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New Challenges in Missile Proliferation, Missile Defense, and Space Security

James Clay Moltz, ed.

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Exploring Linkages among Missile Proliferation, Missile Defense, and Space Security

BY JAMES CLAY MOLTZ

Although missiles, missile defense technology, and space issues are intricately related, most policy analysis tends to treat each in a separate category. This tendency causes policymakers to miss the linkages among them and the overlap in the issues that affect developments in each of the other sectors. For this reason, four organizations—the Mountbatten Centre of the University of Southampton, the Simons Centre of the University of British Columbia, the U.N. Center for Disarmament Research in Geneva, and the Center for Nonproliferation Studies (CNS) of the Monterey Institute of International Studies—decided to organize a joint international conference that would consciously explore these linkages and treat the relevant issues in an integrated manner, benefiting from the expertise of specialists present from each of the three fields.

This collection offers some of the key papers presented at the conference on "Missile Proliferation, Missile Defenses, and Space Security: Confronting and Addressing New Challenges," which was held at Wiston House in England from June 1-4, 2003. The meeting brought together government officials, military personnel, and experts from Austria, Canada, China, Egypt, France, Germany, India, Ireland, Italy, Pakistan, Poland, Russia, South Korea, the United Kingdom, and the United States. In each area, the conference organizers sought out accomplished experts to give technical presentations examining emerging threats and cooperative opportunities on subjects not receiving enough attention in mainstream analysis. Although government officials did participate, the meeting was not "political," and there was a remarkably harmonious discussion of common interests and shared concerns among the many officials present. The discussions were held off-the-record, but a number of participants agreed to share their papers with a wider audience in this publication.

Rather than repeating old questions, the materials presented here examine emerging issues, many of which cut across current disciplines. Dennis Gormley from CNS analyzes the possible terrorist use of unmanned aerial vehicles and cruise missiles, an issue of particular concern given the widespread availability of these systems on the international market. Drawing on the past experience of the United States, Clayton Chun from the Army War College discusses the technical challenges that states with medium-range missiles will face in trying to develop effective anti-satellite weapons. His study provides hope that threats to U.S. space assets may not be as serious or as imminent as feared. Philip Baines, a former aerospace engineer now serving in Canada's Department of Foreign Affairs and International Trade, examines prospects for developing so-called "non-offensive" defenses in space as an alternative to space weapons. In some areas, there are promising new technologies that could make U.S. and other national space assets extremely difficult to locate, track, and attack, evenby sophisticated future weapons. Each of these studies breaks new ground and offers considerable food for thought as the United States and other countries seek to understand the true nature of emerging threats and the range of options states might adopt to combat them.

Other topics that the conference organizers believed merited attention include the new budget politics of U.S. missile defense in the context of a rising U.S. federal deficit and an emphasis on early deployment, factors that did

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not affect the program in the 1990s. David Mosher, a security and budget expert formerly at the General Accounting Office and now at RAND, takes account of these pressures and indicates why the rising cost of specific programs within the missile defense portfolio could make them targets of Congressional cuts in coming years.

The status of the ongoing U.S. missile defense test program also poses challenging questions, particularly given the decision by the United States to move to an initial deployment of interceptors in Alaska by October 2004 without full testing. What are the implications of deploying systems in advance of working out problems or having the advanced radars in place necessary to make them effective? Theresa Hitchens from the Center for Defense Information addresses these and related technical issues.

Finally, another topic of increasing importance is the emerging—but uncertain—role of China as a major space power. Although few beyond the space community have been following these developments, China is likely soon to become only the third country (after the Soviet Union/ Russia and the United States) to launch human beings into orbit. It is also rapidly developing its broader scientific programs and the reliability of its boosters. Yet, China to date has been denied a role on the International Space Station, partly due to U.S. Congressional politics; China is viewed by some members as an untrustworthy partner or even a potential enemy. Some defense officials in the West also harbor concerns about China's intentions in the military space field, despite its repeated opposition to the weaponization of space in a number of international fora. Thus, it remains to be seen if China will become (from a U.S. perspective) the next "Soviet Union" in space, or whether peaceful cooperation will instead emerge. Brian Harvey, a long-time analyst of space activity based in Ireland, examines the history and current trajectory of the Chinese space program.

From the discussions at the Wiston House conference, a consensus emerged that states share a number of common interests in regards to halting missile proliferation and ensuring space security. At the same time, the proliferation of missiles of different capabilities (including propulsion, payload, range, altitude, and radar signature) makes these challenges difficult, particularly when certain countries feel that they are more of a "target" than others and have space assets that are also more at-risk.

Developing protective weapons may be the only answer in certain circumstances. Yet, there may also be useful means of cooperating internationally to mitigate other threats and to isolate those countries or groups that would violate international norms. In still other cases, there may be evasive means to eliminate or greatly reduce the vulnerability of national assets to attack. From the discussions at the conference, it became clear that solutions are not likely to come in a "one size fits all" package. Instead, they are likely to vary across issues, with some calling for formal multilateral treaties, others bilateral cooperation, still others new forms of cooperative defense. The discussions among the experts at the Wiston House conference, however, concluded that governments have not come close to exhausting these various possible options in their current deliberations. Thus, there is considerably more work for states to do. The near-term objective must be to begin a process of mutual engagement on these issues—something that is not occurring today.

The selections in this volume are not meant to present a comprehensive solution or even a complete set of questions. Rather, they are intended to inform and to stimulate debate by highlighting issues that have not achieved wide publicity. They also seek to offer potential new approaches to policymakers.

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UAVs and Cruise Missiles as Possible Terrorist Weapons

BY DENNIS M. GORMLEY

More than 70 countries worldwide have deployed over 75,000 anti-ship cruise missiles (ASCMs). Only about 12 industrialized countries currently produce land-attack cruise missiles (LACMs)—most notably exemplified by the U.S. Tomahawk—although this class of cruise missiles is expected to proliferate greatly by the end of the decade.[1] More widely available is the unmanned air vehicle (UAV). Until recently relegated largely to reconnaissance and target-drone roles, the UAV seems set to become a significantly more prominent means of precise weapon delivery.[2] The Predator reconnaissance UAV has been adapted by the United States to carry two Hellfire missiles and was used in Afghanistan and Yemen to attack Al-Qaida targets. The U.S. use of armed Predator UAVs, coupled with the explosive growth in UAVs for various military roles, begs the question of whether or not adversaries—states and non-state actors alike—will emulate U.S. actions and develop their own LACMs or transform unarmed UAVs or piloted light aircraft into unmanned weapons-delivery systems or crude terror weapons.

Before considering the prospects of possible terrorist employment of UAVs or cruise missiles, some definitions are in order. UAVs and cruise missiles represent a generic class of air systems that are fitted with aerodynamic surfaces that furnish lift to keep them airborne during their entire flight. UAVs are reusable systems that are generally unarmed and used primarily for reconnaissance purposes. The arming of the U.S. Predator reconnaissance UAV illustrates the potential for UAVs to become reusable weapons-delivery vehicles. Target drones, employed as air targets for test purposes, are also UAVs, and they too could be converted into weapons-delivery vehicles. By contrast, cruise missiles are distinguished from UAVs here because they are always armed and are not reusable.[3]

At first blush, the notion that a terrorist group might wish to employ a UAV or cruise missile to execute a mass-casualty attack seems far-fetched. Yet, at least the possibility of such a threat became evident in February 2003 when the new U.S. Department of Homeland Security declared a "Code Orange" alert—the penultimate level of alert indicating a high risk of terrorist attack. Senior Bush administration officials told *Wall Street Journal* reporters that the president was keenly interested in intelligence reports that Iraq was developing small, easily transportable UAVs that could be shipped into the United States or built here and then used to disseminate chemical or biological agents.[4] In the aftermath of the September 11 attacks, the North American Air Defense Command had no domestic air picture, nor were its radar assets linked with those of the Federal Aviation Administration, which controls internal U.S. air traffic. Progress toward making such a linkage has occurred since then, but major holes remain, especially when dealing with the detection of low-flying air vehicles. Thus, with the implementation of the Code Orange alert, the federal government created an "air defense identification zone" that blanketed the Washington-Baltimore metropolitan area's airspace under 18,000 feet and required all general aviation pilots to file flight plans, use two-way communications, and employ discrete beacon codes to distinguish them from potentially hostile air vehicles. Nevertheless, such highly restrictive procedures are impossible to sustain permanently or

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implement broadly across all major metropolitan areas across the nation.

Of course, it is one thing for a state, possessing all the necessary engineering skills and experience, to produce and furnish an armed UAV or cruise missile to a terrorist group. Just such a linkage and prospect were purported to exist between Iraq and Al-Qaida, at least according to the Bush administration. Yet to suppose that a sub-national terrorist group, on its own, could develop such a delivery system deserves closer scrutiny.[5] Certainly, a terrorist group could take advantage of the last decade's quantum leap in dual-use technologies that comprise the chief components of autonomous air vehicles. These include satellite navigation and guidance furnished primarily by the U.S. Global Positioning System, high-resolution satellite imagery from a growing number of commercial vendors, and digital mapping technologies for mission planning. Indeed, the presumption that virtually any person or small group with the appropriate knowledge and skills could build a simple, autonomous, self-guided cruise missile with a significant payload has reached a new and dangerous level. The most egregious example is that of a New Zealand engineer, Bruce Simpson, who runs a popular technical website. To demonstrate explicitly the ease with which such a cruise missile could be built by "almost any person or small group of persons with the necessary knowledge and skills," Simpson has created a website with the title "Do-It-Yourself Cruise Missile," where he is documenting his on-going effort to build one in his garage for under $5,000.[6]

This study assesses the possible use of UAVs or cruise missiles as terrorist weapons from two principal angles: 1) motivations; and 2) capabilities. To be sure, possession of the requisite "knowledge and skills," together with opportunities to procure all the component parts, represents a necessary but not sufficient condition of this examination. All too frequently, proliferation questions are addressed from the standpoint of raw technological determinism. A more complex web of factors or motivations informs whether or not terrorists will pursue the use of UAVs or cruise missiles to achieve their objectives. After considering motivations, the analysis turns to examining two particular scenarios of relevance to possible terrorist use of UAVs or cruise missiles bearing on capability: conversion of an anti-ship cruise missile for launching from an offshore freighter and transformation of a simple airplane into an unmanned means of achieving mass casualties.

