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Threats to U.S. National Security Interests in Space: Orbital Debris Mitigation and Removal

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Summary

After decades of activities in space, Earth's orbit is littered with man-made objects that no longer serve a useful purpose. This includes roughly 22,000 objects larger than the size of a softball and hundreds of thousands of smaller fragments. This population of space debris potentially threatens U.S. national security interests in space, both governmental (military, intelligence, and civil) and commercial. Congress has broadly supported the full range of these national security interests and has a vested concern in ensuring a strong and continued U.S. presence in space.

Two events in recent years dramatically increased the amount of fragmentation debris in orbit. One was the 2007 Chinese anti-satellite test and, in 2009, an active U.S. commercial satellite accidentally collided with a defunct Russian satellite. Although the 2013 movie *Gravity* exaggerated the issue and took certain artistic liberties, the film graphically depicted and drew the public's attention to the potential destruction of operational satellites and other platforms in space from collisions with orbital debris. Some experts maintain the population growth of debris in space will be primarily driven by catastrophic collisions that are likely to occur every five to nine years.

For decades, the United States has worked to minimize the amount of orbital debris left from its space launches and inactive satellites. Many space-faring nations have adopted similar mitigation measures, and additional voluntary international codes of conduct are being pursued.

Many experts now believe that mitigation efforts alone are insufficient to prevent the continual increase of space debris. A growing view among experts holds that some level of active removal of debris from the space environment is necessary. Nevertheless, such efforts are technologically immature and face significant budgetary and legal obstacles.

Congress has an opportunity to explore these issues through hearings, for instance with major stakeholders in the U.S. national security and civil space communities, and the commercial sector. Efforts to find international agreement on mitigation may involve congressional prerogatives on advice and consent, and any program to pursue remediation will likely entail appropriations support from Congress.

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Introduction

The 2011 National Security Space Strategy declared, "Space is vital to U.S. national security and our ability to understand emerging threats, project power globally, conduct operations, support diplomatic efforts, and enable global economic viability."[1] Maintaining the benefits afforded by space is central to a wide range of U.S. national interests. These include significant government (military,[2] intelligence,[3] and civil[4]) and commercial[5] interests. In recent years, recognition has been growing among space-faring nations[6] and the international scientific community that the mass of man-made debris in Low-Earth Orbit (LEO) has reached a critical density that will lead to a slow but unstoppable growth of space debris that could have profound implications for those interests. Significant debris-generating events in the past decade have heightened the issue, and a number of national and international studies confirm that the amount of current LEO debris is both unstable and increasing. This instability in the space environment presents a threat to U.S. national interests in space. U.S. Deputy Secretary of Defense William J. Lynn, III, summarized the national security implications of interference with our satellites and space capabilities: "Space systems enable our modern way of war. They allow our warfighters to strike with precision, to navigate with accuracy, to communicate with certainty, and to see the battlefield with clarity. Without them, many of our most important military advantages evaporate."[7]

Although space debris is not the sole threat to U.S. space assets,[8] this report focuses on the threat posed by orbital debris, the steps that have been taken thus far to mitigate it, and what might be done to ensure the long-term sustainability of the space environment. Although Congress may not need to make key decisions immediately, Congress may want to begin to focus on measures the United States may take to mitigate the threat associated with orbital debris.

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[1] Department of Defense and Office of the Director of National Intelligence, *National Security Space Strategy Unclassified Summary*, January 2011, p. 1, http://www.defense.gov/home/features/2011/0111_nsss/docs/NationalSecuritySpaceStrategyUnclassifiedSummary_Jan2011.pdf.

[2] The Department of Defense depends on space assets to support a wide range of missions including military intelligence collection; battlefield surveillance and management; global command, control, and communications; and navigation assistance. U.S. Government Accountability Office, *Defensive Space Activities: DOD Needs to Further Clarify the Operationally Responsive Space Concept and Plan to Integrate and Support Future Satellites*, GAO-08-831, July 2008, p. 1.

[3] Intelligence interests include, for instance, the acquisition of SIGINT (signals intelligence such as communications intelligence, electronic intelligence, and automated data from non-U.S. space vehicles), IMINT (imagery intelligence such as imagery collection and processing), and MASINT (measurement and signature intelligence, as in measuring specific events such as nuclear explosions).

[4] Civil interests include the many activities of NASA such as space science, exploration, weather monitoring, and imagery used for purposes in agriculture, land planning, mapping and forestry, for instance.

[5] Significant commercial interests in space include satellite navigation systems, communications, television and radio broadcasts, and space tourism.

[6] A number of countries (Russia, United States, France, Japan, China, United Kingdom, India, Israel, Ukraine, Iran, North Korea, and South Korea) and the European Space Agency have demonstrated independent orbital launch capability. A growing number of governments have indirect space access from those countries that provide space launch services to others. Currently over 60 countries and government consortia, as well as numerous commercial enterprises and academic institutions, have some type of operations in space.

[7] William J. Lynn, III, "A Military Strategy for the New Space Environment," *The Washington Quarterly*, vol. 34, no. 3 (Summer 2011), p. 7.

[8] Other threats to space assets include radio frequency interference, cyber-attacks, space weather, micro-meteoroids, Near-Earth Objects, and anti-satellite weapons.

