Verification in space: theories, realities and possibilities

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Throughout the space era, the international community has grappled with the issue of space weapons and conflict in outer space. Definitional issues are daunting, and the treaties or other accommodations necessary to minimize these threats require verification. From the work of the landmark study on verification by the United Nations Disarmament Commission, and additional reports by two groups of governmental experts on verification in 1990 and 1995, verification is defined as "a process in which data are collected, collated and analysed in order to make an informed judgement as to whether a party is complying with its obligations", be these obligations multilateral, bilateral or unilateral.[1] This definition broadens the classical definition of verification relating to arms limitation or disarmament agreements to include new sources of obligations.

This article examines the technical feasibility of verifying space activities during launch, re-entry and on-orbit operations and discusses the political and diplomatic challenges to the implementation of a space verification regime. The article also analyses the changing landscape of the space security regime in response to new geo-political realities—changes that provide opportunities for progress.

Technically feasible verification

Any potential space verification regime must be based on both technical and political realities. Therefore it is important to examine the various phases and components of space operations to determine where verification is feasible and under what circumstances. A significant amount of work has been done on technical verification, much of it by the Soviet Union and the United States during the Cold War. The motivation of the two superpowers was to be able to detect and warn of impending ballistic missile attacks. Many of the technologies and techniques developed for that purpose can also be employed to verify space weapons or arms control, largely because the ballistic missile threat traverses the space domain, and on-orbit satellite systems can observe and monitor ballistic missile launch, midcourse adjustments, de-orbit and the warhead impact. Since the end of the Cold War, some of these technologies have proliferated beyond the two original superpowers and are now available to a number of states and even commercial entities.

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Launch

Perhaps one of the easiest areas of space operations to verify from a technical standpoint is the launch of a space object. This is because launches generate enormous amounts of detectable and measurable thermal energy. Placing an object in orbit requires several goals to be met: the object must be boosted to a specific altitude above the surface of Earth; and the object's mass, shape, density and the velocity vector imparted by the launch's booster and post-boost systems must be sufficient to enable the object to remain in the desired orbit associated with that particular altitude. Without these elements, Earth's gravity and other atmospheric and environmental phenomena will eventually cause the object to return to Earth. Currently the only feasible way of launching and achieving orbit is to employ a massive chemical reaction, using large systems propelled by liquid or solid rocket engines.[2]

Presently, given the amount of energy released, the most effective way to detect space launches is to deploy and operate satellites that detect infrared (thermal) energy, a technology that has been used by the United States since the early 1960s.[3] Since the 1970s, the US military has operated a constellation of Defense Support Program (DSP) satellites in geostationary orbit, which stare at Earth and can detect space and missile launches around the globe. Originally established to provide warning of ballistic missile launches by the Soviet Union, the DSP constellation now has the mission of providing alerts of space launches and theatre missile launches anywhere on Earth, as well as other significant infrared (IR) events. The United States is currently in the process of deploying a new series of geostationary satellites and highly elliptical orbit (HEO) satellite payloads with IR warning capabilities as part of a DSP follow-on system called the Space-Based Infrared System (SBIRS).

In addition to providing notification that a launch is occurring, the DSP and SBIRS systems can also determine the azimuth or direction in which the rocket is heading. Combined with the latitude of the launch site, the azimuth can be used to calculate the eventual inclination of the orbit of any payload on the rocket. As it is very difficult for a satellite to significantly change its inclination, this greatly reduces the volume of space surveillance sensors needed in order to detect or support such launch activity. These data give ground- or space-based tracking sensors a much improved chance of efficiently and accurately tracking any satellite following launch.

The United States is not alone in deploying IR satellite detection capabilities, although it operates the only space-based IR monitoring system that essentially covers the entire globe. The Russian Federation has deployed some space-based infrared detection capability, and France has a programme under way to develop and build its own capability, perhaps for European use.[4] There are also efforts to share some of these data through early warning agreements and other protocols. In 2000, the Russian Federation and the United States agreed to establish a Joint Data Exchange Center (JDEC) to share missile warning data. While progress on that initiative has been slow, recent efforts to make the system operational have intensified,[5] and sharing has been expanded to include a number of states.