A Matter of Motives

Scholars and counterterrorism practitioners alike now believe that a new form of religiously motivated terrorism has emerged that is unconstrained in the level of violence it seeks to achieve. This new brand of terrorism—unlike that practiced by ethno-nationalist terrorist groups such as the Irish Republican Army or Palestine Liberation Organization—is not amenable to diplomatic persuasion or political compromise. Its violence is designed not to secure a place at the bargaining table, but to destroy an existential adversary with whom bargaining is impermissible for theological reasons.[7] For those impelled toward this new brand of terrorism, there exists a complementary relationship between apocalyptic aims and weapons of mass destruction (WMD). Aum Shinrikyo, the perverse Japanese cult that pursued both biological and chemical agents, easily could have killed more people using conventional explosives than it managed to kill in 1995 with its clumsy use of sarin gas in a Tokyo subway.[8] Yet, when it had failed to achieve any success pursuing biological agents, it turned instead to producing chemical—not conventional—weapons to achieve its apocalyptic aims. To these religiously motivated groups, WMD have become the preferred means of killing, almost without regard to the challenges entailed in acquiring them.

The evidence that Al-Qaida is seeking WMD is largely inferential but nonetheless compelling. However sullied by the controversy about the basis for the Clinton administration's attack on the Al Shifa pharmaceutical plant in Khartoum, Sudan, in August 1998, the existence of covertly collected forensic evidence together with the eventual testimony of Jamal Ahmed al-Fadl, who was a prosecution witness in the February 2001 trial for the bombings of two American embassies in East Africa, suggests a strong probability that Al-Qaida was involved in producing chemical weapons in Sudan.[9] Even more convincing is the testimony of Sultan Bashiruddin Mahmoud, a former nuclear scientist at the Pakistan Atomic Energy Agency, who set up a non-governmental organization (NGO) in Kabul called the Islamic Reconstruction. He used it as a vehicle to visit Afghanistan frequently between 1998 and 2001. Mahmoud finally admitted to his U.S. Central Intelligence Agency interrogators that he met with Osama bin Laden and other Al-Qaida members for two to three days in August 2001 to discuss WMD. Bin Laden was interested in nuclear, biological, and chemical weapons and sought advice on how to build a "dirty bomb" to spread radiological debris; the source of the radiological materials was expected to be the Islamic Movement of Uzbekistan. A subsequent search of Mahmoud's NGO offices in Kabul uncovered a history of anthrax, documents on the U.S. military's immunization program, gas masks, and diagrams of an aerial balloon system for dispersing biological or chemical agents.[10]

There is strong evidence that the terrorists who planned and executed the September 11, 2001, attacks on New York and Washington had investigated the use of crop dusters as terror weapons. Zacarias Moussaoui, the so-called "20th hijacker," was arrested after the attacks in possession of a crop-dusting manual.[11] The plot's ringleader, Mohammed Atta, made several visits to a crop-dusting airfield in Florida asking about the speed, range, and volume of chemicals such aircraft hold.[12] In May 2000, Atta even attempted to secure a $650,000 U.S. Department of Agriculture loan purportedly to start a crop-dusting business. He told the Florida agricultural official that he wanted to use the money to purchase a six-seat twin-prop crop duster, after which he intended to remove the seats to fit a large chemical tank inside the aircraft, leaving space for only the pilot.[13]

A pilot willing to die would certainly be needed to guide a notoriously unstable crop duster to its intended target. There is surely an intense fascination with suicide among religiously motivated terrorists, jihadists in particular, that combines an element of romanticism with sacrifice and exculpation. However seductive this emotion, there is also a strong interest in attack effectiveness.

Employing a suicide pilot to guide an airplane to its desired target may be seen as integral to achieving mass casualties. Yet, an aerial balloon does not require a suicide pilot to guide it. Although balloon delivery of biological agents was investigated during the early years of the U.S. biological weapons program, it is not a terribly effective way to disseminate agents for numerous reasons.[14] Conversely, UAVs and cruise missiles are ideal platforms to deliver such agents. The flight stability of these aerodynamic vehicles permits them to release and spray agents along a line of contamination.[15] Modeling of agent delivery indicates that UAVs or cruise missiles enlarge the lethal area for biological agents, conservatively, by a factor of 10 when compared with ballistic missile delivery.[16] Radiological dispersal, an area of acknowledged interest to Al-Qaida, also becomes conceivably effective with a UAV over large urban areas, but only if the source material is cesium chloride—the one radiological source that comes in a powered form.[17] While such radiological dispersal would not truly measure up to the destructive damage of other WMD, it would play on the public's fear of anything radiological and cause long-term disruption. Finally, given the woeful state of U.S. defenses against low-flying vehicles, particularly during periods when the major urban areas are not subject to Code Orange or higher alert procedures, terrorists could be fairly confident that a small UAV would reach its chosen target.[18] Thus, a terrorist group might well see great advantage in using a UAV if it could achieve a spectacular victory without unnecessarily sacrificing a human agent.[19]

Capability Matters Too

Even if sufficient motivation existed to pursue acquiring a UAV (and a suitably destructive payload), a terrorist group would require the necessary engineering skills and component parts to achieve its objective. While the story of the New Zealand engineer's quest to demonstrate (and document, publicly) just how easy it is for a terrorist to build a cruise missile is undoubtedly the most provocative example, other instances also support the notion that the necessary capabilities are attainable. In early 2002, a U.S. Air Force scientist at a test facility in Florida proposed converting Vietnam-era Cessna airplanes (the 0-2 Skymaster) into UAVs to cope with the shortage of Predator drones for use in Afghanistan. He argued that the conversion could be accomplished in several months.[20] One must also consider the fact that one terrorist group, the Revolutionary Armed Forces of Colombia, or FARC, was discovered in possession of nine remote-controlled unmanned aircraft when a Colombian Army unit overran one its remote camps in August 2002.[21] However, such radio-controlled craft can only be flown effectively for a few miles. Heavier payloads and much greater range could be achieved using one of two courses of action—either converting a surplus anti-ship cruise missile into a land-attack system and launching it from a freighter or converting a small recreational airplane into an armed UAV and launching it from a domestic point of origin.[22]

Converting an Anti-Ship Cruise Missile

In the aftermath of the September 11 attacks, U.S. decisionmakers began to take the offshore cruise missile threat more seriously than ever before.[23] The mere fact that a ship-launched cruise missile, fired from just outside territorial waters, could strike many of the world's large population and industrial centers, ought to concern many countries, not just the United States. The latest U.S. National Intelligence Estimate (NIE) draws attention to this possible scenario, including potential attacks by non-state actors.[24] Furthermore, two former National Security Council staff members wrote in *The New York Times* about just such a terrorist scenario, while also noting that Al-Qaida is reported to have 15 freighters as possible launching platforms.[25] Thus, the scenario deserves attention.

Turning cruise missiles designed originally to attack ships at sea into ones that attack targets on land is nothing new. The U.S. Navy has transformed the ubiquitous Harpoon anti-ship cruise missile (AGM-84)—exported to 24 nations—into the Stand-off Land-Attack Missile (SLAM/AGM-84E). Russia's export family of anti-ship cruise missiles, called Klub, has a dual-mode feature on at least one version—the jointly produced Russian/Indian Brahmos cruise missile—that permits both an anti-ship and land-attack capability. Yet these conversions are not broadly representative of what a terrorist group might be able to achieve, given its limited engineering skills. Modern anti-ship cruise missiles like the Harpoon, the French Exocet, and even the Chinese C-802 are considerably smaller in overall size and internal space than most modern land-attack cruise missiles. Even assuming that a terrorist group could get a hold of one of these missiles, which appears questionable, the Harpoon, Exocet, and C-802 are already densely packed with integrated electronics, leaving little room for the kinds of changes required to convert an anti-ship into a land-attack missile.

Two reasons suggest that the most suitable candidate for conversion would be the Chinese Silkworm anti-ship missile.[26] First, the Silkworm is a large missile; its internal roominess and simplicity of design mean that conversion will require less technical skill. With space liberated from replacing the original Silkworm autopilot and radar guidance system with a modern navigation system, a converted Silkworm cruise missile could achieve a range of at least several hundred kilometers, delivering a payload of 500 kilograms. Moreover, its large size is no impediment to hiding the missile in a standard 12-meter shipping container and equipping it with a small internal erector for launching. Secondly, after the American Harpoon and French Exocet, the Silkworm and its near-cousin, the Styx, comprise the third-largest class of exported anti-ship cruise missiles. They appear in the inventories of countries like Bangladesh, the Democratic Republic of Congo, Dubai, Egypt, Iran, Iraq, North Korea, and Pakistan, making it more conceivable that a terrorist group could acquire a surplus missile or two.

Still, two main barriers make the job of conversion very difficult, if not impossible. The first is acquiring a suitable means of flying the missile more than the range of a Silkworm anti-ship missile—90 kilometers. Such a short range would necessitate moving the launch vessel within territorial waters, where the vessel would receive much greater scrutiny. Only the latest version of the Silkworm—the Chinese HY-4[27]—comes equipped with a turbojet engine, which, when combined with proper navigational guidance and additional fuel, could fly a converted Silkworm considerably beyond 90 kilometers.[28] While there are few export restrictions on suitable turbojet engines, equipping the Silkworm with one acquired from the surplus marketplace would require engineering skill in propulsion systems, particularly skills in systems integration.

The second and more formidable challenge is providing a modern land-attack navigation system. Although the component technologies and subsystems are available "off the shelf," it is not easy to integrate individually complex electronic subsystems into a working whole. Particularly daunting is the integration of actuators and servo controls that are crucial for moving the missile's control surfaces based on commands from the flight management computer. What separates the industrial from the developing world in this instance is systems integration experience, or the capacity to incorporate various components into a complex weapon system with confidence that the system will perform as desired. Without the advantage of at least a few tests (requiring multiple vehicles), considerable performance uncertainty will inevitably exist. At the same time, there are shortcuts. The most attractive is to acquire a commercially available UAV flight control system and some outside engineering assistance. There are system integration software tools available to assist in major elements of integrating modern flight management and control systems, but having an experienced system engineer as part of the conversion team would seem a necessity in the absence of access to a complete UAV flight control (or management) system.

