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A Verifiable Limited Test Ban for Anti-satellite Weapons

The growing number of actors pursuing sophisticated outer space programs gives rise to one of the more novel challenges of the global commons. Once the privileged domain of the United States and the Soviet Union, space now accommodates a larger set of countries seeking to enhance their defense capabilities. In January 2007, perhaps most notably, China tested an anti-satellite (ASAT) missile, destroying Fengyun-1C, an old Chinese weather satellite. The weapon was a kinetic-energy ASAT, which homed in on its target and shattered it through high-velocity collision at an altitude of 864 km.[1] The impact created thousands of debris fragments concentrated in orbits between 800 and 1,000 km,[2] approximately doubling the risk of potentially catastrophic collision for satellites in the crowded 800–900 km range.[3] Satellites at these altitudes include commercial communications satellites, a U.S. photoreconnaissance satellite, a Chinese earth science satellite, and a Russian electronic intelligence satellite.[4] Most of the Fengyun-1C debris will stay in orbit for several decades; some is expected to remain in space for centuries.[5]

In February 2008, the United States used a direct-ascent kinetic energy interceptor to destroy, at an altitude of 247 km, a failed U.S. satellite (USA-193) about to make an uncontrolled atmospheric reentry.[6] The resulting debris was comparatively short-lived due to the greater atmospheric drag at the lower altitude of intercept, with 99 percent of the debris expected to enter the atmosphere within one week.[7] U.S. officials have consistently stated that the

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destruction of USA-193 was not intended to test U.S. anti-satellite capabilities. For instance, the head of the U.S. mission at the UN Conference on Disarmament said the "engagement is not part of an anti-satellite development and testing program, and we do not intend to retain the technical capability resulting from the modifications required."[8] The Chinese foreign ministry, however, expressed vague concerns about "possible damage to the security of outer space and relevant countries by the U.S. move."[9] Further, the Russian defense ministry said that the satellite destruction "does not look harmless as they try to claim, especially at a time when the U.S. has been evading negotiations on the prohibition (limitation) of arms race in outer space for a long time."[10]

The recent space intercepts by China and the United States may have alarmed Russia, which had reportedly decommissioned its own Soviet-era ASAT program in 1993.[11] In March 2009, Russian Deputy Defense Minister Vladimir Popovkin, former chief of Russian military space forces, reportedly said at a news conference that Russia "can't sit back and quietly watch others doing that [testing space interceptors]" and is therefore working to develop a similar capability. Popovkin also stated that Russia continues to oppose a space arms race.[12]

Most of the Fengyun-1C debris will stay in orbit for several decades, some for centuries.

More countries are poised to assert military prowess in space. In January 2010, the director-general of India's Defence Research and Development Organisation reportedly said that India plans to develop the capacity to destroy satellites in low-earth and polar orbits, as part of a broader ballistic missile defense program that will reach maturity in 2014.[13] Japan passed legislation in 2008 that permits it to use outer space for military purposes of a defensive nature.[14]

At the Conference on Disarmament in Geneva, a forum in which countries have discussed possible ASAT restrictions since 1982, member delegations broke a decade-long impasse in May 2009, approving a program of work that would have included a working group on "all issues related to the prevention of an arms race in outer space."[15] But due to obstruction by Pakistan on issues unrelated to space, the conference session ended last September without any progress on implementing the work program.[16]

In light of these recent developments, can any verifiable space arms control measures be taken to enhance national and international security? We argue that the answer is yes, and recommend that the chief goal of these new measures should be to protect the space assets of the United States and other countries against the future generation of long-lived orbital debris. Since the United States relies more on space systems for military operations than any other country, it has the greatest interest in limiting the increase of space debris. Moreover, the United States, other space-faring nations, and private companies are poised to embark on more ambitious human spaceflight missions that may be threatened by increasing debris.[17] Measures to minimize orbital debris would reduce the risk to people and property in outer space, and might also reduce the chances of a costly and destabilizing arms race among space powers.