Another technique of detecting space launches uses infrasound. In addition to producing massive amounts of heat, rocket engines and motors also create large amounts of noise. While much of this noise is generated within the human auditory range, a significant portion also occurs in the infrasound range of 20–0.001Hz, far below that detected by human hearing. Infrasound detectors are used to monitor important natural and man-made phenomena, including nuclear detonations. In accordance with the verification requirement of the Comprehensive Nuclear-Test-Ban Treaty, the International Monitoring System operates 60 infrasound monitoring stations in 35 countries. Recent work has established that these same infrasound stations can also be used to detect space and missile launches, although they are not as effective as space-based infrared systems.[6]

Re-entry

Verifying that a space object is going to re-enter Earth's atmosphere and, more important, determining where it will land and the risk it poses to Earth and its inhabitants is more difficult than verifying the launch of a space object. Nevertheless, technology has been developed to achieve some capability in this area.

In verifying that an object will re-enter Earth's atmosphere one must establish an element set (or more precisely ephemerides). An element set indicates where an object is in orbit at a specific time; it also provides information on how the object's orbit changes over time. All objects in orbit are affected by forces called perturbations, and for objects within a few hundred kilometres of Earth one of the most significant perturbations is the drag caused by interaction with Earth's upper atmosphere. This drag causes a space object to lose energy and thus drop lower and lower in orbit, and the closer an object is to Earth the greater the drag. Eventually, atmospheric drag will cause an object not to have enough energy or altitude to remain in orbit and it will re-enter Earth's atmosphere.

Space situational awareness (SSA) systems, which detect and calculate the positions of objects in space, can be used to predict when an object will naturally decay out of orbit, although the accuracy of these predictions can vary widely depending on the accuracy of the underlying positional data and the rate of decay. The United States military predicts and tracks all the re-entries of objects in its satellite catalogue and publishes trajectory and impact prediction alert messages publicly on a web site.[7] In addition, the Inter-Agency Space Debris Coordination Committee periodically chooses a particular object and conducts an international campaign to track its orbit and predict its atmospheric re-entry time and location.

Satellites that are under control and low enough can also deliberately re-enter Earth's atmosphere by performing a manoeuvre called a de-orbit burn. This requires the satellite to fire its manoeuvring thrusters and expend a certain amount of fuel. While commanded de-orbits would not be detectable through orbit prediction, the heat generated by friction on their entry into the atmosphere would be significant and could be detected using space-based infrared detection systems. This has also been observed with objects de-orbiting as a result of natural decay.

Even with a precise orbital element set, it is only possible to predict roughly when an object will re-enter the atmosphere, and current ground impact prediction is limited to calculating a very narrow ellipse, which extends in the direction of satellite motion. Even with tremendous monitoring capabilities, it is still very difficult to predict exactly where on the ground a re-entering space object will land, assuming it does not fully vaporize from the heat of atmospheric friction. The prediction's accuracy is also affected by a number of other variables: wind speeds at various altitudes, the exact size and shape of the object, how many pieces the object will break up into. Many of these variables are difficult to determine precisely before the event. The pieces of the re-entering object will be distributed through the tens to hundreds of square kilometres within the predicted ellipse. Space-based IR sensors can be employed to help confirm, after the event, when and where exactly the atmospheric re-entry happened.

On-orbit operations

Verifying the function of a particular space object already in orbit is significantly more difficult than detecting launch or re-entry. Nevertheless, studies have shown that such verification is possible under certain circumstances. For example, in the mid-1980s, the Canadian government sponsored a study called "PAXSAT A", which explored the concept of using space-based resources to verify the function of objects in orbit. The concept called for a constellation of a minimum of four satellites—two in low Earth orbit (LEO), one in medium Earth orbit and one in geosynchronous Earth orbit (GEO). These satellites would then be equipped with a variety of sensors. These sensors included chemical and nuclear radiation detectors, electromagnetic support measures, and optical, thermal, infrared and microwave radar. The PAXSATs would manoeuvre to within sensor range of the satellite to be investigated and collect sensor readings to determine the satellite's function.

The PAXSAT concept relies on the engineering principle that "form follows function"; that the design of a satellite will closely follow its designated function. The extremely high cost of manufacturing and placing a satellite in orbit means that wasting mass is very expensive. Satellite designers go to great lengths to squeeze every possible reduction in size and mass to optimize efficiency from their satellites, thus a close examination of a satellite's design should reveal its function. Satellites in orbit are closed systems, which is another aid to their examination—satellites must generate all their own power, dump all their own waste heat, and store all their own consumables. The PAXSAT study concluded that it would be impossible to hide heat dumps, power generation, or communications or radioactive materials within the relative sterility of space.