Defining the Threat

What Is Orbital Debris and What Are Its Sources?

Decades of human space flight—primarily U.S. and Russian space activities—have littered the Earth's orbit with debris.[9] NASA defines orbital debris as "all man-made objects in orbit about the Earth which no longer serve a useful purpose."[10] Examples include derelict spacecraft, abandoned space launch vehicle stages, mission-related debris, and fragments created as a result of explosions or collisions.

The U.S. Space Surveillance Network[11] is the leading space object tracking system in the world and catalogues objects as small as about 10 cm (softball size) in LEO and as small as 1 meter in Geosynchronous Orbit.[12] Today, the Space Surveillance Network tracks more than 23,000 objects 10 cm in diameter or larger in orbit around the Earth. Of those, only about 1,100 (5%) are active satellites. The rest is orbital debris. In addition to the debris tracked by the Space Surveillance Network, there are hundreds of thousands of pieces of debris smaller than 10 cm, which are considered too small to track or catalogue, but are still capable of damaging satellites and the International Space Station.[13]

Prior to 2007, the principal source of space debris was the explosion of old launch vehicle upper stages that had been left in orbit with unspent energy sources.[14] Explosions of this type were prevalent in the 1970s and 1980s but have since slowed due to increased mitigation techniques practiced worldwide.[15] Since 2007, two significant debris-generating events have greatly increased the amount of debris in orbit. On January 11, 2007, the Chinese government launched an interceptor missile in an anti-satellite weapon test that destroyed their decommissioned Fengyun-1C weather satellite. This intentionally destructive event created the most severe orbital debris cloud in space flight history, generating more than 3,000 pieces of debris larger than 10 cm and an additional 150,000 pieces larger than 1 cm. The majority of debris particles were thrown into long-duration orbits, and remnants of this event will likely remain in orbit for at least a century. One expert reported it likely that debris from the Chinese ASAT test damaged a small Russian satellite six years later in 2013.[16] But the Pentagon later reported that this Russian satellite most likely broke apart for different reasons and not from debris from the Chinese ASAT

[9] "Satellite Box Score," *Orbital Debris Quarterly News*, vol. 17, no. 4 (October 2013), p. 10.

[10] NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/faqs/html.

[11] The Space Surveillance Network is a Defense Department activity that consists of worldwide network of space surveillance sensors (U.S. facilities in foreign countries include radar and optical telescopes, both military and civilian) that detect, track, catalog, and identify man-made objects in orbit about the Earth.

[12] Low-Earth Orbit is the region of space within 2,000 km of the Earth's surface. Satellites in Geosynchronous Orbit circle the Earth at approximately 36,000 km.

[13] According to NASA, the estimated population of debris particles between 1 and 10 cm (marble size or larger) is approximately 500,000, and the number of particles smaller than 1 cm exceeds 100 million. NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/faqs/html. Some believe that issues with lethal, non-trackable debris (10 cm or smaller) may cause problems much before the cascading effect. See Dr. Darren McKnight, http://swfound.org/events/2013/gravity-in-real-life-legal-and-political-implications-of-an-accident-in-space/.

[14] NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/faqs/html.

[15] Namely passivation (i.e., getting rid of unused fuel or other stored energy on a spacecraft or upper stage vehicle after launch to prevent in-orbit explosion).

[16] Leonard David, "Russian Satellite Hit by Debris from Chinese Anti-Satellite Test," *Space.com*, March 8, 2013, http://www.space.com/20138-russian-satellite-chinese-space-junk.html.

test.[17] Another space expert suggested, however, it was more likely the satellite did not break up on its own and may have been hit by debris too small to be tracked and identified by the U.S. Space Surveillance Network.[18]

Two years after this incident, the first accidental hypervelocity collision occurred between two intact spacecraft. On February 10, 2009, an operational U.S. Iridium communications satellite collided at a near right angle with a defunct Russian Cosmos satellite. The collision resulted in roughly 2,100 new pieces of debris larger than 10 cm. Collision probability reports calculated by the Center for Space Standards & Innovation had predicted a "close approach" between the satellites on the day of the event.[19] This did not cause particular alarm, however, because the approach of these two satellites was not the top predicted close approach that day, nor even the top predicted close approach of any of Iridium's satellites for the coming week.[20] Nevertheless, at the time the approach was predicted to occur, Iridium abruptly lost contact with its spacecraft and the U.S. Space Surveillance Network began detecting debris, confirming that an actual collision had occurred.

These two events increased the amount of objects in Earth orbit cataloged by the Space Surveillance Network by one-third. These collisions alone have been described as essentially negating the results of more than 20 years of international compliance with debris mitigation guidelines. As shown in **Figure 1**, following these two events, the amount of cataloged fragmentation debris in orbit more than doubled after having remained nearly constant for more than 20 years.