In sum, converting a surplus Silkworm for launch from a freighter seems a considerable stretch for a terrorist group not possessing advanced mechanical and engineering experience. Putting aside the corresponding challenges of acquiring or, worse, producing an appropriate WMD payload, this course of action is complicated by several possible critical failure points along the path of developing the delivery system and then getting it into position to execute its mission. Access to a complete flight management system and outside engineering assistance would help overcome, but not eliminate, the high degree of uncertainty associated with this complex task.

Converting a Small Airplane

A simpler way to employ a UAV exists, involving substantially less cost, less significant engineering prowess, and fewer steps—and thus less chance of failure. The kit airplane market, by one accounting, consists of nearly 100,000 copies of 425 different systems produced by worldwide manufacturers.[29] On average, these aircraft have a cruising speed of around 75 knots, a reciprocating engine of 66 horsepower, a range of 500 kilometers, a maximum weight of 400 kilograms, a fuel and payload capacity of 200 kilograms, a takeoff distance of 75 meters, and a beginner construction time of around 260 hours. Between the engine and kit itself, which are normally purchased separately, the average cost is less than $25,000.

Bearing in mind that these are average figures, several kit airplane designs would furnish a terrorist group with the capability to deliver over 200 kilograms of payload to a range of well over 1,000 kilometers. Such payload is much more than needed to deliver biological and some chemical agents. And even though a small airplane cannot begin to compare with a jumbo jet's 60 tons of fuel, the mere fact that gasoline, when mixed with air, releases 15 times the energy as an equal weight of TNT, means that these craft can do significant damage to certain civilian and industrial targets.[30] On the other hand, the significant range these airplanes can achieve is not as necessary as it would be in the case of launching a cruise missile from a freighter located outside territorial waters. Moreover, kit airplanes are not dependent on general aviation airfields; they can takeoff from very short grassy fields (hidden locations), relatively close to the intended target.

As with converting an anti-ship cruise missile, the major technical challenge entails building and integrating a flight management system, along with servo controls and actuators, to fly the system autonomously over the desired range. An apt illustration of the challenge is reflected in the course being taken by the "Do-It-Yourself Cruise Missile" designer, referred to earlier, whose approach to flight management belies the ease with which this task can be accomplished.[31] Given its simplicity of design compared with an anti-ship cruise missile, a kit airplane conversion would be somewhat easier, but still would require several people with advanced mechanical and engineering skills and perhaps two years of determined effort. That task can be made substantially easier, however, by purchasing a complete flight management system. Several new aerospace companies have emerged in the last five years to sell fully integrated flight controls along with an array of system integration support services that greatly ease the task of converting a small airplane into a UAV. This assistance would add $35,000 or more to the overall cost of the project, while cutting the building time perhaps in half and increasing the probability of a successful outcome greatly. At present, no export controls govern foreign sales, nor, of course, domestic transactions of these services.

Implications for Nonproliferation Policy

Thinking about the possible use of UAVs and cruise missiles as terror weapons requires a good dose of humility. The means of perpetrating terrorist harm continue to be decidedly jejune yet effective ones, generally requiring a suicidal agent. There is no doubt, however, that apocalyptic goals remain central to certain terrorist groups—most notably, Al-Qaida. Suicide is a means of achieving an effect, but not an essential requirement of the destructive act. Terrorist groups conceivably might turn to UAVs if they are easy to acquire and useful to achieving mass casualties or lasting psychological effect. Referring to the planning errors surrounding the Japanese attack on Pearl Harbor, American strategist Thomas Schelling admonished planners over 40 years ago to "think in subtler and more variegated terms and allow for a wider range of contingencies."[32] September 11 serves as a harsh reminder that counterterrorism planners should avoid, as Schelling once reflected, confusing "the unfamiliar with the improbable."[33] He continued: "The contingency we have not considered seriously looks strange; what looks strange is thought improbable; what is improbable need not be considered seriously."[34]

Nonproliferation planners have taken the first step in addressing possible terrorist use of UAVs and cruise missiles. At its annual plenary meeting in Warsaw last September, diplomats representing the 33 member states of the Missile Technology Control Regime (MTCR) concluded their discussions with a commitment to examine ways of limiting the risk that controlled items and their technologies could fall into the hands of terrorist groups and individuals.[35] In this regard, were terrorists to entertain the use of a UAV or cruise missile, however improbable, this study argues that the most straightforward course of action would be to convert a small airplane, kit or otherwise, into a weapons-carrying UAV. In either case of conversion—anti-ship missile or airplane—getting the flight management task solved represents the "long pole in the tent" for any terrorist group or individual. Making it more difficult for the terrorist to take the easier route to successful use of a UAV ought to inform specific nonproliferation measures.

Such an objective appears to lie behind a January 2003 U.S. "anti-terrorism" proposal to the Wassenaar Arrangement, a group of 33 co-founding nations that strives to achieve transparency and greater responsibility in transfers of conventional arms and dual-use goods and technologies (including UAVs).[36] Expressing concern about the possible terrorist use of kit airplanes or other manned civil aircraft as "poor man's" UAVs, the U.S. proposal seeks export control reviews and international notifications for all equipment, systems, and specially designed components that would enable these airplanes to be converted into UAVs. However, because the Wassenaar Arrangement does not possess the MTCR's strong denial rules and no-undercut provisions,[37] the MTCR membership should act quickly to improve its existing controls on UAV flight management systems.

Current MTCR coverage of flight control systems and technology (under Item 10, Category II) is too narrowly written to have any beneficial effect on controlling this critical technology. In fact, current language is less effective than the original wording of Item 10, which was changed sometime subsequent to 1987—the regime's first year— in order to remove most case-by-case controls on these systems and their related technologies. Reverting to the original 1987 language would be better than the current language, but an even more systematic treatment of controls on the means of turning airplanes into UAVs appears worthy of urgent examination and action.[38]

As U.S. policymakers turn their attention to the enormous challenges and consequent costs of erecting defenses against low-flying UAVs that could threaten homeland targets, it will become increasingly apparent that effective nonproliferation policies are the first line of defense—and perhaps the most likely to succeed.

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[1] For an extended analysis, see Dennis M. Gormley, *Dealing with the Threat of Cruise Missiles*, Adelphi Paper 339 (Oxford: Oxford University Press, 2001).

[2] See Dennis M. Gormley, "New Developments in Unmanned Air Vehicles and Land-Attack Cruise Missiles," in *SIPRI Yearbook 2003: Armaments, Disarmament and International Security* (Oxford: Oxford University Press, forthcoming).

[3] One might also wish to add so-called unmanned air combat vehicles (UCAVs), a new subset of UAVs that are basically high-performance aircraft autonomously flown by an operator and capable of a variety of lethal and non-lethal missions traditionally performed by manned aircraft.

[4] Marc Champion, David Cloud, and Anne Robbins, "At Davos, Powell Pushes Back Against Resistance Over Iraq," *Wall Street Journal*, January 27, 2003, <www.lexis-nexis.com>. In July 2002, Secretary of Defense Donald Rumsfeld reportedly sent the White House a classified memorandum warning of the spread of cruise missiles, including possible terrorist use of rudimentary cruise missile technology to attack the American homeland. See Bradley Graham, "Cruise Missile Threat Grows, Rumsfeld Says," *Washington Post*, August 18, 2002, p. A1.

[5] Equally important, though not the central focus of this study is the matter of access to, or development of, chemical, biological, or radiological weapons.

[6] As of this writing, Simpson has completed Phase 1, involving the procurement of necessary components. See <http://www.interestingprojects.com/cruisemissile/>. The website includes a project diary. Simpson's popular technology website can be found at <http://aardvark.co.nz/>.

[7] See Steven Simon and Daniel Benjamin, "America and the New Terrorism," *Survival* 42 (Spring 2000), pp. 59-75. For follow-up debate on the subject, see "America and the New Terrorism: An Exchange," *Survival* 42 (Summer 2000), pp. 156-172.

[8] Twelve lives were lost in the attack, but an important psychological barrier was crossed.

[9] See Daniel Benjamin and Steven Simon, "A Failure of Intelligence?" *The New York Review of Books*, December 20, 2001, pp. 76-80. For an alternative view, see Michael Barletta, "Chemical Weapons in the Sudan: Allegations and Evidence," *The Nonproliferation Review* 6 (Fall 1998), pp. 115-136.

[10] For details on Mahmoud's testimony and activities, see Daniel Benjamin and Steven Simon, *The Age of Sacred Terror* (New York: Random House, 2002), pp. 203-205.

[11] "Hijack suspect visited crop dusting airfield," ABCNEWS.com, September 23, 2001, <www.lexus-nexus.com>.

[12] Pete Yost, "Crop Dusters Grounded in FBI Probe," Associated Press, September 24, 2001, <www.lexus-nexus.com>.

[13] Mark Steyn, "Mohammed Atta and his federal loan officer," *National Post* (Toronto), June 1, 2002, <www.lexus-nexus.com>.

[14] Interview with a former biological weapons scientist in the U.S. program on August 18, 1999. Balloon delivery might be able to achieve great ranges if launched into the upper atmosphere, but the corresponding uncertainty of disseminating its payload with any terminal effectiveness is enormous.

[15] Edward Eitzen, "Chapter 20—Use of Bio Weapons," in *Medical Aspects of Chemical and Biological Warfare* (Washington, DC: Walter Reed Army Medical Center, 1997), pp. 440-442.

[16] This is demonstrated through extensive modeling and simulation. Private communication with Dr. Gene E. McClellan, Pacific-Sierra Research Corporation, Arlington, Virginia, August 22, 1997. To illustrate, consider that Iraq is known to have employed an explosive form of dissemination in its ballistic missiles, which results in the destruction of 90 percent of the delivered agent. By contrast, an Iraqi L-29 (a trainer aircraft converted into a UAV with two spray tanks capable of holding 300 liters of agent) would have been capable of disseminating its entire payload—a factor of 15 better than the ballistic missile option. Effectiveness would of course depend on variables such as liquid concentration and droplet size, among others. See "Defending against Iraqi missiles, *IISS Strategic Comments* 8 (October 2002).

[17] Most other radioactive sources of concern, such as cobalt-60 and iridium-192, are solid materials. I am grateful to my CNS colleague, Dr. Charles Ferguson, for bringing these points to my attention. Also see Charles D. Ferguson, Tahseen Kazi, and Judith Perera, "Commercial Radioactive Sources: Surveying the Security Risks," Occasional Paper No. 11, Center for Nonproliferation Studies, January 2003, <http://www.cns.miis.edu/pubs/op11/index.htm>.

