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"Reopening the American Frontier: Exploring How the Outer Space Treaty Will Impact American Commerce and Settlement in Space"

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Thank you Chairman Cruz, Ranking Member Markey, distinguished members of the subcommittee, and your superb staff for inviting me here today. It's a privilege to be here to discuss this important topic and to be with eminent colleagues and friends who are as passionate as I am about commercial space. I am thrilled that this committee has taken on the important work of considering the Outer Space Treaty and appropriate oversight of commercial space activities in the Unites States.

There are many exciting activities and proposals in commercial space. With respect to the Outer Space Treaty, I am deeply concerned that we would be opening a Pandora's Box by attempting to change it. My concern is that the likely outcome would be a lack of consensus, resulting in no amendments. Instead, we will have a weakened dedication to the Principles of the Treaty and the sustainability of space. Great changes are occurring and many countries are developing capabilities that previously were the purview of only a few nation states. Our ability to compete both economically and technologically in space is crucial. These Principles form the basis for the dialog that we have with other countries about what is appropriate and what is not. Without them, the dialog becomes chaos.

Today I would like to discuss a specific activity – satellite servicing. Satellite servicing itself is not new. As a NASA astronaut, I had the privilege of conducting and overseeing robotic activity on the Space Shuttle and the International Space Station (ISS) during its construction, and the opportunity to observe my colleagues conduct extraordinary work on the equally extraordinary Hubble Space Telescope. I saw first-hand the power of the capability to inspect, repair, and upgrade satellites. To date, only the space Shuttle, ISS, and Hubble have been designed to support being serviced, and all of these activities occurred in low earth orbit. Low earth orbit (LEO) is conducive to tele-operation (think "joystick") of robotic arms by astronauts in space, who can observe out the window and use real-time video. In addition, ground operators have proven capable of performing robotics in virtually real time from the ground to LEO. Advances in technology now permit impressive levels of autonomy that are less reliant on the intense supervision of humans that can only occur in LEO. These advances in autonomous rendezvous and docking, and greater levels of autonomy in robotic task performance now provide the potential to push satellite inspection and repair beyond LEO.

From a commercial perspective, the high value orbit is geosynchronous earth orbit (GEO), which is home to hundreds of the most valuable commercial and national security satellites. Commercial revenues from GEO satellites exceeded $110 billion in 2015, according to the

Satellite Industries Association. These satellites reside 36,000 kilometers from the surface of the earth; at present, if they experience any issues they cannot be repaired, losing valuable revenue and national security capability. GEO is a hugely impactful place to take the capability of servicing. And several companies have announced ambitions to develop these capabilities, either on their own or in public-private partnerships with the government.

Let's break down the term "satellite servicing" into the operations terms that best describe the kind of activities that actually occur during servicing. The first is getting close to the client satellite that you intend to service. This intentional bringing together of two objects in orbit is called, in space parlance, rendezvous and proximity operations (RPO). It begins with two spacecraft thousands of kilometers from each other and the orchestration of a suite of sensors to perform precise navigation to converge orbits to a specified location within a centimeter of accuracy on final docking to the client (should it be required). In the most challenging cases, some sort of robotic operations will be required – nudging a solar array or aperture that failed to deploy, grasping a fouled thermal blanket, even replacing a failed system on a satellite.

These activities are massively impactful in restoring capability, but potentially perilous to both the servicer and the client satellite. The consequences for improper actions or inadvertent error during either RPO or robotics are not just the damage to one or both satellites, but more critically the generation of debris. This orbital debris can cause additional damage to the servicer or client, creating even more orbital debris, and it can float away and damage other spacecraft in the same or lower orbits.

The safety issues associated with these space operations are not trivial – in fact I would argue that servicing is the activity most dangerous to space sustainability of any of the proposed commercial operations. NASA and national security operators have demonstrated the capability to safely perform rendezvous and proximity ops, and NASA has perfected and mastered space robotics operations during Hubble repairs and the construction of the ISS. As commercial servicing operations go into business, what assurance do we have of their safety?

These operations are challenging, but the government and its contractors do have over fifty years of experience in this area. In fact, today commercial satellites are safely performing RPO and collaborative robotics with a government satellite. That's thanks to NASA's Commercial Cargo program, where industry has proven capable of maneuvering cargo vehicles in close proximity to the ISS, where they are grappled and docked by astronauts. NASA has proven that the safety and policy issues can successfully be addressed via the contract with the government and these commercial providers. The same companies providing services and performing RPO at ISS are also developing business to service commercial satellites. While we can expect technologies and best practices should transfer, when a commercial provider is servicing another commercial provider and no government experts are involved, how will the government be confident they will be adhered to? That is essence of what I want to talk about today.

The potential for debris generation provides a clear connection to the Outer Space Treaty's Article IX reference to "harmful contamination" and "harmful interference" which the US Government is obligated to avoid. Given Article VI's requirement for continuing supervision, I

think that commercial-on-commercial satellite servicing operations must have some form of scrutiny by the federal government to protect the overall sustainability and safety of the space environment. The lack of clarity on regulatory oversight creates financial and regulatory risks for industry, and diplomatic risks for the US Government.

However, should this oversight regime be too onerous, the business advantage will simply go to other countries. Other nations will pursue this technology whether or not the US does. Having other countries set norms in this area is potentially extremely damaging to both national security and to our economic interests. The US Government must provide support and clarity to enable these new businesses both for the benefit of our satellite systems and benefit for our economy.

So what should be considered when planning oversight responsibilities?

I'll point out again that NASA and its commercial partners are operating just fine right now. Whatever solution is devised, it should not add new layers of oversight onto previously existing arrangements, or reduce any government agency's authority and flexibility to accomplish their mission.