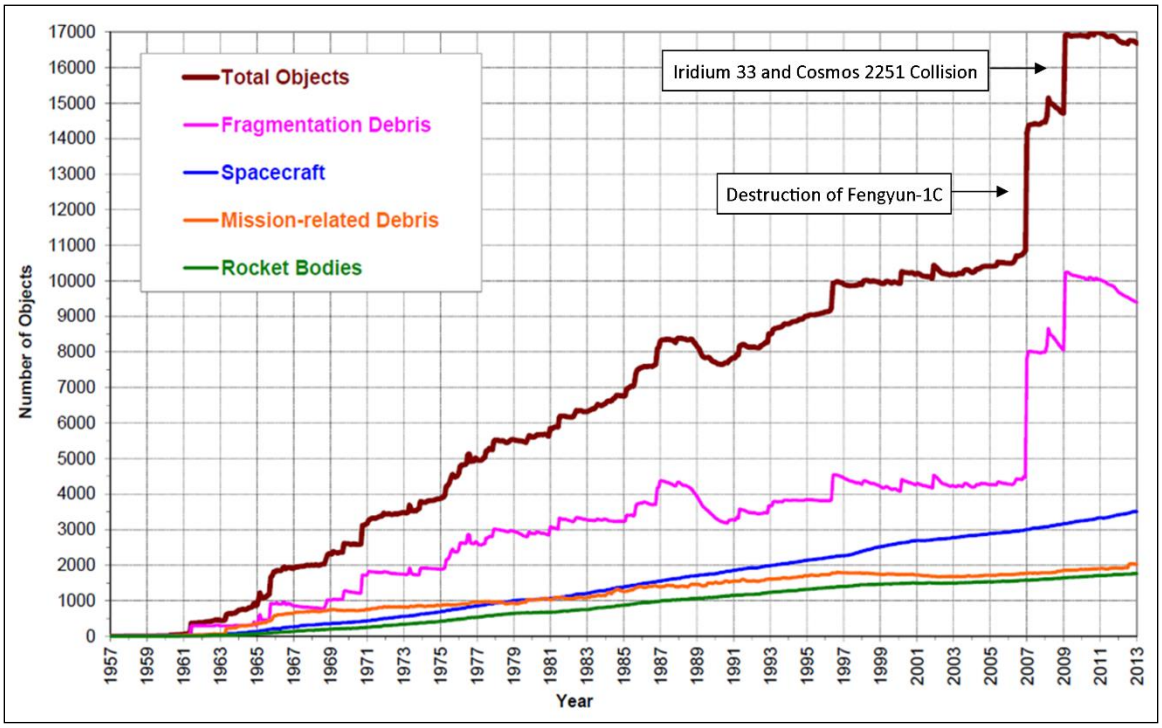
[17] Warren Ferster, "Pentagon: Russian Satellite Not Hit by ASAT Test Debris," *SpaceNews.com*, March 21, 2013, on-line edition.

[18] Ibid.

[19] As a service to satellite operators, the Center for Space Standards & Innovation, a division of the spaceflight software development company Analytical Graphics, Inc., offers SOCRATES—Satellite Orbital Conjunction Reports Assessing Threatening Encounters in Space—on pending conjunctions over the coming week. SOCRATES predicted a close approach between Iridium 33 and Cosmos 2251 of 584 m (1,916 ft.) at the time of the actual collision and in each of the 14 reports in the week leading up to the event. Dr. T.S. Kelso, *Iridium 33/Cosmos 2251 Collision*, CelesTrak, July 15, 2009, http://celestrak.com/events/collision.asp.

[20] Dr. T.S. Kelso, *Iridium 33/Cosmos 2251 Collision*, CelesTrak, July 15, 2009, http://celestrak.com/events/collision.asp.

Figure 1. Monthly Number of Objects in Earth Orbit by Object Type



Source: NASA, "Monthly Number of Objects in Earth Orbit by Object Type," *Orbital Debris Quarterly News*, vol. 17, no. 1 (January 2013), p. 8.

Notes: This chart displays a summary of all objects in Earth orbit officially cataloged by the U.S. Space Surveillance Network. "Fragmentation debris" includes satellite breakup debris and anomalous event debris, while "mission-related debris" includes all objects dispensed, separated, or released as part of the planned mission.

What About Missile Defense Tests in Space?

Since the 1960s, the United States and Russia have conducted a significant number of ballistic missile defense (BMD) tests in space resulting in varying amounts of debris. It appears, however, that the debris created by launching targets and interceptors into space, together with any resultant orbital debris from those tests and intercepts, is unlikely to be consequential in the context of this report. This is especially true of current missile defense testing.

Although the 1963 Limited Test Ban Treaty banned nuclear testing in space, the United States conducted a number of BMD tests in the late 1960s and early 1970s to validate the effectiveness of a nuclear-tipped BMD system deployed briefly in 1975-1976.[21] There are no available data on how much these tests may have contributed, if at all, to the amount of existing space debris.

Since the early 1980s, the United States has conducted a number of hit-to-kill BMD flight and intercept tests outside the Earth's atmosphere in space. In February 2008, a BMD-capable Aegis cruiser used a modified version of the Aegis BMD system to successfully shoot down an inoperable U.S. surveillance satellite that was in a deteriorating orbit. According to the Missile

[21] No actual nuclear tests were conducted, but interceptor missiles and targets were launched into space to validate whether the interceptor came close enough to its intended target such that the target would have been destroyed by a nuclear-tipped interceptor.