[18] Even U.S. missile defense systems, such as the Patriot, which claim to have capabilities against ballistic, cruise missiles, and aircraft, have severe shortcomings detecting and successfully prosecuting intercepts against cruise missiles and UAVs. For example, in the recently concluded Operation Iraqi Freedom, Patriot batteries performed well against Iraqi ballistic missiles, but not against ancient and low-flying Silkworm anti-ship missiles, which went completely undetected. Moreover, two Iraqi ultra-light aircraft managed to fly directly over the 3rd Infantry Division's logistical encampment and disappeared before orders could be arranged to fire at them. Even the use of expensive airborne reconnaissance systems such as AWACS would not help. Their radars intentionally eliminate slow-flying targets on or near the ground to prevent their data processing and display systems from being overtaxed. Lots of human eyes stand as perhaps the most effective means of detecting

such slow-flying threats. For more on the Iraqi cruise missile attacks, see Dennis M. Gormley, "North Korean Cruise Missile Tests—and Iraqi Cruise Missile Attacks—Raise Troubling Questions for Missile Defense," Center for Nonproliferation Studies, <http://cns.miis.edu/pubs/week/030408.htm>. On the ultra-light incident, see Sean D. Naylor, "Iraqi ultralights spotted over U.S. troops," *Army Times*, March 29, 2003.

[19] Victor Mizell, a private security expert and ex-U.S. intelligence officer, has recorded 43 cases involving 14 terrorist groups where remote-control delivery systems were "either threatened, developed, or actually utilized." See <http://www.securitymanagement.com/library/001324.html>. The cases include planning by Osama bin Laden to use remote-control airplanes packed with explosives to kill leaders at the 2002 G-8 summit in Genoa, Italy.

[20] Dave Moniz, "Old Planes Eyed As Drones: Cessnas Could Be Converted 'Easily, Quickly'," *USA Today*, February 4, 2002, p. 10.

[21] "Colombia – FARC Drones Discovered, EFE News Service, August 28, 2002, <www.lexus-nexus.com>.

[22] These two courses of action are by no means the only ones, just the two most prominent options mentioned in either National Intelligence Estimates or the public literature on cruise missiles and UAVs. Another one to consider is the purchase of a surplus reconnaissance UAV or target drone and its conversion into a weapon-carrying system. At least 40 countries produce over 600 different UAVs, nearly 80 percent of which could be flown on one-way ranges of over 300 kilometers (although most with very modest payload capacity), and many substantially farther. See Gregory DeSantis and Steven J. McKay, *Unmanned Aerial Vehicles: Technical and Operational Aspects of an Emerging Threat*, PSR Report 2839 (Arlington, VA: Veridian-Pacific-Sierra Research Corporation, 2000).

[23] Graham, "Cruise Missile Threat Grows, Rumsfeld Says."

[24] For a discussion of NIE assessments (including website references), see Dennis M. Gormley, "Enriching Expectations: 11 September's Lessons for Missile Defence," *Survival* 44 (Summer 2002), pp. 19-35.

[25] Daniel Benjamin and Steven Simon, "The Worse Defense," *New York Times*, February 20, 2003, p. 31.

[26] A more detailed examination of Silkworm's conversion to a land-attack missile is available at Gormley, *Dealing with the Threat of Cruise Missiles*, pp. 29-33.

[27] Thus far, it appears that China has not exported the HY-4.

[28] Save for the HY-4, primarily liquid-rocket engines power Silkworm variants. It would be possible to achieve a range of around 500 kilometers with a suitable turbojet engine, such as the Chinese WP-11, which powers the HY-4 anti-ship cruise missile. See Gormley, *Dealing with the Threat of Cruise Missiles*, p. 31.

[29] This accounting was accomplished by a colleague, Dr. Gregory DeSantis, a private consultant, using Internet searches of the kit airplane literature, primarily *Kitplanes Magazine*'s monthly issues from January 2001 to January 2002.

[30] Richard A. Muller, "The Cropdusting Terrorist," *Technology Review*, March 11, 2002, <http://www.technologyreview.com/articels/print_version/muller031102.asp>.

[31] For obvious reasons, the author prefers not to make these shortcomings public knowledge. Suffice it say, however, that there are commercially available alternatives, as discussed here, that make the task much less difficult. However, they make it more expensive, but still substantially less than the costs associated with acquiring and converting an anti-ship cruise missile.

[32] Thomas C. Schelling, Foreword to Roberta Wohlstetter, *Pearl Harbor: Warning and Decision* (Stanford, CA: Stanford University Press, 1962), pp. viii-ix.

[33] Schelling, Foreword, p. vii.

[34] Ibid.

[35] Press Release, "Plenary meeting of the Missile Technology Control Regime, Warsaw, Poland, 24-27 September 2002," <http://www.mtcr.info/english/press/warsaw.html>.

[36] For background details see Dennis M. Gormley and Richard Speier, "Controlling Unmanned Air Vehicles: New Challenges," a paper commissioned by the Non-Proliferation Education Center, pp. 13-15, available at <http:///www.npec-web.org/>.

[37] If one member denies an export, other members must not undercut that decision.

[38] For example, case-by-case controls should apply not only to UAV flight control systems usable in Item 1 systems (missiles capable of delivering 500 kilograms to a range of at least 300 kilometers), but Item 19 systems (300-kilometer-range missiles independent of payload), too. Given that they are ideal means of delivery for biological payloads, UAVs with substantially less than 500 kilograms of payload can produce mass-casualty effects.

Technical Hurdles in U.S. Missile Defense Agency Programs

By Theresa Hitchens
(with Victoria Samson)

The White House released its "National Policy on Ballistic Missiles" on May 20, 2003, which is essentially an unclassified summary of the Presidential Decision Document signed in December 2002 that authorizes planned Missile Defense Agency (MDA) activities. The central element of this policy is the Bush administration's commitment to "begin deployment of a set of missile defense capabilities in 2004." According to the policy document, these would include "ground-based interceptors, sea-based interceptors, additional Patriot (PAC-3) units, and sensors based on land, at sea and in space."[1]

The report notes that these "capabilities" are later to be updated with:

> additional ground- and sea-based interceptors and PAC-3 units; initial deployment of the Theater High Altitude Air Defense (THAAD) and Airborne Laser systems; development of a family of boost-phase and midcourse hit-to-kill interceptors based on sea-, air-, and ground-based platforms; enhanced sensor capabilities; and development and testing of space-based defenses.[2]

Rather than taking the traditional route to U.S. development and deployment of weapon systems, MDA has been authorized to use a "fast-track" method for fielding these so-called capabilities, under a new acquisition process known as either "capabilities based acquisition" or "spiral development." In practice, this means two things:

- It is impossible to know the final "architecture," cost or indeed the final capabilities, of the U.S. missile defense network, because new "pieces" are intended to be added over time; and,
- Individual systems are to be fielded before they are fully tested.

The Pentagon maintains that this process is intended—indeed necessary—to speed deployment. However, many critics, including those in Congress, believe such an approach makes it likely that technologies may be fielded that simply do not work, or do not work as intended, or may require extraordinarily costly upgrades. It also has had the effect of limiting the ability of both the public and the Congress to understand the program's developmental progress (or problems).

Despite some concerns among lawmakers and Congressional staff about this process, it is nearly certain that MDA will receive its full budget request of $9.1 billion for fiscal year (FY) 2004. The House and Senate are now in the final stages of approving the Pentagon's FY 2004 defense budget authorization bill, and so far, only a few minor tweaks have been made to the MDA budget. As earlier noted, while it is currently impossible to predict with any accuracy the full costs of MDA's plans for a layered missile defense network, a recent study by the U.S.-based Economists Allied for Arms Reduction estimated the total costs at between $800 billion and $1.2 trillion.[3] This is a staggering sum, and adds to the concern about continued lack of Congressional oversight of the program.

Ground-Based Midcourse Missile Defense

The centerpiece of the current MDA architecture is the Ground-Based Midcourse Missile Defense (GMD) system, which is being designed to use ground-launched intercep-

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tors to knock down enemy missiles during the midcourse of their flights outside the atmosphere. GMD is to begin initial deployment at Fort Greely, Alaska, in October 2004. Despite the nearness of that deadline, the program has faced a host of technical difficulties during its testing.

Until now, GMD has made five intercepts out of eight attempts in its flight testing program. But this number is somewhat misleading due to the fact that a number of the tests simply repeated test parameters used before. In addition, the Integrated Flight Tests (IFTs) to date have been heavily dependent on prior information programmed into the Kill Vehicles (KV). The KVs are told the exact characteristics of what to look for and intercept, a trick that would be impossible in a real-world engagement. Finally, the target sets used thus far in the flight tests are not nearly as complex as real-world targets and possible countermeasures. Moreover, although MDA has now classified all but the broadest information about the target sets being used, it is apparent that that situation will not change much in upcoming tests.[4]

Perhaps even more importantly, the current test program is *developmental* testing, not more realistic *operational* testing. Operational tests will not begin until *after* the initial deployment in Alaska. Indeed, in his FY 2002 annual report, Pentagon Director of Operational Test and Evaluation (DOT&E) Thomas Christie determined that the GMD program had "yet to demonstrate significant operational capability" and criticized the test program as needing to "go beyond the typical proof-of-concept demonstrations in order to provide a higher confidence in estimates of operational capability…."[5] Interestingly, the Pentagon—in a reversal of past practice—limited the availability of Christie's DOT&E report, refusing to post it on the Department of Defense (DOD) website and rationing hard copies.

The most recent flight test of the GMD program was IFT-10 in December 2002. That test failed because the KV did not separate from the booster due to a faulty computer chip. MDA maintains that the problem was simply due to poor quality control, which is now being addressed. However, it is interesting to note that an earlier test, IFT-5 in July 2000, also failed because of a communications failure between the KV and booster.[6]

The next flight test is IFT-14 scheduled for late 2003. But MDA cancelled IFT-11 and -12, originally planned for the end of the year. Those tests were to use the so-called "place holder booster" used in earlier tests, but which is to be replaced before deployment of the system. That booster is still being developed. Indeed, IFT-13, originally designed as another fight intercept test, was cancelled—one of nine IFTs cancelled so far. That test has now been restructured as IFT-13A to be held in July 2003 and IFT-13B to be held in August, neither of which will be attempted interceptions but instead tests of the new booster rocket designs being developed by Lockheed Martin and Orbital Sciences.[7] IFT-14, therefore, is being planned to incorporate the new booster.[8] However, the reason there are now two designs underway is that the original effort by the Boeing corporation became bogged down in technical problems and cost/schedule overruns.