The Space Debris Hazard

Almost 930 operational satellites currently orbit the Earth, including about 437 from the United States, 95 from Russia, and 58 from China.[18] Nearly half of all active satellites operate in Low Earth Orbit (LEO), between 200 and 2,000 km in altitude. Most of the rest are located in geosynchronous orbit, a special orbit at 35,876 km in which satellites circle Earth in exactly one day. Geosynchronous satellites in equatorial orbit, therefore, appear to hover above the same point on the Earth's equator and are called geostationary.[19] About 10 percent of satellites are in other types of intermediate orbits.[20]

In addition to these active satellites, there is an enormous amount of orbiting debris. The U.S. Space Surveillance Network (SSN) of optical and radar sensors tracks more than 14,000 objects larger than ten cm in diameter.[21] The SSN can detect debris in the five to ten cm size range in LEO, and objects larger than a meter in Geostationary Earth Orbit (GEO). There are about 22,000 known objects larger than 10 cm at all altitudes, with the highest concentrations in LEO.[22] This figure includes active and inactive satellites, but most of the objects tracked are debris. Estimates are that about 500,000 debris fragments larger than 1 cm in size are orbiting the Earth.[23] Because of the high velocities of objects in orbit, debris greater than 1 cm in size can seriously damage or destroy a satellite in collision, and debris greater than 10 cm in size may generate a large amount of additional debris from the collision. NASA models predict that the density of orbital debris will increase in the future (due to collisions between objects already in orbit) faster than debris density will decrease due to drag on these objects from the extremely thin atmosphere in LEO.[24]

The Inter-Agency Space Debris Coordination Committee (IADC) is a consortium of space agencies established in 1993 to examine and address the issue of orbital debris. NASA and the Russian Federal Space Agency were among the founding members of the IADC, with the Chinese National Space Administration joining in 1995. Other current members are the national space agencies of France, Germany, India, Italy, Japan, Ukraine, and the United Kingdom plus the European Space Agency. In 2002, the IADC issued a set of debris mitigation guidelines, including the recommendation that:

> Intentional destruction of a space system (self-destruction, intentional collision, etc.), and other harmful activities that may significantly increase collision risks to other systems should be avoided. For instance, intentional break-ups should be conducted at sufficiently low altitudes so that orbital fragments are short lived.[25]

The U.S. destruction of USA-193 was consistent with this guideline; the Chinese intercept of Fengyun-1C was not.

Although the IADC guidelines are not legally binding, they represent a strong international consensus on the growing threat that orbital debris poses to all space assets, including human-crewed spacecraft and the International Space Station. Existing debris mitigation proposals—such as de-orbiting inactive satellites or capturing orbiting debris—seem, at present, to be prohibitively expensive.[26] For the foreseeable future, the most viable mitigation measure is likely to be minimizing the creation of new debris.

A Brief History of ASAT Weapons

The Fengyun-1C intercept created more than 2,300 pieces of trackable debris and an estimated 150,000 pieces of debris larger than one centimeter in size.[27] China is not the only country to have tested ASAT weapons at an altitude too high to allow for rapid debris removal by atmospheric drag, but it is the first to have done so since the end of the Cold War.

The U.S. military conducted the world's first ASAT test in October 1959.[28] Early U.S. tests, which continued until 1970, involved components of systems that would have relied on nuclear detonations to destroy their targets. Renewed Soviet ASAT testing in 1976, among other factors, led the United States to develop a kinetic-energy ASAT missile launched from an F-15 fighter. Between 1984 and 1986, the United States conducted five tests of this system, only one of which damaged a satellite. In September 1985, the Air Force crashed an ASAT homing vehicle into Solwind P78-1, a solar research satellite, at an altitude of 525 km. The impact created 285 pieces of debris large enough to be tracked by the SSN. Most of this debris decayed out of orbit within a decade, with the last piece falling back to Earth in 2004.[29]

The Soviet Union began research into ASAT systems around 1960 and first tested prototype components in 1967. Moscow then conducted seven ASAT tests between 1968 and 1971, and an additional 13 tests from 1976 to 1982. The Soviet tests employed a co-orbital interceptor system, in which an attack satellite would be launched into space and, after one or two orbits, close to within a kilometer of a target satellite. In the first four tests of this system, the interceptor then detonated a conventional explosive, strewing small metal pellets meant to destroy the target. Subsequent tests aimed for a close rendezvous without proximity detonation; the interceptor was then either de-orbited to burn up in the atmosphere, or maneuvered into a higher orbit where it would self-destruct.[30]

Space assets need to be protected against the future generation of long-lived orbital debris.

