should be responsible for the damage that they cause, you said a simple answer is no, but there's no obligation to clean up space debris.

I know you were giving a high-level answer, but don't states have a responsibility to not cause harmful interference with other states, freedom to use and explore outer space under Article IX?

Jim: You're absolutely right, but part of the problem is, we have a dual liability regime under the Liability Convention, which says that states are strictly liable for damage in the air and to the ground objects, but it's a negligence theory in space.

For negligence, as you know, you have to have a duty, you have to have causation, and so even if you take a look at actual collisions, Cosmos Iridium. I've actually sat and done mock trials of that as if we were to take that to trial.

It runs off the rails pretty quickly. You look at historically what states have done, they haven't accepted that actual duty to get rid of their stuff. Without a duty, there is no negligence. That's where, my suggestions, we've got to start changing that thinking. We've got to make it so that states, in fact, are responsible to get rid of their stuff or they're going to be held liable for it.

Brian: I think I would interpret Jim's comments as, they are potentially liable under the Liability Committee as he said, but state practice has basically been to ignore the problem. There hasn't been a court case, there hasn't been a case brought that would prove damages. There's no standard of care. None of that has existed.

Even Article IX talks about the responsibility for consultations. Can you name an instance where there's been an international consultation as a result of harmful interference? I can't think of any.

Jim: Cosmos 954 over Canada, but that was under the atmosphere liability. Not for anything in space, no.

Brian: Correct. I think what he's saying is the state practice has been to not deal with this issue, even though they do have potential liability for it. I would suggest maybe that needs to change.

Audience Member: Sorry. Just as a note. Because Article IX was like was drafted in response to Project Westford where everyone was afraid that a giant belt of needles would prevent us from being able to explore outer space, I think that there might be some, even though that's pretty outer space creative, that might provide some kind of a precedent.

Victoria: That actually begs the question -- maybe Brian, or if anyone else wants to discuss this -- what do the international fora discussing with debris removal. What's happening in the United Nations?

Brian: They're talking.

Jim: Between cocktail parties.

[laughter]

Brian: It’s not that bad..

Brian: Victoria asked what's going on in the international forum. I would say, historically, the space agencies have led on this issue because they're primarily the ones doing the research. There are international bodies where they come together to share that research.

The technical guidelines the space agencies agreed to in 2007 at the IADC, they were endorsed by the UN Committee of Peaceful Uses of Outer Space at the end of 2007, basically saying, "We approve these." Since then, there has been a lot of discussion in the international arena about states humblebragging about, "We've implemented these in our international law and policy," and encouraging each other to do that.

More recently, there has been some discussion about moving beyond just space debris mitigation guidelines. They're talking about things like, SSA data sharing, guidelines for collision avoidance best practices, pre-launch collision avoidance screenings.

They're still in the realm of voluntary guidelines, but that's where that international discussion has been. I have not seen any significant interest in moving toward more legally-binding discussions. It's all how can we move toward more voluntary practices.

Jim: Interestingly, IADC did come up with a relatively new distinction between an operating satellite and a derelict satellite, which has not yet filtered down into any domestic. That has actually, in my mind, the first critical step of moving, again, toward a more maritime approach to this.

That recognizes that once your object becomes a derelict, it is a hazard and really, you've either got to do something about it, or you've got to give up your right to jurisdiction over that object. Again, that's an IADC policy that hasn't filtered down into any state actions yet.

Victoria: An enthusiastic question right there.

Audience Member: My name is Alfred [inaudible 82:19]. I used to work for Oceans, Environment and Space in the State Department. I've been interested in salvage. Jerome mentioned bounty hunters getting paid for various kinds of salvage that they do and there's a long history, a long heritage of salvage in the maritime world. It goes back all the way to the Greeks and the Romans.

You have also the London Dumping Convention. What do you see as analogous things that we can do with space law? Do you think there's a possibility for an international space salvage convention some day?

Jim: I think that's possible but whenever we start talking anything about an international convention or treaty, that is a can of worms that I usually run screaming away from, not that I have anything against worms.

But in this case, I do, because every time, at least the United States has tried to put forward a new approach to doing this, the discussions get derailed and we ultimately end up in this black hole called The Moon Treaty because that's where everybody devolves to.

But by the same token, there is some things we can do, as we're doing with asteroid mining. We basically stepped out, as a country, the United States adopted domestic legislation to recognize the right of harvested minerals, extracted resources from space, even though there's an argument that there's an Article II issue.

We could do the same thing when it comes to orbital debris. We could, as a national policy, adopt a derelict definition by IADC, which says, "If you are no longer able to control your satellite, it is now a derelict and it is open to be removed." Now that's the first step and then eventually, we can talk about potential bounties or ways that we can pay for that.