In another change, IFT-16 is now renamed IFT-16A, and will not be an intercept attempt but simply a radar characterization flight. Therefore, between now and the October 2004 deployment, there will be *at best* two real IFTs.[9]

Finally, in regard to the GMD program, the interceptors are supposed to be guided by a new X-band radar, which is considered critical to the system's ability to quickly and accurately detect and track target missiles. Unfortunately, the X-band radar will not be ready by the GMD's initial deployment in 2004. Instead, MDA currently hopes to have a sea-based X-band radar "test bed" in place by 2005.[10] This test radar, budgeted at a total cost of $900 million, is being designed by Boeing. However, many independent scientists are skeptical of the sea-based option, to be located on an oil-rig-like platform off the coast of Alaska, where seas and weather conditions can get extremely rough. It remains somewhat unclear if MDA's original plan to put a ground-based X-band radar in Shemya, Alaska, will go forward. MDA continues to pursue with the United Kingdom and Denmark (for Greenland) options for upgrading their current U.S. early warning radars as part of the GMD system. In the meantime, the older Cobra Dane radar, which is much weaker and is configured only to track missiles shot from Russia, is being upgraded to give it a limited ability to track U.S. flight tests and any missile launched against the United States by North Korea.[11]

This is not a trivial issue. As recently as a year ago, senior MDA officials testified before Congress that a GMD system without an X-band radar would have essentially no capability to do its job of shooting down enemy interceptors.[12] But because of the technical challenges, an X-band radar cannot be developed and deployed in time for President Bush's mandated deployment deadline of 2004 (a presidential election year). Since that deadline was announced, the urgency and criticality formerly placed on the X-band radar by MDA seem to have disappeared.

Aegis Ballistic Missile Defense

Also in the midcourse segment of MDA's plans is the Aegis Ballistic Missile Defense (BMD), which used to be part of the program called Navy Theater Wide. The Pentagon announced in December 2002 that up to 20 Aegis BMD interceptors would be deployed by the end of FY 2005. A current Aegis cruiser, the *Lake Erie*, has been dedicated to missile defense testing. This program has actually done better in its testing than the GMD. The first intercept was originally planned as a fly-by; and three intercepts have been successful. A caveat is that the targets used are larger and brighter than any real world ones, so they are not truly representative of the threat against which the Aegis BMD system is meant. The FY 2002 DOT&E report notes that the program still has "significant capabilities yet to be demonstrated before the engagement conditions can be considered operationally realistic."[13]

Flight Mission-4 (FM-4) was held in November 2002—and represented the first of six planned flight tests to develop an emergency sea-based short- and medium-range defense capability. The test achieved a first: an intercept during the target missile's early ascent phase. This test demonstrated the ability of the Aegis interceptor, Standard Missile 3 (SM-3), to switch its aimpoint to improve its accuracy. However, the latest test, FM-5 held on June 18, 2003, was unsuccessful, with the SM-3 failing to intercept an Aries target missile off the coast of Hawaii.[14] MDA has yet to release any official analysis of what caused the failure, but *The Washington Times* has cited Pentagon officials as blaming the problem on the solid-fuel guidance system used by the Navy. That guidance system has long been criticized by MDA as more difficult technology than one using a liquid-fuel divert system, but Navy officials have insisted that liquid fuel is too dangerous for storage aboard a ship.[15]

At least two more tests of the Aegis system are planned by the end of FY 2004.[16]

It should be noted, however, that the current system is being designed—and is technically limited—to address threats from short- or intermediate-range missiles. This limitation is important, because the Aegis system is also being touted as a possible boost-phase intercept solution. However, MDA and the Navy have admitted that the SM-3 will have to be upgraded to a faster, bigger missile to give the Aegis system any capability against long-range intercontinental ballistic missiles (ICBMs) or for use in boost-phase. This will require modification of the launchers on board the cruiser; indeed, it may require a completely new ship design.[17]

Airborne Laser

The Airborne Laser (ABL) is one of the other programs touted as pivotal in the drive for boost-phase missile defenses. At the same time, it is possibly the most troubled of all the MDA programs: it has consistently slipped its schedule and, according to Congressional staffers, MDA has admitted that it is currently at least 20 percent over initial cost estimates. MDA recently took over management of the ABL from the U.S. Air Force, and there is rampant speculation among Congressional staffers and MDA officials that the ABL may be the first missile defense program to be eliminated. The ABL is currently scheduled to have so-called "first light"—where the laser attempts to produce a beam (not necessarily a lethal beam) this summer in a ground-based test.[18] A shootdown is tentatively scheduled for 2005 or 2006, though few familiar with the program believe it will hold to that schedule.

The ABL is essentially a modified Boeing 747 aircraft designed to carry a high-powered chemical oxygen iodine laser (COIL) that would knock down enemy missiles in their boost phase not by burning a hole in the missile, as many mistakenly assume, but by causing a structural failure (less power is required for the latter). In theory, lasers are excellent for missile defense. In reality, engineering and designing lasers for this purpose have proven enormously difficult.

The ABL laser beam design calls for 14 laser modules to achieve the power needed to disable an enemy missile. However, Team ABL (consisting of Boeing, TRW, and Lockheed Martin, as well as MDA) is currently working on developing a six-module system for testing. Unfortunately, those six modules are currently estimated to weigh 180,000 pounds—5,000 pounds more than the maximum weight limit set by the design for the entire 14-module system.[19] Even worse, the current weight of only *one* module is too much for the aircraft's structure. If put into the current aircraft, the module would break through the floor—something ABL program officials have admitted to Congressional staffers is a serious issue.

Furthermore, there is a serious question about the type of laser currently being used in the testing of the system. Team ABL announced in March 2002 that one of the test modules had demonstrated "118 percent" of its required power. The problem—revealed in a July 2002 report by the General Accounting Office (GAO)—is that the laser demonstrated is fundamentally different from the type of laser called for in the design of an operational system. This has to do with the fact that a different sort of laser resonator (the mechanism that essentially bounces the laser's light back and forth to make more energy) is being used on the test module than would be used in an operational system. The laser design being tested for power output is a so-called "stable" resonator, whereas the operational system is supposed to use a so-called "unstable" resonator.[20]

While it may be unfair to accuse the ABL team directly of the classic "bait and switch" technique, scientists and the GAO agree that it is not a simple task to replace one type of laser with the other. Indeed, it will be an enormously difficult technical challenge. A 2002 GAO report stated directly that the test laser does not represent the operational laser.[21]

In a more recent report, the GAO concluded that "only one of the ABL's five critical subsystems"—the modified 747—"represents mature technology." The study continued:

> A second subsystem, which directs laser energy through the aircraft, consists of several technologies that have been tested in a simulated environment. However, the three other subsystems—that is, the laser itself, the battlefield management subsystem and the ground-support subsystem—consist of low-fidelity prototype technologies that have only been tested in a laboratory environment.[22]

Similarly, the DOT&E report found that "there is currently no Airborne Laser emergency capability apart from some passive detection capabilities."[23]

Finally, while lately MDA officials have been touting the ABL as a possible solution for shooting down long-range ICBMs in their boost phase, the current design of the ABL was optimized for theater missile defense operations against short-range (i.e., Scud) missiles. Indeed, the ABL program office has long continued to insist that it has not studied the system's potential use against ICBMs.

Boost Phase Interceptor Program and Space-Based Test Bed

As noted above, it is difficult to pick apart the MDA effort because of new budgeting processes that lump technologically disparate efforts in the same pot. One of the areas where this is particularly true is in the fledgling effort to develop a new interceptor that could be used by various platforms (ground-, sea- or space-based) for boost-phase kills. Under MDA's 2004 budget plan, roughly $295 million is to be spent on development of such a new interceptor in 2004, and $529 million in 2005.[24] Most of that money is targeted at a ground-launched version. However, there is also $14 million in 2004 for a concept study, and $119 million in 2005 slated, according to Congressional staffers, for granting design contracts for a new space-based test bed.[25] MDA plan for a handful of interceptors to be orbited and tested by 2008.

There are serious technical obstacles to shooting down ballistic missiles in their boost phase from space, many of which were detailed in relation to the original Brilliant Pebbles scheme first touted in the Reagan-Bush "Star Wars" era. These include the necessity for large numbers of orbiting interceptors to assure ground coverage at all times and to assure an actual kill (scientists estimate that at least three interceptors would need to be targeted at any one enemy missile launched). Indeed, according to experts involved, sometime in fall 2003, the American Physical Society intends to release a major study of boost-phase systems that is expected to question seriously the viability of a space-based effort.[26]

Furthermore, even if workable, a space-based system would likely be accomplishing the same job for a higher cost than could be accomplished by a sea- or ground-based boost-phase system. Officials at U.S. national laboratories and other proponents of the system have estimated that a Space-Based Boost Phase Interceptor network could be fielded in three to five years for a cost of $5-7 billion.[27] However, independent analysis is emerging putting launch costs alone for even a regionally limited system as high as $40 billion. These numbers are highly speculative, however, and depend almost entirely on the weight of the interceptors and how many are orbited. This is because launch cost, hovering at about $10,000 per pound, will make up a significant fraction of the total cost.

Unfortunately, it is unclear at this time how many interceptors are eventually envisioned. Officials at MDA, the U.S. national laboratories, and other supporting organizations have used figures ranging from 300 to 1,500 to 8,000. Obviously, the size of the system would be determined by the target set: whether regional or global. However, if the target set is only regional, it would probably be more cost-effective to use other means, such as ground- or sea-based options.

Although it is still in its early stages, the space-based effort is already starting to draw fire from the Democrats in Congress, who recognize it as a back-door method of crossing the long-standing taboo against weaponizing space. Interestingly, even if these few orbiting KVs being used for testing had *no* capability against missiles, because of the physics involved they could be effective as anti-satellite weapons (ASATs). This is worrisome, because the test-bed therefore is likely to draw international ire. This fact also raises some questions as to the motives of proponents of this approach—questions that become even more relevant because, according to Congressional staffers, the money for this program in the FY 2004 budget request was *not* asked for by MDA, but was inserted into the budget by "the powers that be" at the Pentagon and National Security Council.