Leveraging the results of the PAXSAT study, the operational and technical feasibility of such on-orbit rendezvous and inspection is already being investigated. The United States military has flown several demonstration missions, including a pair of Micro-satellite Technology Experiment satellites in GEO and the XSS-11 rendezvous and inspection satellite in LEO. These satellites carry a variety of sensors, including laser and optical imagers, and they have reportedly demonstrated the ability to inspect a specific object in orbit.[8]

Verifying the on-orbit actions of a space object is easier than verifying its functions. It can be done using a large number of ground-based (and a few space-based) sensors that are already employed to track objects in orbit. The ground-based sensors are primarily radars and optical telescopes. Observations from multiple sensor viewings are then combined to produce the object's element set, and changes that have occurred over a period of time can be measured and evaluated.

This ability to verify actions on orbit is greatly aided by the inherent predictability of objects in space compared to objects in flight or at sea. Once an object is placed in orbit at a specific altitude and speed, it will generally remain in that orbit and follow a predictable path. The only changes in the orbit result from natural perturbations (most of which are well-known and can be calculated), unnatural perturbations (such as explosions and venting) or human-directed manoeuvres. Once an element set is established for an object, routine follow-ups will usually keep it up to date and also provide warnings of any sudden or unexpected changes in the orbit. Closer examination of the object and its new orbit can reveal whether the change was commanded or whether the change involved an unforeseen event, such as a collision with another object or an internal explosion.

The orbital parameters of space objects can be collated into a satellite catalogue. A conjunction analysis can then be performed among all the objects in a catalogue to determine which ones will pass close to each other. Although the technology does not exist to provide a precise yes or no answer to whether two space objects will collide, if the orbital elements are known with enough accuracy a probability of such a collision can be determined. A periodic conjunction analysis across the entire catalogue can provide vital information to warn satellite operators about possible collisions with space debris and other satellites. If timely, it could also determine purposeful manoeuvres by space objects that could then intercept or collide with another space object. This information could be used to verify deliberate use of a space object as a co-orbital anti-satellite (ASAT) weapon, and separate such incidents from accidental collisions between satellites or with space debris.

Many elements of what could be combined into a global space surveillance system are already in place. The United States military operates a large network of SSA sensors, known as the Space Surveillance Network, and uses the data to maintain a catalogue of over 21,000 objects in orbit, each greater than 10cm in diameter.[9] The Russian Federation operates its own space surveillance network, with more limited but complementary coverage, and maintains its own satellite catalogue. Many other states operate individual space surveillance sensors, and Europe currently has a programme under way to develop its own space surveillance system. There are also non-traditional space surveillance systems such as the International Scientific Optical Network, which uses telescopes designed for science and research. Amateur observers can collect surprising amounts of information about satellites, some of which are officially classified or not acknowledged by states.

The US military uses its SSA information to perform a daily conjunction assessment screening of all operational and active satellites and provides warnings to satellite operators about potential collisions. Although it does not share the entire catalogue with the public or other states, the US military has begun to institute expanded data sharing agreements and protocols and is moving toward sharing more data.[10]

While on orbit, space operators may be required to deal with two other types of attack beyond the vital threats of direct ascent and co-orbital ASAT weapons: those of lasers and radio frequency (RF) jamming. Lasers have been envisioned for use both in space and on the ground, although to date the only major weapons-related development and deployment have been in the terrestrial environment. There is a science-fiction notion that lasers can be used outright to destroy a target: such technology remains in the realm of science fiction, but is evolving.

Lasers used for weapons applications have unique advantages and disadvantages. If the laser has properly acquired its target and can continue to track it, it is impossible to dodge or perform evasive manoeuvres. Laser systems can be very effective against certain types of target, especially those with sensitive optics or containing volatile substances. The most feasible use of a laser against a satellite would be to destroy or damage the optics of a remote-sensing satellite, rendering the satellite unable to collect data while still being largely intact.

Of course, for lasers to be effective, the light must be held on a target for a sufficient period of time to deposit its destructive energy, sometimes measured in seconds or even minutes. For laser weapon system operators, acquiring, tracking and maintaining laser focus on the target during this time can be a challenge, especially if this has to be done through the atmosphere. Additionally, lasers are line-of-sight only—they can only engage targets that are in their field of view. Relatively simple countermeasures such as coating the target with reflective material or even white paint could dramatically reduce the effectiveness of some laser weapons on satellite systems.