From a governance perspective, there are significant national security implications to these activities. It will be extremely important to verify that operators are trained to prevent debris generation – that is obvious. But it's also important to national security to verify that a commercial satellite is in fact acting cooperatively when it approaches another satellite, and is operating in a predictable way to prevent misunderstandings. In the long term, verification of proper behavior – and attribution of improper behavior – will also be necessary. Unfortunately, the ability to have real-time information about the space domain – all space objects, at all orbits, at all times - is a challenge that has yet to be overcome. Tracking and verification of RPO activities will likely be the most stressing case for space traffic management technical capabilities – far more difficult than predicting potential collisions with debris in slow-changing orbits. As discussions inside the government continue about who should be responsible for space traffic coordination, please consider that those activities will have to be closely coordinated with any servicing oversight. It seems best to consider having a single window to industry that oversees both the authorization and the verification of servicing activities.

Another consideration is that national security satellites do not like having their picture taken. This is not shyness, but in fact needed protection of our capabilities and support for operational activities on the ground. Commercial satellite operators turn out to be just as concerned on this point. A competitive advantage may be gained by learning exactly what equipment a specific satellite is carrying and if there are any failures evident. Today most cameras in space are pointed down at the earth, not at other satellites. Any future regulator must consider the powerful suite of sensors that servicing satellites carry to accomplish RPO with respect to the protection of both national security operations and proprietary commercial information.

In terms of what oversight should look like to industry, careful thought and caution is needed. At the FAA's Office of Commercial Space Transportation, I learned that a simple regulatory change – even editorial – takes a minimum of two years to accomplish if you simply put the days required by the process end to end. A complex rule – even the revocation of a rule – can take five

or more years to achieve. This is a nightmare in the face of rapidly evolving technologies and business plans. One process I observed at the FAA on the aviation side was the use of standards which the FAA scrutinized, then issued a statement to advise that compliance with the standard was adequate to meet the intent of corresponding simple, performance-based regulations. Standards can be updated much more easily and a relatively short process used to validate that they continue to meet the intent of the regulations. Standards can be tremendously helpful in enabling regulations that are performance-based, and not prescriptive.

At this time, there is no single agency with clear authority to oversee all of these types of on-orbit activity. As has been described by others, the FAA has launch and entry oversight. The FCC has spectrum oversight. NOAA has oversight of remote sensing of the earth. But even if today, with a mighty penstroke Congress decided to issue such authority, none of these agencies yet has the resources – including operational experts in these areas - needed to perform oversight of specialized activities like RPO and robotics. It will take years to develop regulations, and these regulations may be outdated by the time they are passed.

It is my assertion that industry consensus standards can fill in the gap and provide a basis for evaluating safety by future regulators when they do have this authority. Industry must be involved from the beginning and provide the advocacy for their innovative technologies and business plans. Industry consensus standards will allow an agency tasked with oversight to consider and nurture these needs, while still being mindful of best practices learned over decades of government servicing activities.

It might appear that the wholesale transfer of NASA's safe operating procedures and "flight rules" could solve the problem. However, these operating procedures are written with the specific design of the client satellite – in this case, ISS – in mind. The size of the solar arrays, and the desire not to spray them with the outflow from the thrusters of the approaching spacecraft, and similar constraints dictate the approach corridor, keep out zones, and safety gates. One example of the difference between a flight rule and a standard which applies to all vehicles is the concept of a passively safe orbit. A passively safe orbit means that you have designed the approach using orbital mechanics that will allow the two spacecraft to pass by each other harmlessly with no collision. At some point you then initiate the final approach which will result in docking. Keeping that point as late as possible limits the amount of time that you are exposed to the risk of collision if there is a failure on either spacecraft or a loss of communications. The size of the client spacecraft dictates the distance at which you can continue to be passively safe. Therefore, a standard would not give a distance; rather, it might state that approaches should be passively safe until as late as practical. This is but one example of how government know-how can be translated into standards. NASA experts carry the vast store of knowledge we have about RPO in low earth orbit, and robotic servicing operations. Other experts around the government have also been involved in various RPO activities. Government experts must also be involved in the development of these standards.

So if this model is such a paragon, why isn't it in practice today in other areas of commercial space? The good news is that the advantages of industry consensus standards is well understood. The Commercial Space Transportation Advisory Committee (COMSTAC), the FACA

committee advising the FAA is working on standards around a variety of areas that the FAA already has jurisdiction over. It was recently announced that ASTM International has formed a working group to develop a standards roadmap for commercial space.

RPO and servicing are arguably a very small part of the range of commercial space activities, but a vital one, and require the attention of specialists. When I was at DARPA, I advocated for and helped initiate a joint program with NASA called CONFERS – Consortium for Execution of Rendezvous and Servicing Operations. The goal of the program is to fund the creation of an industry/government consortium to develop non-binding consensus technical standards for safe rendezvous and servicing operations. I emphasize technical, because it is not the intent for these standards to incorporate policy guidance or preferences for behavior, but physics and operational safety-based best practices.

Often standards development is hindered by the lack of funding for administrative support; technical experts are willing to have discussions but there is less interest in the administrative tasks of writing everything down, tracking issues to be resolved, etc. If it's no one's "day job" – much less full-time day job – the process can take many years. By funding an Executive Director and a standards organization to provide the persistent leadership to develop this special set of standards, CONFERS will ensure that the effort will more quickly produce those standards. I believe that this approach will enable the US government to have a technical and safety basis for understanding servicing activities when oversight is eventually put into place. This approach may prove a successful model for future oversight of other areas as well under the Outer Space Treaty.

Thank you for the opportunity to discuss this important and exciting topic with you, and I look forward to lending my technical expertise to the discussion.