Defense Agency (MDA) "nearly 100 percent of the debris safely burned-up during reentry within 48 hours and the remainder safely re-entered within the next few days."[22]

Currently, MDA plans and designs flight tests to mitigate and minimize any potential hazards.[23] According to MDA, debris modeling predicts that almost half of the mass would be vaporized during the intercept collision and about a quarter of the mass would be dispersed into fine particles with masses of less than a few tens of grams that then burn up on reentry. The remaining mass is predicted to be in pieces large enough to survive reentry and reach the ground. It is not known how long any of this debris remains in orbit before it reenters the atmosphere. It should be pointed out, however, that of the 10 most significant events that generated space debris, none are attributed to any U.S. BMD tests.[24]

Why Is Orbital Debris a Threat?

Orbital debris can instantly destroy or disable space-based resources. A collision with a 10 cm object would catastrophically damage a typical satellite, a 1 cm object would likely disable a spacecraft or penetrate the shields of the International Space Station, and a 1 mm object could destroy satellite sub-systems.[25] Once a risk of collision has been identified, the only effective way to mitigate the risk is to move the spacecraft out of the way. Moving a satellite, however, entails costs. Avoidance maneuvers cost fuel, shorten a spacecraft's lifetime, and may disrupt data and service continuity. A 2013 European Commission Memorandum reported that some European space agencies operating satellites carry out one satellite collision avoidance maneuver each month on average.[26] It is important to note, however, that most objects in space are not under control, and their orbital paths cannot be altered. This means that the majority of potential collisions cannot be avoided using evasive maneuvers.

In 2011, U.S. Deputy Secretary of Defense William J. Lynn, III, summarized the threat from orbital debris: "Whether or not we can see it, the debris is there. The danger is that each collision exponentially raises the potential for another, such that a debris cascade could someday render entire orbits unusable."[27] But this danger has been known since the late 1970s.[28] Current research suggests that the current LEO debris environment is unstable: The amount of orbital debris will continue to grow, in spite of debris mitigation measures, because collisions will generate new

[22] Aegis Ballistic Missile Defense, One-Time Mission: Operation Burnt Frost, http://www.mda.mil/system/aegis_one_time_mission.html. For a more detailed analysis of the intercept debris from this mission, see http://celestrak.com/events/usa-193.asp.

[23] Missile Defense Agency Response to Congressional Research Service Request for Information, CMDGRP-D-2014-0616, November 26, 2013.

[24] See NASA Academy of Program/Project & Engineering Leadership, *Orbital Debris Management & Risk Mitigation*, September 2012, p. 7, http://www.nasa.gov/pdf/692076main_Orbital_Debris_Management_and_Risk_Mitigation.pdf.

[25] European Space Agency, http://www.esa.int/Our_Activities/Space_Engineering/Clean_Space/FAQ_s.

[26] European Commission, "Avoiding damage from space debris - space surveillance and tracking proposal," press release, February 28, 2013, http://europa.eu/rapid/press-release_MEMO-13-149_en.htm.

[27] William J. Lynn, III, "A Military Strategy for the New Space Environment," *The Washington Quarterly*, vol. 34, no. 3 (Summer 2011), p. 9.

[28] In 1978, two NASA scientists concluded that a significant amount of debris could be generated by satellite collisions in the near future, possibly before the year 2000. The study predicted that fragments from satellite collisions would lead to further collisions, exponentially increasing the debris population and creating a "belt of debris" around the earth. The study warned this could impact future spacecraft design, and recommended studying various methods to slow or stop the formation of a debris belt. Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: The Creation of a Debris Belt," *Journal of Geophysical Research*, vol. 83, no. A6 (June 1, 1978), pp. 2637-2646.

debris faster than it is removed by natural forces. A number of studies, both national and international, have concluded that orbital debris has already reached a "tipping point."

- A 2011 study by the National Research Council of the National Academies reported that NASA's models showed the orbital debris population would continue to increase as a result of random collisions involving non-operational intact debris.[29] The study concluded that the amount of debris currently in orbit will continually collide with itself, leading to the growth rate of debris and increases in spacecraft failures. The study noted that the debris increase thus far has occurred most rapidly in LEO, but Geosynchronous Orbit may potentially suffer the same fate over a longer time period.[30]
- In 2013, the Inter-Agency Space Debris Coordination Committee (IADC)[31] reported the results of a NASA-led comparison study on the space debris environment. The study suggests that the orbital debris mitigation measures commonly adopted by the international space community are insufficient to stabilize the orbital debris environment.[32] According to the report, simulations show that the current population of man-made objects in LEO has reached a critical density that will lead to a slow but unstoppable cascading effect of mutual collisions. In the study, each participating space agency used its own model to simulate the future space debris environment through 2209. The six model predictions were consistent with one another and found that even with 90% compliance with commonly adopted mitigation measures, LEO debris is expected to increase an average of 30% in the next 200 years. The population growth will be primarily driven by catastrophic collisions that are likely to occur every five to nine years.

Mitigation

What Mitigation Efforts Have Been Taken?

In the context of orbital debris, "mitigation" refers to operational and design measures that limit the generation of debris by space launches and spacecraft that are under control. Since 1988, the official policy of the United States has been to minimize the creation of new orbital debris.[33] NASA and DOD have requirements governing the design and operation of spacecraft and upper rocket stages to mitigate the growth of orbital debris.[34] NASA's current orbital debris programs are recognized as models both nationally and internationally. Most relevant federal agencies accept all or some of the components of NASA's orbital debris mitigation and prevention

[29] Committee for the Assessment of NASA's Orbital Debris Programs, National Research Council, *Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs*, 2011, p. 10.