In terms of verification, and in the case of a ground-based laser being used to attack a satellite, it is fairly easy to determine the geographic area from which a laser was fired, especially if the owner-operator of the targeted satellite can pinpoint the exact moment it lost contact or the satellite was damaged. The more difficult challenge is determining that a laser was used against a satellite at all, especially in the case of total failure of that satellite. Unless satellite telemetry indicates a spike in thermal energy or sudden saturation of optical sensors, there could be many valid reasons for the satellite failure. It could be possible to detect laser energy reflected from the target, which could help to determine that a laser was the source of any damage or malfunction, if certain types of optical sensor sensitive to laser light were looking at the satellite or neighbouring satellites during the attack.[11]

Radio frequency interference, and more specifically intentional jamming, presents perhaps the most difficult verification challenge, in part because it can easily happen accidentally or unintentionally. RF interference can occur as part of normal satellite operations, for example when an active satellite drifts past another active satellite operating on the same frequency. There are two main reasons why RF interference can be accomplished so easily. The first is that the vast majority of satellites use the same frequency bands for their communications and transmissions. Earth's atmosphere absorbs a large portion of the electromagnetic spectrum, allowing only optical wavelengths and radio wavelengths to penetrate from space to the ground (or vice versa). The latter are currently most viable for space-to-ground communications.

The second reason why RF interference is so easy is that it involves transmitting a signal on the same frequency at the target with enough strength either to drown out the target signal or to create enough noise to prevent users from receiving the target signal cleanly. Almost any antenna that can be used to receive an RF signal could also be used as a jammer for that signal. It is very difficult to certify that a particular system will only be used to transmit and not to receive signals.

Political challenges to space verification

The technical side of verification presents specific challenges given the unique physical characteristics of space: the politics of reaching agreement on international verification mechanisms for space pose equally complex concerns.

Defining "space weapons"

The underlying concept of verifying arms control agreements for space weapons is a misleading one. Since the 2008 introduction of the China–Russian Federation Draft Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects (PPWT) to the Conference on Disarmament,[12] the international community has once again been struggling to define what a space weapon actually is. We believe that this is the wrong question to ask. Targeting issues aside, the nature of space physics means that any object with manoeuvring capabilities can also in theory be used in an offensive capacity as a kinetic-kill vehicle. Indeed, there are a wealth of technologies that can be used peacefully, such as for docking and rendezvous, as well as offensively. From a verification standpoint, the definitional challenges raise potentially insurmountable barriers for any comprehensive regime to limit the development, deployment and use of weapons that can engage space systems. If there cannot be consensus on the definition of a space weapon it could be impossible to verify its use. Given the fundamentally dual-use nature of most space technologies, a more strategic approach is required to support an effective, verifiable space security regime. Leaving aside the few technologies that have no dual-use application, at the base of any future regime should be a focus on actions, not on technologies: the crux is not *can* such dual-use technologies be used as weapons but were they specifically *intended* to be used as such?

Taking such an approach may make it easier to verify certain, intentionally offensive, technologies. It does not, however, make these technologies easy to ban. It is possible to identify ground-to-space direct ascent kinetic ASAT weapons as a clear threat. But a ballistic missile system used for such a purpose is virtually indistinguishable from a ballistic missile used to attack targets on the ground. The only way to differentiate between the two is by examining the launch trajectory—the ASAT weapon will hit its target somewhere along its trajectory, typically near the highest point, while the ballistic missile's target is located on the surface of Earth, at the end of the trajectory.

Ballistic missile tests are, for the most part, carried out in a relatively standard manner and there are existing protocols in place that most states follow, including notification, which helps verification considerably. For example, the Russian Federation launches over Siberia, the United States launches from California to Kwajalein in the Marshall Islands. By tracking the ballistic arc of a specific vehicle, it is possible to identify if the trajectory is unusual and thus analyse the purpose of the flight.

The use of force in space

A key component of future verification regimes in space involves determining what constitutes the use or threat of the use of force in space. Legal use of force concepts have been defined to some extent in the terrestrial sea, land and air warfare regimes but have not been fully defined with regard to outer space. The international community can agree that the intentional destruction of the satellite of another entity could amount to a violation of the prohibition on the use of force as defined in Article 2(4) of the United Nations Charter;[13] however, there are many other actions which remain in a very grey area. Specific examples of such actions are the use of lasers and RF jamming and other counterspace techniques that have "temporary and reversible" effects.