China started to research ASAT weapons in the 1970s and began to develop a kinetic-energy weapon in the 1980s.[31] From 2004 to 2007, China is believed to have conducted one test of a kinetic ASAT weapon per year, although only the 2007 test damaged its target.[32] The earlier, non-destructive tests may have been deliberate fly-by maneuvers or technical failures.

The Verification Challenge

Any agreement to limit space debris by restricting ASAT use would need to be carefully drafted and effectively verified.[33] The George W. Bush administration argued that it is not possible to devise a verifiable space arms control treaty that does not infringe on valid U.S. interests.[34] For instance, how could "anti-satellite weapons" be defined without including all maneuverable satellites—any of which has the ability to collide with a target? Banning research and development on ASAT weapons could preclude, for instance, the further development of automated transfer vehicles for delivering cargo to the International Space Station; these could be portrayed as a proxy for the development of ASAT guidance, navigation, and control systems. Attempts to carve out exceptions for such cases could lead to severe verification challenges. Furthermore, ASAT systems could be launched within other payloads, or in the form of satellites that hid their weaponized nature until the operator decided to break out from an arms control regime.

The potential that ballistic missile defense systems could be used as ASAT weapons must also be considered. Certain weapons systems in the U.S. ballistic missile defense program should be able to intercept targets at altitudes that encompass nearly every satellite in LEO.[35] Dual-use concerns are likewise raised by the existing or prospective ballistic missile defense systems of other countries, such as China.[36] It is possible that countries could devise software-only modifications to convert ballistic missile defense systems to ASAT weapons, enabling a sudden breakout capability from a ban on ASAT possession that would be impossible to detect under any realistic verification regime. For this reason, proposals for complete bans on ASAT weapons seem incapable of achieving what Paul H. Nitze called "effective verification," the ability to detect a militarily significant violation in time to respond effectively and deny the violator the benefit of the violation.[37]

China and Russia have also acknowledged the difficulties of verification in space arms control. In a joint unofficial presentation to the Conference on Disarmament in August 2004, the Chinese and Russian delegations reviewed the verification measures previously envisaged by various countries for space arms control. After summarizing political, technical, and financial objections to these proposals, they conceded that "many practical problems are to be solved before codifying meaningful verification provisions for the new outer space treaty."[38] Last year, China and Russia reiterated their desire for a new legal instrument on arms in outer space, and proposed that "to facilitate an early consensus," countries could "set aside the question of verification and other contentious issues for the time being."[39]

> A limited ban on ASAT testing can meet the standard of effective verification.

We believe, in contrast, that any efforts to reach a binding treaty on space weapons should emphasize, rather than disregard, the issue of verifiability. Specifically, a limited ban on ASAT testing can meet the standard of effective verification.

The Case for a Limited Test Ban

The United States and other space powers could enhance the security of their space assets with a ban on debris-producing intentional destruction or damage of space systems above a specified altitude in LEO. By focusing on the effects of ASAT testing, rather than the definition of an ASAT weapon, the ban would be far easier to negotiate than previous space arms control proposals. Even if the term ASAT is not used in the agreement text, the ban would encompass tests of kinetic-energy ASAT weapons as well as ASAT weapons that employ proximity explosion. This proposal is intentionally limited: it does not address ASAT attacks that do not create debris; nor would it prevent a potential adversary from placing offensive satellites in parking orbits, or from conducting fly-bys of target satellites. Some of these behaviors could be addressed in a so-called "rules of the road" or code-of-conduct agreement. That is a separate option, perhaps complementary to our own proposal, but it is not our focus.[40]

There are at least two arguments that favor a ban on debris-producing intentional destruction of space systems. The first is that the United States has the greatest stake in minimizing the amount of orbital debris, since the United States makes the most use of space. The limited ban proposed here would be both an arms control measure and an environmental measure to decrease debris collision risk for astronauts and space systems. Such a proposal would also be consistent with safeguarding the more ambitious, and strongly international, human spaceflight program that is likely to develop in the coming decades.[41]