[30] Ibid., p. 1.

[31] The IADC is an international governmental forum including eleven national space agencies and the European Space Agency.

[32] J.-C. Liou, A. Rossi, and H. Krag, et al., *Stability of the Future LEO Environment*, Inter-Agency Space Debris Coordination Committee, IADC-12-08, January 2013.

[33] The most recent National Space Policy continues to emphasize this goal. *National Space Policy of the United States of America*, June 28, 2010, p. 4, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[34] NASA Orbital Debris Program Office, http://orbitaldebris.jsc.nasa.gov/faqs/html.

guidelines.[35] The Federal Aviation Administration, the National Oceanic and Atmospheric Administration, and the Federal Communications Commission also consider orbital debris issues as factors in the licensing process for spacecraft and upper stage rocket engines under their auspices.[36] The United States continues to lead the development and adoption of international and industry standards and policies to minimize debris, such as the United Nations Space Debris Mitigation Guidelines.[37]

The United States also pursues efforts to prevent future collisions in space. The National Space Policy directs the government to improve its ability to rapidly detect, warn of, characterize, and attribute potential disturbances to space systems, whether natural or man-made.[38] This ability to detect, track, identify, and catalog objects in outer space is known as "Space Situational Awareness." The State Department reported that, as of May 7, 2013, U.S. Strategic Command has concluded 37 Space Situational Awareness agreements with commercial satellite owners and operators to improve cooperation in this area.[39] The State Department also actively supports efforts to establish two-way information exchanges with foreign satellite operators to facilitate urgent transmission of notifications of potential space hazards. DOD provides notifications to other governments and commercial satellite operators of potentially hazardous conjunctions between orbiting objects. The United States is currently reaching out to all space-faring nations and organizations to ensure that the Joint Space Operations Center has current contact information for both government and private sector satellite operations centers to facilitate notifications. In 2011 alone, the United States provided over 1,100 notifications to nations around the world, including to Russia and China.

In addition, the United States is pursuing bilateral "Space Security Dialogues" as part of the pursuit of transparency and confidence-building measures (TCBMs) to help prevent mishaps, misperceptions, and mistrust in space. The purpose of TCBMs is to encourage responsible actions and peaceful use of space, and to increase familiarity and trust among space actors. The United States believes that space TCBMs should be pragmatic, voluntary, near-term actions.[40] Examples include establishing "best practice" guidelines or a "code of conduct," enhancing the transparency of national security space policies, strategies, activities and experiments, and providing prior notification of launches of space launch vehicles. The United States is also involved in U.N. efforts to develop a list of voluntary and pragmatic space TCBMs and takes an active role in the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS) working group aimed at developing voluntary best practices guidelines for enhancing safety and sustainability of space activities.[41]

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[35] Committee for the Assessment of NASA's Orbital Debris Programs, National Research Council, *Limiting Future Collision Risk to Spacecraft: An Assessment of NASA's Meteoroid and Orbital Debris Programs*, 2011, p. 59.

[36] Ibid.

[37] *National Space Policy of the United States of America*, June 28, 2010, p. 7, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[38] Ibid., p. 14.

[39] Frank A. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State, *Remarks at Global Space and Satellite Forum*, Middle East 2013, Abu Dhabi, United Arab Emirates, May 7, 2013, http://www.state.gov/t/avc/rls/2013/209192.htm.

[40] Frank A. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State, *Protecting Space for Future Generations is in the Vital Interests of the Global Community*, Space Security Conference 2013: United Nations Institute for Disarmament Research, Geneva, Switzerland, April 2, 2013, http://www.state.gov/t/avc/rls/2013/206967.htm.

[41] The UN COPUOS Long-term Sustainability of Outer Space Activities Working Group is currently undertaking a multi-year study designed to develop guidelines to support the long-term sustainability of the space environment. The

What Additional Mitigation Measures May Be Pursued?

Many experts believe that the need for increased international compliance with debris mitigation standards cannot be emphasized enough. Compliance with debris mitigation measures, such as the "25-year" rule, is the first defense against the increase of orbital debris.[42] The 25-year rule is an international understanding related to post-mission disposal. It stipulates that nations should not launch an object whose lifetime in space will exceed 25 years after the completion of its mission. Adherence to the 25-year rule is a U.S. Orbital Debris Mitigation Standard Practice. Increased compliance with this and other mitigation standards[43] is viewed as necessary because the studies predicting the growth of orbital debris used highly favorable compliance assumptions in their environmental models. If the international space community does not reach those higher levels of compliance soon, the growth of the future debris will likely be worse than predicted.[44]

In addition, some believe that perhaps one of the most beneficial TCBMs for ensuring sustainability and security in space could be the adoption of best practice guidelines or a code of conduct to promote responsible behavior in space. The European Union has a draft Code of Conduct that includes provisions on space debris mitigation.[45] The Stimson Center, co-founded by Michael Krepon (a long-time proponent of a code for space-faring nations), also promotes a model Code of Conduct it drafted with international NGO partners.[46] On January 17, 2012, the United States announced its decision to initiate consultations and negotiations with the European Union and other space-faring nations to develop a non-legally binding International Code of Conduct for Outer Space Activities.[47] The United States views the EU Code as a good foundation for developing a legally non-binding International Code of Conduct.[48] The United States has been consulting closely with the EU and others and will continue to shape a voluntary, non-legally binding International Code.[49] The State Department reportedly affirms that the code of conduct

group is expected to complete its work in 2015.