The current case of alleged Iranian RF jamming of a Eutelsat satellite is a case in point.[14] If the jamming activities as alleged are substantiated, they would amount to a violation of Iran's obligations under the International Telecommunication Union (ITU) Convention, but it is not clear that they have crossed the threshold of hostile action. Additionally, if Iran were to allege that it considers the Eutelsat broadcasts an attempt to undermine the legitimate Iranian government and thus a threat to its national security, it could argue that it has the right to invoke the national security exception in the ITU Convention and lay the groundwork for a defence of its action based on an interpretation of the doctrine of self-defence, which is allowed and recognized under Article 51 of the UN Charter. This argument is, of course, a reach, but it highlights the need for the international diplomatic community to define the "line in the sand" for key dual-use space activities and establish the framework for translating the principle of the prohibition of the threat or use of force into practical application to space.

Attribution

To expand further on the Eutelsat example, another key concern with space technologies when analysing verification options is the question of attribution of attacks. The use of a ground-to-space kinetic ASAT weapon is fairly easy to attribute, but with RF interference the technological barriers to entry are much lower and it becomes much more difficult to definitively attribute such acts to a state. The rise in the capacity of non-state actors in many parts of the world makes the issue of attribution even more complex. Once the approximate origin of interference or lasing is pinpointed, clearly establishing from which state the interference originates and establishing that it was deliberately intended are by no means easy to achieve. Without being able to attribute such actions to state-sanctioned actors, verification in such cases may be impossible.

Further, the timing of attribution is critical. For nearly all potential space threats it is very hard, if not impossible, to identify an offensive weapon before it is deployed, given the dual-use nature of most of these threats. Overall, attribution and verification are tools which can easily be applied to analysing the actions of space actors, but when one starts trying to apply such concepts to "weapons", that analysis is quickly clouded, because establishing the purpose of a specific space system is technically difficult and, as previously noted, often of no value given the dual-use aspects of the vast majority of space technologies.

Space politics

In reference to outer space, use of the term "arms control" is at best inappropriate and at worst detrimental to making practical progress on a safer space environment and increasing confidence among all space actors and interested parties. The current world order is no longer the bipolar security environment of the Cold War era. Today, nowhere more so than in outer space, there is an increasing diversity of capabilities, intentions and motivations among a growing pool of actors. In space, two states may have the same technology and use it for remarkably difference ends—one offensive, one peaceful. As such, the traditional arms control paradigm of limiting hardware, a numbers game in the case of nuclear weapons, does not easily fit the challenges of securing the space environment. An effective regime aimed at preventing conflict in outer space must take this into account. For verification, the realm of the politically possible is much smaller than the realm of the technically possible. The PAXSAT concept mentioned above is a prime example. Technically, it would be possible to verify the functions of satellites. However, from a political perspective, such an undertaking could actually heighten rather than reduce international tensions as states with sensitive national security systems would see surveillance of this kind as a major threat to their national security. If PAXSAT-type operations were undertaken as a national endeavour of one state, it would be difficult for that same state to appear impartial or neutral. Alternatively, if PAXSAT operations were to be performed as an international endeavour, they would seem likely to fail given the international community's consistent rejection of any concept of an "international policeman" for space.

Similar concerns have also been raised in the civil arena with respect to sharing SSA data and confidence in its reliability. As mentioned above, the United States is currently the pre-eminent provider of such data to the international community. It does not share all its data, however. China, the Russian Federation and various other states also have some SSA capacity, but none matches the US system. In the case of the Iridium–Cosmos satellite collision that occurred in February 2009, the United States military was the world's primary source of data analysing the origins of the satellites' break-ups. Further, it was the United States, and not other states, that declared that the French satellite Cerise was struck by debris from an Ariane space rocket in 1996. Although the international community did not dispute the United States' findings in either event, the international community's confidence in the impartiality of the United States' analysis may not have been as strong if the systems concerned had involved a state that was not a US friend or ally, or the incidents had been more controversial in nature.

Recommended steps for space verification

The goals of building stability and sustainability into the space environment and augmenting predictability and clarity all rely on confidence: confidence in the data and information provided; confidence that states understand the consequences of specific courses of action; and confidence in mutually shared objectives toward the continued long-term ability to utilize space. For this reason, it is the opinion of the authors that several key steps need to be taken before we can achieve a politically realistic approach to building elements of a verification regime to enhance space security.