Patriot Advanced Capability-3 (PAC-3)

PAC-3 is a hit-to-kill version of earlier PAC-2 Guidance Enhanced Missiles (GEM) variants, which rely on blast fragmentation warheads. PAC-3 did well in developmental testing, but failed in five out of seven intercept tests in operational testing completed by MDA in May 2002. At that time, MDA had decided to delay moving the system into low-rate initial production in the fall of 2002 as originally planned.[28] But then came the Iraqi war, where PAC-3 was used for the first time.

Press reports and official Army accounts on PAC performance during Operation Iraqi Freedom differ. In the Army's version, nine Iraqi missiles were engaged by Patriots: two by PAC-3s; six by PAC-2/GEMs; and one by a PAC-2/GEM+.[29] This is important, because while many media commentators and supporters of the program have touted the PAC-3's performance in Iraq as proof of the hit-to-kill concept and a success for missile defense writ large, this is patently not true if most of the Patriots that engaged missiles were not even PAC-3 versions. Of course, there also is the issue posed by the three "friendly fire" incidents involving the PACs, including the British Tornado aircraft that was shot down, killing two British pilots. At least one of those incidents, the April 2 shootdown of a U.S. Navy F/A-18 that resulted in the pilot's death, involved a PAC-3.[30]

At this point, follow-on testing of the PAC-3 has been pushed back from May until summer 2003. MDA has planned approximately 23 more flight tests through 2006.

Despite the lack of operational testing, the PAC-3 is being produced and the Pentagon has been trying to speed acquisition. Gen. Ronald Kadish, MDA head, told the Senate Armed Services Committee on March 18, 2003, that there were about 50 in the arsenal (prior to the Iraqi war). Each Patriot costs about $2.5 million, and the Pentagon currently plans to buy 100 more by the end of 2003.[31]

THAAD

Another long-troubled program—flight testing of the Theater High-Altitude Area Defense (THAAD), designed to counter short- and intermediate-range missiles—began in 1995 and was halted in 1999 after six misses and two successful intercepts. The program has since been restructured and 16 more flight tests are scheduled through 2009.[32] Current MDA plans are to complete THAAD missile and launcher designs, initiate manufacturing of the missile and ground test units, and begin testing of the first completed radar antenna in 2003. Also in 2003, two full-up missiles are slated to undergo lab testing. MDA intends to decide in 2007 whether to take THAAD into low-rate initial production, but officials have also stated that the system might be able to provide an "emergency" capability by late 2005.[33] How this might be done is unclear.

Space Tracking and Surveillance System

Another critical element of the overall missile defense architecture is the Space Tracking and Surveillance System (SSTS), formerly known as Space-Based Infrared System (SBIRS)-Low. This was originally planned to be composed of a constellation of 21 to 28 satellites networked together to detect and track enemy missiles through all phases of their flights, anywhere in the world. Most importantly, an SSTS system is necessary for *target discrimination*, that is, distinguishing the re-entry vehicle on the incoming missile from other objects, such as decoys, the launch bus itself, and debris, and doing so in the presence of other countermeasures. This program is in serious trouble; the Pentagon over the past 20 years has been attempting to develop a space-based missile tracking capability, spending billions since 1984 on various development and acquisition programs. But it has failed to launch a single satellite or demonstrate any capability. The SSTS's immediate predecessor program, SBIRS-Low, spent $1.7 billion over five years and was finally restructured and renamed in 2002 because of cost and scheduling problems.

Now, a new GAO report has come out sharply critical of the restructured effort titled "Missile Defense:

Alternate Approaches to Space Tracking and Surveillance System Need to Be Considered." The title alone is notably harsh for the typically understated GAO.

In particular, the report criticizes MDA's decision to use satellites and ground components developed under the SBIRS-Low program and put into storage two years ago to assemble two satellites and launch them in 2007 so they could be used in broader missile defense testing. GAO found that the:

> MDA's decision to launch in 2007 was based on limited knowledge. MDA established a launch date before it had completed its assessment of the working condition of the equipment it needs to assemble in order to finish building the two satellites it would like to launch. As a result, it does not know the extent of work that must be done or how much it will cost. More specifically…it does not know how many components will be found in non-working order, nor the costs to fix these components.[34]

The GAO report says that to track missiles from space successfully, MDA still needs to demonstrate that:

- Tracking information can be passed between sensors within a satellite;
- Tracking information can be passed between satellites;
- Missiles can be tracked in the midcourse phase of their flight;
- Data from two satellites at different locations and angles can be successfully integrated, processed, and analyzed;
- Data from satellites can be successfully passed to other space-, air-, land- and sea-based platforms;
- Satellites can operate and make some decisions autonomously; and
- Satellites can discriminate warheads from decoys.[35]

It goes on to state that:

> Achieving these capabilities is technically challenging given the difficulties associated with tracking cool objects against the cold background of space as well as the harsh space environment and the short time frames required to successfully identify, track and intercept an incoming warhead. Yet MDA believes most of these capabilities are needed to have a system that can play a useful role in the overall missile defense system.[36]

The GAO essentially recommends delaying launch of the two test satellites; a recommendation with which DOD has disagreed.[37]

CONCLUSION

In general, it is safe to say that missile defense technical progress has been slower and more limited than either promised by MDA or commonly expected. Almost all major programs face continued technological obstacles, and most are running behind their originally scheduled testing plans. The fact is that it remains rocket science.

While in the current climate—both budgetary and political—the technical and schedule troubles may not present the Pentagon with serious problems, that situation could well change over the next year or two. Already, Congress is becoming more restive about the size of the defense budget and the likely enormous costs of the Iraqi war, as well as more willing than during the past two years to question the Bush administration's missile defense plans.

In particular, there is agitation on Capitol Hill—among both Republicans and Democrats—about the need for MDA to concentrate more on near-term programs, such as Patriot, THAAD, and the GMD program, rather than on the more exotic sea-based and boost-phase technologies. Both supporters and skeptics of missile defense are beginning to worry about what they see as a scattershot approach to development: i.e., funding being thrown at many different programs with no real strategy for prioritizing efforts on systems and technologies that are more promising for successful near- and mid-term deployment.

For example, in Armed Services committee action on the FY 2004 defense budget bill, the House cut $150 million from MDA's $301 million budget for development of new ground-, sea-, and space-based boost-phase interceptors, and the Senate cut $70 million from the same line.[38] Both committees cited concerns about the readiness of the technologies; and both committee bills were accepted by their respective houses.

Furthermore, the House side directly shifted some of the funds cut from the boost-phase interceptor development program to buy additional PAC-3s and also increased funding for THAAD. The House Armed Services Committee added $90 million to buy 30 more PAC-3s, $79 million for PAC-3 research and development, $10 million for PAC-2 research and development, and $36 million to upgrade Patriot radar and communications systems. It also added $37 million to THAAD to accelerate the test program.[39]

The Senate Armed Services Committee, for its part, used the boost-phase cut to help facilitate a $100 million increase in the GMD program—in order to ensure that MDA added another intercept test prior to the scheduled 2004 deployment.[40]

Indeed, both the House and Senate authorizers have expressed concern about the lack of testing of the GMD program prior to deployment at Ft. Greely. The House Armed Services Committee urged the Pentagon to "focus this asset [the Ft. Greely test bed] on the developmental and operational testing that will lead to effective defenses over the long term." Likewise, the Senate committee exhorted MDA "to ensure that assets used in an operational defense role undergo the full and rigorous testing required by law, prior to being placed in an operational status."[41]

The issues of testing and oversight are ones that could come to haunt the Bush administration as Ft. Greely gears up for its debut in fall 2004, and perhaps even become problems during the presidential election campaign. Both the House and Senate committees, for example, took issue with reduced budget transparency and reporting on the performance of individual program elements by MDA and the Pentagon.[42] Moreover, the Democrats already are sounding the alarm over the possibility of fielding an expensive system that does not work. In a statement accompanying the Senate Armed Services Committee authorization report, Sen. Jack Reed (Democrat, Rhode Island) said:

> The planned fielding date is September 2004, weeks before the presidential elections, but years before the system is scheduled to conduct any realistic operational testing to prove that it actually works. So the plan is to field the system before we even know if it will work.[43]

While they may not have been so vocal, Republicans too are now concerned about lack of GMD testing, and the dearth of information on GMD and other program element performance goals and progress. Even though both the House and Senate are dominated by the Republican Party—which has a party manifesto supporting rapid deployment of missile defense—both parties agreed during debate on the FY 2004 budget to authorization language clearly designed to force the Bush administration's hand on these issues.

This incipient sea-change in the Congress leads to an intriguing political possibility: It may be that rather than having to fight only the Democrats on the question of whether the GMD system is "ready for primetime," the Bush administration may find itself also wrangling with some of the more ideologically driven members of its own party who want to see a system that actually *works.* For the true believers in missile defense, claiming a pre-election victory for Ft. Greely with a system that has no real-world capability simply may not be good enough. If that were to happen, the debate on missile defense could become very interesting indeed.

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The Budget Politics of Missile Defense

by David E. Mosher

Ballistic missile defenses have been to date one of the most divisive issues in the U.S. national security community. From the anti-ballistic missile (ABM) debates of the late 1960s to the debate over the past decade about what kind of system the United States should deploy to protect itself from attacks by emerging missile states, the issue has cut to the heart of questions and philosophies about nuclear deterrence and strategic stability.

Almost three years ago, I examined why the costs of missile defense programs seemed to rise so rapidly, well beyond the sort of cost growth that is considered normal.[1] I developed a hypothesis that I believe goes a long way towards explaining the phenomenon. It posits that high cost growth in missile defense programs stems from three factors: the programs are highly political; they respond to a perceived, urgent near-term threat; and the technical challenges are significantly underestimated. Since then, the politics, budgets, and status of the U.S. missile defense program have undergone some important changes. At the same time, the United States has started running record budget deficits to finance wars, defense modernization, and homeland security. This essay examines those changes in the context of my theory and use it to predict what effect they will have on the future budget politics of missile defense in the United States.