Right now, we're not even to that point, but that's a really important first step that I think the United States could go it alone and the same thing we're seeing in asteroid mining, the same thing we're seeing with sub-orbital tourism. The rest of the world will follow on with what the United States does.

Audience Member: In the maritime context, how do the salvage get paid?

Jim: In the maritime, what they do is they file a claim in a maritime court and say, "I removed this barge, which was sitting at this location in this river. It belongs to X, Y and Z, it cost me $240,000 to remove it, I therefore ask for $400,000 to be paid by the barge owner."

Then it's lawyers going at it. "It wasn't my barge," or, "It was just sitting there. I still had control of it." Basic tort issues you can go for. We could see that. I could foresee a regime where that could happen in space as well. I think it would be a very positive regime. If anything else, nobody wants to litigate so everybody would start getting rid of their junk. Less work for me but you know...

[laughter]

Brian: More jobs for lawyers.

Jim: Exactly. All right.

[crosstalk]

Victoria: I think one of the issues for that as well if you have to actually know who it belongs to and for space debris, that's not always the case. We have a question here.

Audience Member: Sure. [inaudible 86:00] EPA attorney super fund and McGill Aviation and Space Law Grad ’14. I like your idea about the dollar tax on the GPS chips but we need to expand on that, launch user tax, launch tax. These large constellations, taxing individual satellites. That can create a super fund or pot of money to fund the R&D necessary for space debris removal and mitigation.

These orbits are finite, natural resources. This isn't really natural resources but finite resources. We need to permit, regulate and remediate.

Jim: I actually used to have a slide that had a super fund analogy on it and every time I showed it, at least two or three people came up and beat me over the head with a baseball bat saying, "Never talk about super funds. It's such a bad program."

[laughter]

I don't use that slide anymore but the concept does remain the same. Pigovian taxes on the uses of outer space resources that spreads that cost around.

Brian: I think that has value, particularly as we go forward to a more commercial portion of activities, but at the moment, it's still 40 to 50 percent government activities in space. Yes, for the commercial side, but I'm not sure how that addresses government behavior.

Governments are often not responsive to price incentives for how they behave, particularly if they're doing something for a national security or defense mission.

Audience Member: They do retain liability.

Brian: Absolutely. That's getting back to something we had earlier. They do have liability if you can prove negligence. Unfortunately, at the moment, they're sort of the arbiters of what constitutes negligence or not. The first step of the liability convention, my understand is basically government-to-government negotiation.

In the case of Iridium Cosmos, my sense is US and Russia were like, "I'm good if you're good. Are you good? Yeah, I'm good." One was a dead military satellite. One was a commercial satellite that had been fully depreciated and was part of a redundant constellation.

There really wasn't any economic damage there that you could claim. The question comes 10 years from now when a piece of that hits somebody else. Can they go after US and/or Russia? That's going to be fun for whoever's around in a legal sense.

Siegfried: You won't be able to tell which satellite it came from.

Brian: Yes. That's the other challenge. Who owned that piece of debris that just hit me? You can do that for things bigger than this [cell phone] but for smaller than that, it's really hard to do.

Victoria: Your question.

Audience Member: Yes. [inaudible 88:43] European Space Agency. You took a bit of the wind out of my sails, Victoria.

Victoria: I'm sorry.

Audience Member: I was going to ask about verification and enforcement. For me, anything would not work if we cannot verify and enforce.

Another comment, if I may, this issue is eminently global, however, what we have experienced so far is that every time we want to try and talk to partners about active removal of space debris, we are told, "No, no." That is because of the military flavor.

Brian: If I could just point out that contrary to the US, the EU is actually investing tens of millions of euros in developing debris removal technologies and at least one, if not several, flight demonstration missions through the Clean Space Program.

Audience Member: It's not EU, it's ESA.

Brian: Well, ESA's doing it, but where's the money coming?

Audience Member: No, no, it's ESA money.

Brian: ESA, then.

Victoria: Thank you.

[crosstalk]

Brian: So it's a case where, at the moment, ESA, I think, is putting more into this money than the US is, even though the US has far more assets in orbit. I would commend ESA on that part of it.

Audience Member: We do have Envisat.

Victoria: Question right there.

Audience Member: Alicia [inaudible 90:13] . I think you can talk about this a little bit more but, Brian, you mentioned that the US has a lot of stuff out there right now. It seems like, do you guys think it's reasonable or feasible to ask commercial companies to follow really strict rules or to invest in active debris removal. The US government, so far, seems like their problems.

Brian: I don't think so.

[laughter]

But I would ask some of the commercial operators.

Siegfried: We're not commercial operators. [laughs]

Marshall: Nobody wants to pay for it. There has to be a situation where they have to pay for it. That's why we're in business.