[42] J.-C. Liou, A. Rossi, and H. Krag, et al., *Stability of the Future LEO Environment*, Inter-Agency Space Debris Coordination Committee, IADC-12-08, January 2013, p. 17.

[43] Examples of other mitigation standards include passivation (getting rid of stored energy on a spacecraft or upper stage vehicle after launch to prevent in-orbit explosion), limiting release of mission-related objects, collision avoidance, and impact shielding.

[44] J.-C. Liou, A. Rossi, and H. Krag, et al., *Stability of the Future LEO Environment*, Inter-Agency Space Debris Coordination Committee, IADC-12-08, January 2013, p. 17.

[45] European Union, *International Code of Conduct for Outer Space Activities*, Draft, September 16, 2013, http://eeas.europa.eu/non-proliferation-and-disarmament/pdf/space_code_conduct_draft_vers_16_sept_2013_en.pdf.

[46] The Stimson Center, *Model Code of Conduct*, October 2007, http://www.stimson.org/research-pages/model-code-of-conduct/. The Model Code of Conduct was drafted by experts from NGOs in Canada, France, Japan, Russia and the United States.

[47] Hillary Rodham Clinton, Secretary of State, Department of State, "International Code of Conduct for Outer Space Activities," press statement, January 17, 2012, http://www.state.gov/secretary/rm/2012/01/180969.htm.

[48] Frank A. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State, *Pursuing an International Code of Conduct for the Security and Sustainability of the Space Environment*, National Space Symposium, Colorado Springs, CO, April 18, 2012, http://www.state.gov/t/avc/rls/188088.htm. For instance, the Code includes language in which subscribing states pledge to refrain from actions that intentionally damage or destroy space objects. The key purpose of this is to prevent the creation of long-lived space debris such as China's 2007 ASAT test.

[49] Frank A. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State, *Pursuing Space TCBMs for Long-Term Sustainability and Security*, International Symposium on Sustainable Space Development and Utilization for Humankind, Tokyo, Japan, February 28, 2013, http://www.state.gov/t/avc/rls/2013/205362.htm.

"is not a legally binding treaty or international agreement that would impose legal obligations on the United States."[50]

Some in Congress have expressed various concerns about an international code of conduct for space.[51] Some of these include concerns that such agreements may not be in the national security interest of the United States, or that a less formal code of conduct could evolve into a more formal treaty without sufficient oversight from Congress. Although executive branch officials have agreed to continue to consult with Congress,[52] congressional support or opposition will likely depend on the final details of any international agreement that may be reached.

In addition to these various voluntary efforts, more formal treaty efforts have also been proffered. The National Space Policy directs that the United States "will consider proposals and concepts for arms control measures if they are equitable, effectively verifiable, and enhance the national security of the United States and its allies."[53] State Department officials have stated, however, that they have not yet seen a proposal that meets these criteria, and it specifically rejected the 2008 Chinese-Russian "Prevention of Placement of Weapons in Outer Space Treaty" on those grounds.[54] For a list of existing space treaties, conventions, codes, and proposals, see the Stimson Center's Space Norms Matrix.[55]

The United States also plans to upgrade the Space Surveillance Network in the coming years. The new Air Force Space Fence is due to begin operation by the end the decade and be fully capable within the next. This radar system will operate in the S-band frequency range and is designed to detect objects in LEO as small as about 2 cm.[56] Although this will increase the amount of debris that can be tracked, there will still be potentially lethal objects too small to be tracked by the Space Surveillance Network.

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[50] Eli Lake, "Space Station's Near Miss Underlines the Dangers of Debris in Space," *The Daily Beast*, March 26, 2012, http://www.thedailybeast.com/articles/2012/03/26/space-station-s-near-miss-underlines-the-dangers-of-debris-in-space.html, quoting Frank A. Rose, then Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State.

[51] Subcommittee Chairman Rep. Michael R. Turner expressed reservations and Ranking Member Rep. Loretta Sanchez said she was encouraged about ongoing consultations and raised some additional questions at a hearing of the House Armed Services Committee Strategic Forces Subcommittee on March 8, 2012. U.S. Congress, House Committee on Armed Services, Subcommittee on Strategic Forces, *Rep. Michael R. Turner Holds a Hearing on National Security Space Activities Budget*, 112th Cong., 1st sess., March 8, 2012. Subcommittee Chairman Sen. Ben Nelson and Ranking Member Sen. Jeff Sessions also raised various concerns at a hearing of the Senate Armed Services Committee Strategic Forces Subcommittee on March 21, 2012. U.S. Congress, Senate Committee on Armed Services, Subcommittee on Strategic Forces, *Sen. Ben Nelson Holds a Hearing on Military Space Programs Authorization*, 112th Cong., 1st sess., March 21, 2012.