The second argument is that members of the Conference on Disarmament have linked discussions on space arms control to negotiations on a fissile material cut-off treaty (FMCT), a priority of the Obama administration.[42] U.S. leadership in space arms control discussions does not guarantee progress on an FMCT—indeed, Pakistan's apparent concerns with an FMCT seem to be holding up progress on all issues at the Conference on Disarmament. China, however, has consistently linked discussions on the "prevention of an arms race in outer space" with negotiations on an FMCT, suggesting that a lack of serious U.S. engagement on limiting space weapons could impede FMCT progress.[43]

A limited test ban would be verifiable by the United States via its unmatched ability to track launches, satellites, and debris. The ban would not address the possibility of breakout, in which an adversary stockpiles ASAT weapons without testing them. Stockpiling would be very difficult to monitor. But research, development, or stockpiling—including placing ASAT weapons in orbit—would not violate the proposed agreement, which would not change the current lack of legal restrictions on these non-destructive actions. This proposal also would not address ASAT weapons that do not produce debris.

Under this limited ban, the inability to assess what states possess on the ground—and some of what states do in space—is accepted. As is the case today, the United States could maintain or develop its offensive capabilities, and so could its potential adversaries, so long as they do not cause deliberate collisions or detonations above a certain altitude.

The maximum permissible test altitude would reflect the need to protect important space assets against the generation of additional orbital debris, as well as to slow the worsening of the "cascade" or runaway-debris effect, whereby collisions among existing orbital objects increase the total amount of debris, even in the absence of new spacecraft launches or ASAT tests.[44] Data on debris generated by past collisions would inform the choice of maximum altitude, and it is not hard to bracket what an acceptable altitude ceiling might be.

The U.S. Missile Defense Agency reports that its ballistic missile intercept tests were conducted at an altitude of 230 km.[45] Presumably, this low altitude was chosen in part to limit the production of long-lived debris.[46] In the event of actual war, ballistic missile intercepts might take place at much higher altitudes, but evidently a ban on testing above 250 or 300 km would not unduly interfere with missile defense tests. Likewise, the SM-3 interception of USA-193 took place at an altitude of 247 km. It seems probable that if the United States decides to intercept another satellite undergoing uncontrolled reentry in the future, it would choose a similarly low altitude to minimize the creation of persistent debris. A test ceiling in the range of 250–300 km above the Earth would, therefore, appear acceptable to the United States.

Other factors bracket the maximum test ban altitude from above. For example, the International Space Station orbits at an altitude around 350 km; it would be prudent to minimize the production of debris near this altitude. More generally, debris that is too small to be tracked from the ground—and therefore harder for satellites and spacecraft to avoid—will fall to Earth in about a year from orbits around 400 km, and in about a month from orbits around 300 km.[47] These orbital decay estimates also argue for an upper limit on intercept altitude in the 300 km range.[48] The exact choice of limit should be further informed by an analysis of debris distributions from known fragmentation events, simulations of a wide variety of kinetic-energy intercept scenarios, analysis of the stability of reentering satellites as a function of altitude, and a more comprehensive review of satellite functions and orbits.

The limited ban would permit all countries to test debris-producing ASAT systems below the agreed altitude, so it would not cap the number of countries with this capability. But for this same reason, it would be more likely to receive broad multinational support. Such an agreement would, after all, represent no more than a quantification and elevation to a legal obligation of the existing IADC debris mitigation guidelines. The United States would remain free (as would other nations) to intercept de-orbiting satellites or to conduct ballistic missile intercept tests below the specified altitude. A test ban above 250–300 km has evidently been the de facto, voluntary practice of the United States in recent years. Furthermore, since satellites closer to the Earth move faster, a country that has confidence in its ability to intercept a satellite below 300 km would likely feel confident that it could target slower-moving satellites at higher altitudes in LEO, provided that the country has a weapon system capable of reaching those altitudes.