Victoria: I guess that kind of leads to another question. Where is Russia in this discussion?

Brian: [laughs] Well, if you measure by objects, they have about 30 percent but if you measure by mass, they've got about half of the mass, particularly in low earth orbit.

Victoria: Of debris in orbit.

Brian: Yeah, debris in orbit. That's a challenge. I've been to several international conferences on the subject and there are people there from Roscosmos, and elsewhere and they've got ideas on how to do this.

I don't think, from my understanding, the Russian government is not in a place to get to the point where they're...The sort of thing with the US, they're discussing concepts but not quite funding, but that's a very important part of it. Half the mass, particularly large rocket bodies in a couple of low earth orbits that are a significant challenge.

Jim: It's interesting, I've read a couple of different arguments made by Russian lawyers that, in fact, Russia is not responsible for any of the Soviet because they did not accept the liabilities of the Soviet Union when the government was reformed.

Now, on the flip side, those same people, when we've talked about commercial bounty programs and said, "Hey, if we paid you X amount of dollars, would you let us take those upper stages out of the 600-700 polar...?" They say, "Yeah, of course, we'd let you do it."

Wait a second, how can you give me authority to take down if you're saying that you don't have any liability for that object? That's usually when the language barrier conveniently gets in the way.

[laughter]

Victoria: A question in the back.

Audience Member: Knowing that we're essentially a reactionary society, what kind of an event do you think it would take to actually snap people into action? We've already seen some collisions and obviously, that doesn't really seem to be enough to spur...

What kind of realistic events or collisions could you see that would spur us to really take action on the space debris question?

Jim: I think, obviously, if there was an ISS, International Space Station got hit by something, that's number one on the list that would make everybody go. My second and close behind is, "I want my MTV." What would happen if one of the major DVS satellites was taken out and couldn't be quickly replaced and suddenly every EchoStar Direct TV subscriber no longer got their television.

The phones would be ringing in every single one of these offices on Capitol Hill. I would guarantee something would happen if that were to be the case. After that, I can't really think of a scenario that would automatically trigger. If you look at the numbers and the way that chart bumped up after Cosmos Iridium, if that didn't light a fire, it's hard to think.

It's going to have to be something that hits a wide number of people. Either because there's a human involved or because they're losing something that they desperately need. I guess GPS would be the third, if suddenly we lost a bunch of GPS satellites.

Jerome: How about a couple of Russian Zenit upper stages colliding and creating millions of new bullets?

Brian: I think that would get the scientists and us that care fired up but I don't know if it would motivated political will.

Marshall: I think when the frequency of collisions is such that we start losing active satellites quickly and the insurance rates go sky high, I think then we'll take some action.

Brian: I would add one more to the losing, loss of life on the ISS and that would be a national security satellite. If there was a couple of billion-dollar national security asset that got taken out by a piece of debris, that might motivate that community. By the way, that community has a lot of money. That's something else I could think of.

Victoria: Those satellites tend to be pretty high though.

Brian: No, there are some in GEO, obviously, but there's also quite a few in low earth orbit as well.

Victoria: Question right here.

Audience Member: I thought I'd just ask, where are the Russians? Where are the Chinese? Has their position changed in the last five years?

Brian: We talk by numbers, it's roughly 30 percent of the debris is US, 30 percent is Russia and 30 percent Chinese with 10 percent everybody else. If you talk by numbers of objects. The vast majority of that Chinese percent is from the ASAT test because they haven't had the history of rocket bodies and satellites that US and Russia have had.

They're definitely talking about this. I mentioned there were some conferences back in 2010, '11 that were on this issue. I'm the one that was sitting in Chantilly saying, "Where are the Russian and Chinese at this conference?" Then we, Secure World, went and held a couple of workshops in Beijing to bring experts from the US and Europe there to have that discussion.

It was a bit awkward for them after the Chinese ASAT test because they had an IADC meeting that was scheduled to be hosted in Beijing a few months after that test. My sense in talking in China, they're concerned about, particular because they're starting to launch far more satellites of their own and they're becoming more reliant on space...

They're having some of the same discussions we are about the debris mitigation, the technical design, implementing all of that. As far as the removal, there is some discussion of technologies and concepts. I'm not aware of it going beyond that.

There have been a couple of recent satellites they've talked about having robotic arms that have been talked about as possible debris removal experiments but there's not a lot of information out there and public domain to validate that one way or the other.

The international level, they're definitely involved in this issue, they're definitely talking about it. As far as a priority over anything else, I'm not sure it's the biggest priority but they're definitely involved in the discussion.

Victoria: Other, Jim?