First there is a need to define the "red lines" of space—what actions does the international community consider to be a step too far? What do we consider a threshold for use of force in space? The context also has to be reconsidered—as Cold War thinking still looms large in doctrinal and academic considerations of issues such as verification and deterrence, it is time to reassess how we think about verification as it applies to space in order to reflect the new realities of the global security situation.

Second, there is a need to expand the efforts of the actors that can provide credible SSA data. The basis of any verification regime is knowledge—the more information actors have and the more sources from which they can obtain corroborating data, the more sound a future space verification regime will be. A contributing factor to the escalation of the 1962 Cuban missile crisis was a lack of access to information outside of that being provided by the national technical means of either the Soviet Union or the United States. With today's broad access to satellite images, a similar situation is unlikely to reach the fever-pitch that it did. Encouraging national, regional and international initiatives on SSA can contribute to a similar level of stability in space for all, and such stability is of greater strategic value than the loss of dominance of the few.

Third, in developing a verification scheme for outer space launch, re-entry and on-orbit operations, a bottom-up approach would seem to be the most effective method of progression. Such an approach might start with monitoring actions that are easy to verify and are also universally seen to be irresponsible, such as the destruction of a satellite by a kinetic-kill ASAT weapon, and progressing to those actions which are technically more complex and difficult to define. In the meantime, the international community should look to contribute to the establishment of norms of behaviour in space, which could serve to clarify and define more complex uses of space and lay the groundwork for future verification mechanisms.

Finally, the technical principles of outer space need to be translated into effective concepts that have diplomatic utility. Simply put, the space environment is not simple. While parallels and analogies to other arenas and other verification regimes are useful, it is critical to bear in mind that the physics of outer space make it unique. The negotiation of verification methods for space security will always be a fundamentally political process, and therefore it is essential that diplomats undertaking that endeavour have a clear, intelligible basis of knowledge of what is possible and what is not.

Notes

1. *Report of the Secretary-General: Verification in All Its Aspects, Including the Role of the United Nations in the Field of Verification,* UN document A/50/377, 2 September 1995, paragraph 15. See also *Special Report of the Disarmament Commission to the General Assembly at Its Third Special Session Devoted to Disarmament,* UN document A/S–15/3*, 28 May 1988, paragraph 60, and *Verification in All Its Aspects: Study on the Role of the United Nations in the Field of Verification,* UN document A/45/372, 28 August 1990.
2. While nuclear-powered rockets are technically feasible and various designs have been developed, the 1963 Partial Test-Ban Treaty and 1967 Outer Space Treaty placed legal restrictions on the testing and use of nuclear detonations in the atmosphere and space, effectively ending the pursuit of nuclear rockets.
3. Jeffrey Richelson, "Space-Based Early Warning: From MIDAS to DSP to SBIRS", *National Security Electronic Briefing Book No. 235,* The National Security Archive, 9 November 2007, at <www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB235/index.htm>.
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8. Craig Covault, "Secret Inspection Satellites Boost Space Intelligence Ops", *Spaceflight Now,* 14 January 2009, at <www.spaceflightnow.com/news/n0901/14dsp23>; Air Force Research Laboratory, "XSS-11 Micro Satellite", Fact Sheet, December 2005, at <www.kirtland.af.mil/shared/media/document/AFD-070404-108.pdf>.
9. James Miller, Principal Deputy Under Secretary of Defense for Policy, Statement before the House of Representatives Committee on Armed Services, Subcommittee on Strategic Forces, 16 March 2010, p. 10, at <armedservices.house.gov/pdfs/StratForces031610/Miller_Testimony031610.pdf>.
10. General C. Robert Kehler, Commander, Air Force Space Command, Statement before the House of Representatives Committee on Armed Services, Subcommittee on Strategic Forces, 21 April 2010, at <armedservices.house.gov/pdfs/SF042110/Kehler_Testimony042110.pdf>.
11. "US Claims that China Has Used Lasers to Attack Satellites", *Janes Defence Weekly,* vol. 43, no. 42, 16 October 2006.
12. Document CD/1839, 29 February 2008.
13. "All Members shall refrain in their international relations from the threat or use of force against the territorial integrity or political independence of any state, or in any other manner inconsistent with the Purposes of the United Nations", Article 2(4), Charter of the United Nations.
14. Peter de Selding, "ITU Implores Iran to Help Stop Jamming", *Space News,* 26 March 2010, at <www.spacenews.com/policy/100326-itu-implores-iran-help-stop-jamming.html>.