[52] Frank A. Rose, Deputy Assistant Secretary, Bureau of Arms Control, Verification and Compliance, Department of State, *Pursuing an International Code of Conduct for the Security and Sustainability of the Space Environment*, National Space Symposium, Colorado Springs, CO, April 18, 2012, http://www.state.gov/t/avc/rls/188088.htm.

[53] *National Space Policy of the United States of America*, June 28, 2010, p. 7, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf.

[54] Walter S. Reid, United States Deputy Permanent Representative to the Conference on Disarmament, *Statement by Delegation of the United States of America*, Department of State, October 23, 2012, http://www.state.gov/t/avc/rls/199713.htm. The primary U.S. opposition to this treaty is that it is not in the national security interests of United States to add additional prohibitions to military or intelligence uses of space beyond the current regime, and the treaty fails to preserve the rights of the United States to conduct research, development, testing, and operations in space for military, intelligence, civil, or commercial purposes.

[55] The Stimson Center, *Space Norms Matrix*, January 20, 2011, http://www.stimson.org/essays/space-norms-matrix/.

[56] P. Krisko and A. Vavrin, "The NASA Orbital Debris Test Populations for the U.S. Air Force Space Fence," *Orbital Debris Quarterly News*, vol. 17, no. 4 (October 2013), p. 7.

Is Mitigation Enough?

Although international compliance with common mitigation measures is widely accepted as necessary, as mentioned earlier there is a growing view within international space agencies and the scientific community that mitigation alone is no longer sufficient to prevent the continual increase of space debris. According to many experts, more aggressive measures, such as active debris removal, should be considered to stabilize the future LEO environment.

Remediation

"Remediation" of the space environment denotes taking action with respect to inactive objects in space. Remediation is complex and would likely require significant resources, technological advances, and international cooperation. The 2013 IADC comparison study recommended that the international community "initiate an effort to investigate the benefits of environment remediation, explore various options, and support the development of the most cost-effective technologies in preparation for actions to better preserve the near-Earth environment for future generations."[57]

Active Debris Removal

Active Debris Removal is a form of remediation and, as the name suggests, involves the deliberate removal of debris objects from orbit. Various studies have asserted that the removal of orbital debris should be considered to stabilize the LEO environment. The National Space Policy directs that the United States will "[p]ursue research and development of technologies and techniques ... to mitigate and *remove* on-orbit debris...."[58] According to simulations based on NASA's current long-term orbital debris projection model, the LEO environment can be stabilized in the next 200 years if at least five large, intact objects are removed per year over the next 100 years.[59] This assumes, however, that 90% of future launches follow NASA's current mitigation guidelines and that no further explosions or other major debris releases occur. If international compliance with the 25-year rule does not reach the 90% level, the number of intact objects required to be removed each year could be higher.

In December 2009, the Defense Advanced Research Projects Agency (DARPA) and NASA sponsored an international conference that identified many possible technologies for debris removal. However, all of the technologies required further development and none had been fully tested or tried in the operating environment. Additionally, another key issue with debris removal technologies is that they are "dual use" capabilities that can be used to support anti-satellite programs. This is a concern for the United States. In 2011, DARPA released the final report of their "Catcher's Mitt" study that focused on the technical challenges of the orbital debris removal problem. The study found that active debris removal would be required at some point to maintain an acceptable level of operational risk and outlined several reasons to begin development of a

[57] J.-C. Liou, A. Rossi, and H. Krag, et al., *Stability of the Future LEO Environment*, Inter-Agency Space Debris Coordination Committee, IADC-12-08, January 2013, p. 18.

[58] *National Space Policy of the United States of America*, June 28, 2010, p. 7, http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf (emphasis added).

[59] J.-C. Liou, N.L. Johnson, and N.M. Hill, "Controlling the growth of future LEO debris populations with active debris removal," *Acta Astronautica*, vol. 66, no. 5-6 (March-April 2010), pp. 648-653.

solution today.[60] A central finding of the study was that "the development of debris removal solutions should concentrate on pre-emptive removal of large debris in both Low Earth Orbit and Geosynchronous Orbit."[61] It was noted that the greatest threat to operational spacecraft actually stems from medium-sized debris (defined as 5 mm–10 cm), but no reasonable solution was found to effectively remove that size of debris. For this reason, proposals for active debris removal generally focus on large space debris objects.

Proposals for active debris removal face significant technical challenges, but various concepts for removing large debris were discussed in the DARPA study, which captured some of the large number of technical approaches outlined in the scientific community. The DARPA study found that the removal of large objects generally employs advanced rendezvous and proximity operations and sophisticated grappling techniques. Various methods of capturing large objects were proposed involving a net, inflatable longeron,[62] tethered harpoon, articulated tether/lasso, and an electrostatic/adhesive blanket. Some solutions attached or used an active thrust device, while others made use of natural forces found in the space environment to impart a force on the debris to relocate it.

Legal Issues

The 2010 National Space Policy currently limits debris removal activities to research and development of technologies and techniques. The actual cleanup and removal of orbital debris would raise some major legal issues.