Audience Member: Jim Armor, Orbital ATK, first paid political announcement, we're launching our first life-extension satellite in one year for life extension in the GEO belt. But in looking at the business case, we have not found any place that is trying to measure the value of debris removal.

We're sort of waiting for the actuaries in the insurance world to kick in but is there any government centers of excellence or even independent think tanks or whatever that said, if you remove this debris, here is the benefit? I mean, here's how it goes down and start to get an angle of the value that can be then translated into a budget or into a business case that in you see in that community.

Jerome: Actually, in discussions with OneWeb, they have indicated that it would be worth their while to pay for someone to remove their dead satellites if it didn't cost more than the satellite plus the cost of launch. That's a target we can meet.

Marshall: We hope to have some answers for you in about six months.

Brian: I'll just say, I don't know if we can get to that. If I remove this particular pollutant from the air, can you measure what the impact's going to be to you or that person over there? This is the challenge when you have these kinds of externalities.

The cost of doing something is borne by one entity or maybe a few entities but the benefit is distributed across everybody. That's what makes it really hard to come up with that sort of a model to answer this kind of a question.

Audience Member: Yes but even like in spectrum or super fund, when you make a stab at it, that lets you communicate to the public or other elected officials in a little more communicative way.

Jim: Again, the analyses that I've seen, because any particular object, the probability of it causing damage is so many places to the right of the decimal sign, it's really hard to come up with anything that shows a number greater than one.

You have to do this more...Exactly. More macro rather than micro. There have been a couple of good studies but there's a lot of work that needs to be done in this. That's a great challenge to take on.

Victoria: After the great definition of low probability, high impact sort of event. Any last questions from the audience? Any last thoughts from the panel?

Siegfried: It's a legal question.

[laughter]

Siegfried: If I have a satellite in orbit below 1,000 km, it's affected more by air drag than solar pressure and anything else. If I put it up there and it's a dead satellite and it hits something else, shouldn't that be considered an act of God because the sun's cycles are changing its orbit.

[crosstalk]

Jim: That's been pretty much the argument for the last 60 years. It's a big sky and let God sort it out.

Siegfried: But nobody wants to buy that argument.

Jim: But nobody wants to buy it.

[laughter]

Victoria: It is a challenge.

Jim: The only thought I want to give, Brian has been referencing the conference in Chantilly back in 2009, which was a fabulous conference by the way, probably the best conference I've ever been to. It went from the totally macro all the way down to sub-components of techniques to do it.

A lot of great presenters. It was sponsored by DARPA. The problem is, the existence of that conference, no longer exists. You can't find any reference to it anywhere and, in fact, you almost find no reference to the DARPA Catcher's Mitt program any more.

DARPA, for some reason, just totally walked away from the field, and in doing that, scorched the earth behind them. I mean, I would love to have copies of all those presentations because some of them were just fabulous.

Marshall: I have them all, by the way.

Jim: You've got them all? All right.

[laughter]

Jim: We'll talk.

Siegfried: The presenters are still alive, right?

Jim: Most of them. Yeah, not many of them have been found in ditches, no. That's true.

[crosstalk]

Jerome: I'd like to ask Jim Dunstan a question based on what he said a little earlier. Since the Soviet Union no longer exists, what's the reason why we can't go up and get rid of one of their space vehicles and salvage it and use it ourselves?

Jim: There again, you get these countervailing arguments or, on the one hand, they don't want to accept liability but on the other hand, they don't want anybody touching their stuff either.

You really get cross discussions with them. I am sure if somebody went up and took down one of the Zenits, there would be a complaint lodged by Russia against it. It would make some sort of argument that even though we're not responsible for what happens to this, nonetheless, under the registration convention it is still our property and under Article VII.

They would argue both sides, as I've been known to do from time to time.

[laughter]

Victoria: I think one of the principles we're hearing over and over again today is the idea that there's some responsibilities in using space. It has to be done in a manner that doesn't interfere with other people's ability to harness it. Along those lines, I can just end with a quick advertisement for a product that we put out there.

Some of you have probably seen many times the "Handbook for New Actors in Space." Secure World put this together earlier this year there are free copies available on our website via PDF. We had a bunch outside but I think they're gone. There are postcards now. Let it coincide to say, "Hey, new actors in space, welcome to the club. Here's just what I think you should know."

We split it up into three sections. One section looks at the international legal regime, treaties that sort of thing. This next section looks at the national regulatory means, regulating spectrum. Then finally, the third section talks about on orbit operations, really, from life to death operations.

It might of interest, these unfold. It's nice for new actors who find it helpful. Existing actors find that there's always something more. Again, it's free on our website. You can get copies from us, hard copies, and then it's available even on Amazon.

With that, please join me in thanking the panel. It was a very lively discussion.

[applause]

Transcription by CastingWords