Potential opponents of our proposal may argue that it could be hard to know whether damage to a satellite was intentional or accidental, thereby allowing an enemy to attack space assets with impunity.[49] An adversary state could claim that the destruction or damage of a satellite operated by another state was inadvertent. But in practice, whether an event was intentional could likely be determined from factors, such as the launch site and the identity of the damaged satellite, and be informed by the international political situation.[50] Despite the absence of an ASAT test ban to date, it appears that no country has ever deliberately destroyed the satellite of another country. States that agree to a limited test ban should feel even more obliged not to harm foreign-owned satellites.

Another problematic scenario would be if a state party to a limited ban claimed that damage to one of its own satellites was the inadvertent result of a non-destructive fly-by test gone awry. Such a claim, however, would raise strong suspicions. Navigation errors are far more likely to cause a miss than a hit. Parties to a limited ban on debris-producing destruction or damage of satellites are, therefore, unlikely to attempt a covert intentional collision, whether with their own satellites or those of other states, given the high probability that non-compliance will be immediately suspected.

On the other hand, proponents of more extensive arms control have suggested that the United States should pursue a total ban on ASAT testing in space.[51] Under a complete test ban, no further collisions of ASAT weapons with targets would be permitted. Countries that agreed to such a ban prior to testing ASAT weapons could never fully develop that capability. A complete test ban that somehow gained universal adherence would therefore lock in an advantage for China, Russia, and the United States, a prospect that could be a nonstarter for newly spacefaring states.

By focusing on the effects of ASAT testing, the ban would be far easier to negotiate.

Such countries, which are in the early stages of developing space capabilities, might view a universal test ban as unacceptably discriminatory, and therefore choose not to join or to undermine such an agreement. A total test ban would also prohibit the United States from intercepting satellites undergoing uncontrolled reentry, or at least require it to make the difficult argument that such an intercept does not constitute a violation of the test ban. Finally, it might prove difficult to draft a treaty that forbade debris-producing ASAT tests but permitted midcourse-intercept ballistic missile defense tests, which China and the United States may view as essential to their national security. For all these reasons, a complete test ban is not a strong option.

If our proposed ban on ASAT testing above a specified altitude in LEO is also not achievable, a ban on testing in GEO would be a beneficial fallback position. It would, of course, mitigate much less of the potential debris threat than a limited test ban in LEO. Nevertheless, dangerous orbital debris produced in GEO effectively lasts forever, and threatens some of the most important space assets. It is hard to envisage circumstances, even in war, under which the United States would take any intentional action that created debris in GEO.

ASAT Arms Control: Process and Precedent

It is in the interest of the United States and all space-faring nations to prevent further ASAT tests at altitudes like that of the Fengyun-1C intercept. As a result, we recommend that the United States pursue a limited (by altitude) ban on orbital debris-producing intentional destruction of space systems. Such a ban would be effectively verifiable, avoiding the problems of definition and verification that have plagued other space arms control proposals.

The ban could be pursued in a number of venues. A first step could be for the IADC to specify an altitude above which debris-producing intentional destruction of any space system should be avoided. Whether or not the IADC recommends a particular altitude cap, a binding ban could be pursued in direct talks with other space powers or through negotiations at the Conference on Disarmament. Many different criteria would influence the final choice of altitude for the limited ban. But to be useful without being a de facto complete ban, it seems likely that that specified altitude ceiling would prove to be within or near the range of 250–300 km.

> The United States has the greatest stake in minimizing the amount of orbital debris.

It is possible that a limited treaty constraining ASAT weapons could lay the groundwork for broader agreements, just as the Limited Test Ban Treaty (LTBT) of 1963 helped pave the way for the Comprehensive Nuclear Test Ban Treaty (CTBT) of 1996. The multilateral LTBT prohibited nuclear weapons tests in the atmosphere, in outer space, and under water. The parties to the LTBT proclaimed their desire "to put an end to the contamination of man's environment by radioactive substances."[52] In effect, the LTBT was both an arms control and an environmental treaty. A total nuclear test ban was beyond reach in 1963 for a number of reasons, including an inability to verify a ban on underground testing without a level of intrusiveness that the Soviet Union would not accept.[53] Yet, the LTBT proved viable for two key reasons. First, it was effectively verifiable. Second, there was strong public interest in negotiations to ban such tests, driven by sustained concern over the dangers of radioactive fallout.