Cost has played an important role in the missile defense debate over the years. It is often the anvil upon which the success or failure of a missile defense scheme (or any other weapons system) is forged. Cost is never the sole reason why a system is deployed or scuttled, nor should it be. But it is a hurdle, a reality check, that any proposed system must pass to survive. If the threat to the United States is great enough and a weapons system can help counter that threat, cost becomes a secondary issue. But if the threat is not compelling enough or the strategic rationale is not perceived as clearly benefiting national security, cost can play a central role in changing or even terminating the program. Congressional oversight and competition for resources within the Pentagon will focus on the program and gradually squeeze the life out of it. The history of weapons acquisition is filled with such examples, including the Sergeant York air defense system, the A-12 fighter, and the B-70 bomber.

In short, budget battles have a disciplining effect—a program that is perceived as weak, either because of technical problems or lack of high-level support within the executive branch or Congress, will be tripped up. Budgets will be trimmed or appropriations redirected, slowing the program down until it proves itself to be stronger. Leverage to slow a program comes from one of the ironclad laws of research and development: it takes money to fix technical problems. So even if a program manages to shake off attempts to cut it, it may not get the extra resources it needs to solve the problems and remain on schedule.

Understanding why the costs of missile defense programs seem to grow faster than other types of weapons systems is important because, if any of those systems are to succeed, rising costs must be contained.

An Historical Perspective

Missile defense programs have experienced inordinately high rates of cost growth—that is, costs have escalated

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well above the initial estimates made for virtually every program the United States has started. On average, major acquisition programs experience cost growth on the order of 20 to 30 percent from the time they enter the demonstration and validation phase of their development (when the first prototypes are developed, built, and tested).[2] In general, the increase has varied by type of system: ships tend to have the lowest rates (roughly 15 percent on average), whereas tactical munitions and vehicles have the highest (roughly 100 percent on average). The average cost growth for other types of systems fall somewhere in between, with most in the 20-30 percent range. Individual programs vary significantly from those averages: a few, such as the MLRS rocket system and the Aegis cruiser, have cost less than initial projections; others, such as versions of Sparrow and Sidewinder air-to-air missiles have more than doubled.

The cost-growth literature is by necessity historical, so there are too few data points for missile defenses to have their own category—only Safeguard and the original Patriot system have been included in most academic analyses of cost growth. But costs of strategic ballistic missile and space programs, which are similar in some respects to missile defense programs, have on average only risen by 20 percent and 30 percent, respectively. Thus a 20 to 30 percent growth rate would not seem unreasonable for missile defenses, close to the average for all programs.

But over the past two decades, the experience has been quite different. Missile defense programs have experienced cost growth that is significantly higher. A system proposed by the Clinton administration in 1996 featured 100 interceptors based in North Dakota. This so-called 3+3 system would take at least three years to develop, according to the administration, and another three to deploy the first 20 interceptors if deployment became necessary. The price tag for this 100-interceptor system was estimated by the Pentagon to be just short of $8 billion.[3]

By 1999, the original 3+3 system had become the first and second phase of the National Missile Defense (NMD) system that the Clinton administration was preparing for deployment. In the process, the schedule had slipped and the price had risen. According to the schedule announced in 2000, the system would have taken at least nine years to deploy and cost at least $20 billion to build, or 2.5 times the price that was advertised four years earlier for the 3+3 system with the same capability.[4] Much of this huge price rise and schedule slippage can be traced to overly optimistic assumptions about technology and costs—an optimism that can be found in almost every missile defense program that the United States has tried over the past two decades. Definitive analysis of the extent of cost growth in missile defense programs is not yet possible because the United States has fielded very few systems—primarily minor upgrades of the Patriot PAC-2 system and a significantly upgraded PAC-3 system. But the pattern to date is clear: missile defense programs have been plagued by significant cost growth and schedule delays.

Why Do Missile Defense Costs Continue to Rise?

Why do missile defense programs experience abnormally high cost growth? My theory is that missile defense programs (at least over the past 20 years or so) are fundamentally different from other development programs, and therefore do not lend themselves to simple projections of cost growth based on historical experience. There are three interrelated and interacting reasons for this[5]:

- Missile defense programs are highly political.
- Missile defense programs respond to a perceived, urgent near-term threat.
- The technical challenges of missile defense are significantly underestimated.

As a result of these factors, the costs of ballistic missile defense programs have been significantly underestimated in almost every case. Other types of weapons programs may encounter one or more of these factors, but few, if any, suffer from all three. Rapidly rising costs jeopardize the chances for success and slow the program down. If missile defense is to succeed, more realistic estimates of the technical challenges, costs, and schedules will be required.

Recent Changes in Missile Defense

There have been seismic shifts in the missile defense arena over the past few years. Senior officials within the George W. Bush administration, including the president himself, are strong supporters of missile defense. Under their guidance, the administration has taken a number of steps aimed at deploying missile defenses as soon as possible and has been willing to upend years of orthodoxy about nuclear stability and the U.S.-Russian nuclear relationship. So far, those efforts have culminated in the U.S. withdrawal from the ABM Treaty in June 2002 and plans to deploy missile defenses in Alaska by the fall of 2004 and in California soon thereafter.

The result of those actions is that the ideological flavor of the missile defense debate has been significantly muted. This seemingly counter-intuitive outcome is the result of several factors. The most important is the demise of the ABM Treaty and Russia's very quiet response to the U.S. withdrawal. One of the strongest arguments that supporters of arms control made for preserving the ABM Treaty was that the treaty was needed for stability and that Russia would react strongly if the United States abandoned the treaty, particularly at a time when Russia's nuclear forces were in sharp decline. Russia was expected to respond by abandoning the first and second Strategic Arms Reduction Treaties, by building up its forces, and by taking a harder line against the United States on many other issues. This would lead to a marked souring of relations between the two countries, the argument went, and a worsening of U.S. security.

Little of this has happened. In fact, Russian President Vladimir Putin pushed for the ratification of the 2002 Moscow Treaty, a treaty that calls for cuts in nuclear forces without the types of verification that would ensure that the United States is complying. President Putin apparently calculated that ties to the West are more important; economy and trade have trumped concerns about nuclear stability and parity. He may also have calculated that a functional missile defense is many years away, particularly one that would be effective against Russian forces and countermeasures. Or, he may believe that the nuclear component of Russia's relationship with the United States is no longer important and that the two countries should begin interacting as normal states without the shadow of nuclear war hanging over them. Whatever his reasoning, the result has been that the ideological icon—the ABM Treaty—championed by arms controllers has been removed from the debate.

Another important factor in reducing the ideological flavor of the missile defense debate is that proponents of missile defense are now running the show. Proponents dominate the national security apparatus in the executive branch and control both houses of the Congress, which has allowed them to work cooperatively and significantly reduced the criticism from Capitol Hill.

Taken together, the unremarkable end of the ABM Treaty and the ascendance of missile defense proponents in the White House and Congress have allowed the Missile Defense Agency (MDA) to focus on developing a missile defense system without being whipsawed by high-stakes political fights.

Finally, the September 2001 terrorist attacks on the United States have empowered the president on national security issues, reduced the public's focus on missile defense issues, and made opposing the president on defense programs tough.

The net result of all these changes is that the highly charged political atmosphere has dissipated significantly. Make no mistake, the passion is still there. Proponents still believe in missile defense and believe that their position is justified on moral as well as security grounds. Critics are still concerned about the repercussions of U.S. deployments on strategic stability and international relations, in general, but they have lost their ideological rallying point and been weakened by the president's popularity after September 2001. Now, they must focus on oversight and budgets for specific missile defense programs.

Current Risks of Cost Growth

How will these changes affect the prospects for controlling cost growth in missile defense programs? The cooling of the politicization of the missile defense debate (Factor 1 from the theory) could potentially have a very positive effect on cost growth in missile defense programs. Proponents are now able to rely on the administration to propose and develop missile defense programs. They will probably not feel compelled to propose their own solutions because the administration is doing everything it can to deploy defenses. Critics, meanwhile, have limited leverage with which to force changes. MDA will be able to develop a program for research and deployment that is largely isolated from political firestorms about missile defense policy. It has already been able to do this to some degree. If MDA can remain free from political interference with deployment deadlines, this continuity and stability will reduce cost-growth risks.

Recent changes, however, do not bode well for the second factor that contributes to cost growth—missile defense programs are accelerated to respond to a perceived, urgent near-term threat. The current plans explicitly call for deployment of missile defense capability as soon as possible and frequent upgrades. The administration has adopted what it calls a "block" approach to deployments, where it plans to deploy whatever components and systems are available every two years, with the first block deployment starting within 18 months. This is a sharp departure from typical acquisition programs, where a weapon system is not deployed until it and all of its components have been carefully tested in an operational environment. Components are rarely deployed alone. MDA has adopted an approach whereby systems can be deployed as prototypes after very limited testing. The underlying philosophy is that the threat is serious and pressing and therefore that the United States must deploy whatever it can to counter the threat as *soon* as it can. The block approach provides a mechanism so that these deployments can happen on a regular basis. The first block, which is scheduled to begin limited operations by September of 2004, is supposed to include at least 20 ground-based midcourse interceptors when it is completed that will be deployed in Alaska and California, augmented by an upgraded L-band radar in Shemya, Alaska. Twenty sea-based interceptors will also be deployed on Aegis ships. Aegis destroyers with upgraded radar software will be deployed as sensors. A floating X-band radar could be added to the system later to provide some discrimination against decoys. The second block (Block 06, as it is known) is supposed to include upgrades to the first interceptors, possibly more interceptors, and better radars. It is also supposed to include prototypes of space-based sensors and the Airborne Laser.

This approach has been called "capabilities-based planning," a concept that has largely been developed at RAND. According to one definition, "Capabilities-based planning…is planning, under uncertainty, to provide capabilities suitable for a wide range of modern-day challenges and circumstances while working within an economic framework that necessitates choices. It contrasts with developing forces based on a specific threat and scenario."[6] The key driver of this approach is the need to plan in an environment that is characterized by uncertainty and developing an approach that "emphasizes flexibility, adaptiveness and robustness of capability," which imply a building block approach.

MDA has adopted this approach and is using its block system to implement it. However, MDA's emphasis on extremely rapid deployments, particularly of the first two blocks, raises many of the same concerns that have lead to cost growth and program cancellations in the past. This continued, and even heightened, emphasis on rapid deployment suggests that recent changes have made no improvement in this area.