First, it should be noted that there is no international consensus on the legal definition of "space debris." The current space law treaty regime defines "space object," but there is no agreement on a definition of space debris as a subset of that term. The most prominent legal issue associated with debris removal relates to the ownership of objects in space. Article VIII of the 1967 Outer Space Treaty declares that space objects continue to belong to the country or countries that launched them. The launching state retains "jurisdiction and control" for a space object while it is in outer space, on a celestial body, and upon its return to Earth. The launching state never loses authority over the object, and no other nation has the legal authority to remove or otherwise interfere with it without authorization from the state of registry. This is true even if the space object is nonfunctioning or fragmented. "There is no right of salvage analogous to the right found in maritime law, which means that even though a satellite or some other space object may not be functioning, it does not imply that it has been abandoned by the nation that launched it."[63] In addition, "international space law deems fragments and components from space objects as individual space objects in and of themselves, which would require identification to determine the owner and either individual or blanket consent to remove it from orbit."[64] Absent some form of consent or international agreement, the United States would be limited to retrieving and removing objects only from its own registry.

Second, active debris removal raises significant questions of liability. Under the current space law treaty regime, damage caused by spacecraft is covered by the 1972 Convention on International

[60] Wade Pulliam, *Catcher's Mitt Final Report*, Defense Advanced Research Projects Agency, 2011.

[61] Ibid., p. 2.

[62] In aeronautics, a longeron is a major structural member of an aircraft fuselage, running from fore to aft.

[63] Michael Listner, "Legal issues surrounding space debris remediation," *The Space Review*, August 6, 2012, http://www.thespacereview.com/article/2130/1.

[64] Ibid.

Liability for Damage Caused by Space Objects (Liability Convention). Article II of the Liability Convention states that the launching state is absolutely liable for damage caused by its space object on the surface of the Earth or to aircraft flight. When space objects cause damage in outer space, however, a fault standard is applied.[65] If one spacecraft collides with another in space there is only liability if negligence can be proved. This could lead to extremely complicated fault assessments if damage or fragmentation occurred during removal operations, particularly operations involving multiple governments.

Additional considerations arise from the exchange of technical information that would be required as part of the debris removal process. Successfully approaching and removing an object from space necessitates a detailed knowledge of that object. This could require the exchange of confidential or proprietary technical information, which might require the negotiation of licensing and nondisclosure agreements.[66] For spacecraft with U.S. content, export control regulations could apply if removal involved a foreign government taking control of the debris, especially if exporting technical data was involved.

These issues demonstrate that, even if there were a consensus about the need for orbital debris removal, the necessary economic, legal, political, and technical considerations have not yet been fully examined.

Issues for Congress

Congress briefly addressed space debris issues in the 1990 NASA Authorization Act and more recently in the 2010 NASA Authorization Act. In the 2010 Act, Congress acknowledged that "national and international effort is needed to develop a coordinated approach towards the prevention, negation, and removal of orbital debris."[67] A few hearings[68] in recent years have touched on orbital debris issues, but Congress might consider additional hearings from major stakeholders in the military, intelligence, civil, and commercial sector on whether proposed mitigation measures are in the national interests of the United States. Possible questions could focus on the perceived severity of the problem, whether mitigation efforts to date are adequate, and whether there should be any commitment to pursue remediation in earnest. Congress might also consider requiring DOD and NASA to develop a roadmap outlining a range of possible remediation programs to consider.

Regarding possible appropriations considerations, the 2011 National Research Council study found that new resources would be required if NASA is to pursue the 2010 National Space Policy goals of research and development of technologies and techniques to mitigate and remove on-orbit debris. If the technologies to remove on-orbit debris are developed and implemented, the management requirements on NASA may become as significant as those associated with any major NASA program. Congress might find it useful to begin investigating those potential

[65] Liability Convention, Article III.

[66] Listner, "Legal issues surrounding space debris remediation."

[67] P.L. 111-267, Section 1202.

[68] U.S. Congress, Senate Committee on Commerce, Science and Transportation, Subcommittee on Science and Space, *Assessing the Risks, Impacts and Solutions for Space Threats*, 113th Cong., 1st sess., March 20, 2013; U.S. Congress, Senate Committee on Armed Services, Subcommittee on Strategic Forces, *FY2013 Budget Request for Military Space Programs*, 112th Cong., 1st sess., March 21, 2012; and U.S. Congress, House Committee on Science and Technology, Subcommittee on Space and Aeronautics, *Keeping the Space Environment Safe for Civil and Commercial Users*, 111th Cong., 1st sess., April 28, 2009, H.Hrg. 111-22 (Washington: GPO, 2009).

budgetary costs, and whether funding should borne wholly by NASA or by DOD or some combination.

Conclusion

Some observers have noted that the danger posed by orbital debris should be thought of fundamentally as a long-term environmental problem. Others perceive the danger as potentially affecting U.S. security interests, especially in its ability to interfere with consistent satellite support to U.S. military and intelligence organizations. However the issue is characterized, the space debris population, particularly in LEO, may have reached a tipping point. Catastrophic collisions are likely to continue to drive its growth, and the threat posed by orbital debris may be exacerbated by accidental or intentional debris-generating events. International compliance with mitigation measures is widely seen as critically important, but many experts believe that mitigation efforts alone are insufficient. For this reason, more aggressive measures, such as active debris removal, could be considered to protect U.S. national security interests in space and the long-term sustainability of the space environment.

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