Today, the risks posed by space debris do not prompt similar public concern. The remoteness of space renders the debris problem obscure to anyone who does not take an active interest in the issue. It might take a catastrophic or near-catastrophic incident caused by debris—such as the loss of a human-crewed spacecraft—before the general public would pay close and persistent attention. Additional ASAT tests at high altitudes could rapidly increase the debris hazard to human spaceflight missions and to vital military, scientific, and commercial satellites. It is, therefore, time to pursue a ban on debris-producing intentional destruction or damage of space systems above a specified altitude in LEO.

Notes

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34. See Paula A. DeSutter, "Is an Outer Space Arms Control Treaty Verifiable?" (remarks, Washington Roundtable on Science and Public Policy, Washington, D.C., March 4, 2008), http://www.marshall.org/pdf/materials/592.pdf.
35. See David Wright and Laura Grego, "Anti-Satellite Capabilities of Planned US Missile Defence Systems," *Disarmament Diplomacy*, no. 68 (December 2002–January 2003), http://www.acronym.org.uk/dd/dd68/68op02.htm.
36. China announced in January 2010 that it successfully tested a "ground-based midcourse missile" interceptor. A Pentagon spokesperson confirmed that the U.S. military observed two missile launches and "an exo-atmospheric collision." It is unclear whether this Chinese weapon system has an altitude range similar to analogous U.S. systems. See Tania Branigan, "China 'Successfully Tests Missile Interceptor,'" *Guardian*, January 12, 2010, http://www.guardian.co.uk/world/2010/jan/12/china-tests-missile-interceptor.
37. See Paul H. Nitze, "Security Challenges Facing NATO in the 1990s," address before the Nobel Institute, Leangkollen Seminar, Oslo, Norway, February 6, 1989, *U.S. Department of State Bulletin* (April 1989), p. 46, http://www.archive.org/download/department ofstatb89unit/departmentofstatb89unit_bw.pdf.
38. Permanent Mission of the People's Republic of China to the United Nation Office at Geneva and Other International Organizations in Switzerland, "Verification Aspects of PAROS [Preventing an Arms Race in Outer Space]," August 26, 2004, http://www.china-un.ch/eng/cjjk/cjjblc/cjlc/t154645.htm.
39. "Principal Questions and Comments on the Draft Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force Against Outer Space Objects (CD/1839), and the Answers Thereto," CD/1872, August 18, 2009, http://disarmament.un.org/library.nsf/a61ff5819c4381ee85256bc70068fa14/4a10c7c900aa03c28525762500713d69/$FILE/cd-1872.pdf.

40. A prominent example of a "rules of the road" proposal suggests the negotiation of a code of conduct for space-faring nations, in some ways analogous to those that exist for ships, in which, *inter alia*, rules of safe space operation and traffic management are developed and "harmful interference against space objects" is avoided. See Michael Krepon, testimony before the House Committee on Armed Services, Subcommittee on Strategic Forces, March 18, 2009, http://armedservices.house.gov/pdfs/SF031809/Krepon_Testimony031809.pdf.
41. Review of U.S. Human Spaceflight Plans Committee, "Seeking a Human Spaceflight Program Worthy of a Great Nation," pp. 105–108.
42. For one nongovernmental version of the scope of a possible FMCT agreement, see International Panel on Fissile Materials, "Global Fissile Material Report 2008: Scope and Verification of a Fissile Material (Cutoff) Treaty," October 11, 2008, http://www.fissilematerials.org/ipfm/site_down/gfmr08.pdf.
43. For example, see Hu Xiaodi, statement at the Plenary of the 2002 Session of the Conference on Disarmament, CD/PV.900, March 28, 2002, p. 21, http://disarmament.un.org/Library.nsf/a61ff5819c4381ee85256bc70068fa14/b16f9f8c1cf762d285256bdd0053524d/$FILE/pv900.pdf.
44. See Donald J. Kessler and Burton G. Cour-Palais, "Collision Frequency of Artificial Satellites: the Creation of a Debris Belt," *Journal of Geophysical Research* 83, no. A6 (June 1, 1978): 2637–2646; Liou and Johnson, "Risks in Space from Orbiting Debris"; and William J. Broad, "Orbiting Junk, Once a Nuisance, Is Now a Threat," *New York Times*, February 6, 2007, http://www.nytimes.com/2007/02/06/science/space/06orbi.html.
45. See Major General Willie B. Nance, "MG Nance Provides Update on Missile Test," press briefing, August 9, 2001, http://www.defense.gov/Transcripts/Transcript.aspx?TranscriptID=1568 and Lt. General Ronald T. Kadish, press briefing, November 30, 2001, http://www.defense.gov/transcripts/transcript.aspx?transcriptid=2483.
46. See NASA, "NASA Procedural Requirements for Limiting Orbital Debris," May 14, 2009, http://nodis3.gsfc.nasa.gov/npg_img/N_PR_8715_006A_/N_PR_8715_006A_.pdf and U.S. Government Orbital Debris Mitigation Standard Practices, n.d., http://www.orbitaldebris.jsc.nasa.gov/library/usg_od_standard_practices.pdf.
47. Debris less than 5–10 cm in diameter is generally too small to be tracked by ground-based sensors. See National Research Council, Committee on Space Debris, *Orbital Debris: A Technical Assessment* (Washington, D.C.: National Academies Press, 1995), p. 29. This idealized analysis assumes that the debris is made of aluminum and is spherical in shape. The timescale for orbital decay depends on the 11-year solar cycle, with resulting variations of factors of two or three around the time limits given here. The ballistic coefficient of debris, which depends on its shape, also affects decay time. In all but unusual cases, the smaller the debris, the faster its orbit will decay.
48. The destruction of USA-193, which the U.S. government stated was not a test of ASAT capability, created a large amount of debris that, though short-lived, had maximum orbital altitudes (apogees) well above the intercept altitude of 247 km. Indeed, NASA data from about two days after the intercept indicate a median debris apogee of 600 km. An agreement to ban ASAT tests above a certain altitude might also include a provision that requests that countries take steps to minimize the creation of debris whose apogees lie at altitudes much higher than the limit. We received the data on the USA-193 debris cloud from the NASA Orbital Debris Program Office on December 10, 2009. NASA is not responsible for the content of this article or the views expressed by the authors.

49. A dispute would have some precedent. In February 2009, when a commercial U.S. communications satellite collided with a Russian satellite believed to be defunct and non-maneuverable, a retired Russian general claimed (without citing any evidence) that the incident was, in fact, a U.S. military test of anti-satellite technology. See "Russian general says U.S. may have planned satellite collision," RIA Novosti, March 3, 2009, http://en.rian.ru/russia/20090303/120392490.html. Also see William J. Broad, "Debris Spews Into Space After Satellites Collide," *New York Times*, February 11, 2009, http://www.nytimes.com/2009/02/12/science/space/12satellite.html.
50. If countries develop and deploy sea-launched ASAT weapons, it could become more difficult to determine the launching state of an ASAT missile. Although the U.S. government states that the destruction of USA-193 should not be viewed as a test of ASAT capability, the engagement nonetheless constituted the first destruction of a satellite in orbit by a missile launched at sea.
51. For instance, Kurt Gottfried, Richard Garwin, and Len Meeker, "A Draft Treaty Limiting Antisatellite Weapons," testimony for Controlling Space Weapons, U.S. Senate, Committee on Foreign Relations, 98th Congress, 1st sess., May 18, 1983, pp. 112–129, http://www.ucsusa.org/nuclear_weapons_and_global_security/space_weapons/policy_issues/a-draft-treaty-limiting.html. More recently, Bruce W. MacDonald, "China, Space Weapons, and U.S. Security," *Council Special Report*, no. 38, September 2008, p. 30, http://www.cfr.org/content/publications/attachments/China_Space_CSR38.pdf.
52. Preamble to the Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water, August 5, 1963, http://www.state.gov/t/isn/4797.htm.
53. United States Arms Control and Disarmament Agency, *Arms Control and Disarmament Agreements: Texts and Histories of the Negotiations* (Washington, D.C.: U.S. Government Printing, 1996), p. 26.