Recent changes have had a mixed effect on the third factor—the significant underestimation of technical challenges—in relation to cost growth. Missile defense is by far the most complicated, multi-faceted, and challenging defense problem that the United States has attempted to solve, and a successful program must begin by recognizing those challenges. There has been some progress in this arena in recent years, but in some important areas things have not improved. Perhaps the area of greatest progress is the recognition by MDA that the missile defense challenge is so difficult that it will require layers to solve it.[7] Having defenses that engage ballistic missiles or their warheads during the boost, midcourse, and terminal phases of their flight increases the chances that they will be successfully intercepted before they reach their targets. Using layers in ballistic missile defense does more than improve the odds with simple statistics familiar from the classic submarine warfare problem. It improves the defense in more complicated ways because each layer can employ different countermeasures, which complicates the job of the attacker. Layers are also important because the midcourse layer is so vulnerable to lightweight decoys. Along with the recognition of the need for layers, MDA is investing significant amounts of money to develop systems in all three layers.

Another positive aspect of recent developments is that there have been significant increases in budgets for system integration and flight testing, with totals for these categories approaching half a billion dollars a year. There have also been greater efforts to mitigate risks by having contractors that are developing some vital system components build competing versions. For example, this past year when MDA contracted with two companies to develop a booster for the midcourse system. Overall system risks have also been mitigated to some degree because MDA is now developing several different approaches to the missile defense problem, working on different layers, and even exploring different technical solutions within each layer. Another encouraging sign is that MDA, after initially supporting virtually every system on the books, has backed off of a few, acknowledging that some technologies are too unproven to develop seriously at this time. The demotion of the space-based laser to a research effort is the most prominent example of this prioritization.

Despite progress on acknowledging and addressing some of the technical challenges, there have been some reversals in other areas. Most prominent among them is that the administration has fallen into the trap of promising deployment of a system before the technology is close to being ready. The Block 04 deployment of a system in

Alaska and California and interceptors at sea is the classic example of this. Although such a deployment is possible in theory, decades of acquisition experience suggest that it will be highly unlikely to yield a system that meets even the minimal standards of effectiveness. It is also unclear whether the systems proposed for the Block 06 deployment will be ready in time. Another example of the push for rapid deployment is the plan to conduct a test of prototype space-based interceptors by 2008, just five short years from now. Although block deployments may be a hallmark of capabilities-based planning, it has yet to be proved that the technologies for missile defense against intercontinental ballistic missiles (ICBMs) have advanced far enough that deployments can begin in less than two years and that the program can sustain rolling deployments every two years. This approach to deployment has never really been tried before, at least not since the dawn of the nuclear age. Starting out with such a complex and challenging problem as missile defense may not be the best test of the theory.

In sum, the recent changes in missile defense have brought some welcome improvements with respect to potential cost growth. Most notably, the political intensity surrounding missile defense has waned with the demise of the ABM Treaty and Russia's extremely muted response. In addition, there has been some stability in the program and a recognition that missile defense will require layers and significant expenditures to have a chance for success. Unfortunately, those gains in the battle to limit cost growth have been largely undermined by the current fixation on extremely rapid deployment. The concern is that unfulfilled promises and oversold claims will, at the very least waste money, and may even erode support for missile defense in general.

Implications for Budgets and Budget Politics

What are the likely implications of the recent changes in missile defense for future budgets and budget politics? At the moment, few signs of past epic struggles over missile defense are visible. Budgets are up, not only for missile defense (at $8 billion in 2003, more than $9.4 billion in 2005, and expected to keep climbing), but also for the entire Department of Defense and for homeland security. In this environment, there will be little budget discipline to pressure programs to perform.

However, the era of growing resources will not last long. Budgets will not rise indefinitely. Already budget deficits have risen precipitously over the past two years, from a surplus of $127 billion in 2001 to a projected deficit of $287 billion in 2003 and $338 billion in 2004, according to the Congressional Budget Office.[8] The administration's tax cut will likely compound these problems in the coming years. Although homeland security, the war on terrorism, and two real wars over the past two years have been enough to sustain support for deficit spending so far, this is unlikely to last for more than a few years. Deficit politics will return to the United States, much as they did in the late 1980s and throughout the 1990s.

When budgets stop growing and begin to ebb, other major claimants within the Department of Defense will begin to fight for their share. Among them are the administration's ambitious plans to transform the U.S. military so that it is more agile, lethal, and easier to deploy and to continue modernizing conventional forces with so-called "legacy" systems. Operations and maintenance costs are likely to continue to rise, buoyed by the inexorable growth in those accounts and the costs of fighting wars and operating forces around the world in peacekeeping and nation-building missions. Manpower costs may also rise if the current trend of providing raises greater than the rate of inflation continues, or if force levels must be increased to handle the higher operating tempo of troops around the world. Retirement costs will also rise in the future, reflecting the sharp increase in retirement benefits instituted near the end of the Clinton administration. Finally, the costs of medical care for the military and their families are likely to continue rising at nearly the rate experienced in the U.S. economy more generally. At roughly $10 billion a year, missile defense is not that expensive in an annual defense budget that is likely to rise above $400 billion. But the services and other claimants will view the struggle for resources as a zero-sum game: each dollar spent on missile defense is a dollar less spent on their programs.

There will also be rising demands from outside the Pentagon to compensate domestic programs that have been cut back in recent years and to address demographically driven requirements for social security and Medicare programs. Homeland security demands may also keep rising for domestic political reasons as much as threat perceptions.

Against this backdrop, missile defense programs will have to compete for additional resources and, if programs are unsuccessful, compete to maintain the levels they have. Old-fashioned Congressional scrutiny will begin to slow programs and spending, particularly as programs begin to face the technical realities of building such complex systems. Programs that become viewed as weak or vulnerable will be slowed down, and ultimately thinned from the herd during internal Pentagon battles for resources or during the Congressional authorization and appropriation process. The best-managed programs with the most compelling rationales and track records are likely to survive.

In short, budgets for missile defense are likely to continue their rapid growth for a few more years, but the pace will moderate in the following years, possibly even falling as government-wide budget pressures curtail defense spending. The degree to which budgets will rise, fall, or remain steady beyond the next few years will depend on several wild cards. Foremost among them are how successful the technology for missile defense proves to be and how rapidly the threat develops.

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Striking Out to Space: Technical Challenges to the Deployment of ASAT Weapons

BY CLAYTON K. S. CHUN

The United States military is currently undergoing efforts to transform itself in order to meet perceived future challenges. Two of these challenges involve protecting space assets and ensuring that any potential threats from space do not endanger U.S. national security. Although not official policy, the development and deployment of anti-satellite (ASAT) weapons could provide a potential operational capability to meet both challenges. The U.S. government has experimented with developing ASATs in the past and may do so in the future.[1] These weapons might find themselves in the limelight. After all, the United States has decided to build an anti-ballistic missile capability to protect the country from rogue nations and accidental launches. This type of program was hotly debated and thought, by many, impossible to build due to cost, technical, and political constraints, yet it is now scheduled for initial deployment in late 2004. Could ASATs experience the same transformation?

In recent years, scholars and policymakers have discussed the issue of space weapons and control. In a 1999 study commissioned by the U.S. Space Command, James Oberg concluded that it was "almost certain that sometime early in the 21st Century, the fielding of space-based weapons will occur under the auspices of defense."[2] Technology, threats, and politics have changed the future of space. Today, a new administration views space differently than previous administrations. In 2001, as chairman of a Congressionally sponsored commission, Donald H. Rumsfeld submitted a report that captured U.S. objectives in space. The report identified a particular objective to "[d]evelop and deploy the means to deter and defend against hostile acts directed at U.S. space assets and against the uses of space hostile to U.S. interests."[3] Such plans may be realized sooner than expected.

The United States and, increasingly, other nations rely heavily on space-based systems for commercial, military, and public uses. These nations use a host of domestic and international satellites to support their interests and economies. Potential adversaries could severely affect any state's ability to conduct activities—ranging from commercial to military—by affecting certain space systems. These weapons could also affect international arms control verification means. If a nation decides to design, deploy, and operate ASATs as a possible method to conduct offensive or defensive counter-space activities, then it must consider several aspects of employing such weapons that may reduce their value. Although many might believe that ASAT weapons are merely extensions of traditional surface-to-air missiles, there are a number of other ways to conduct actions against satellite operations.

KNOCKING DOWN A SATELLITE?

Most people who think about ASAT weapons believe that the primary means to eliminate a satellite is to destroy it. However, if the country only desires to stop another state from benefiting from its access to satellites, then it can conduct a number of actions, such as disruption, denial, degradation, and deception of the space system in question. Depending on the choice of attack, operations against a target can take a number of approaches that have

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a range of impacts. For example, an actor trying to limit space capabilities could target the satellite itself. Unless the space system has an autonomous mission, however, it also relies on other components—such as communications between itself and a ground station—to conduct its mission. Military activities could take the form of destroying the ground station or jamming the communications signal. A state can easily take actions to attack or sabotage ground facilities by using a number of readily available conventional means, such as aircraft, cruise and ballistic missiles, surface forces, or terrorists. Another method to eliminate signal traffic between ground facilities and satellites is to jam or spoof uplink and downlink communications. Electronic attack from the surface or airborne platforms could render the satellite useless. A country could also introduce an information attack on the satellite's command, control, and communications network by introducing a computer virus that would also degrade or possibly lead to the destruction of the satellite. However, the one method to ensure space capability elimination is the physical destruction of a satellite.

ASAT operations focus on an enemy's actions to ensure the denial of a space system through attack on a satellite. These satellite systems might include an orbital weapon system or critical support system such as a reconnaissance or communications satellite. The attack can take the form of destroying the satellite in total or, if the weapon is sufficiently accurate and sophisticated, the degradation and disruption of particular functions to render its target useless. There are several forms that ASATs can take.[4] A state can deploy a direct ascent weapon, orbital device, or a directed energy weapon. In some respects, countries have experimented with all three approaches, with varying degrees of success. These techniques require particular parameters and conditions that can create devastating consequences to the target, but also have other operational and political considerations.

Direct Ascent ASATS

Direct ascent weapons are usually associated with the interception of a target in orbit. These weapons normally use a rocket booster to provide sufficient thrust to propel a warhead or device towards its target. The weapon could include a nuclear or conventional munition. These types of weapons require a host of elements to accomplish their mission successfully. First, they must have a reliable booster system with a sufficient payload capacity. The type of target and the weapon aboard the booster also affect the choice of delivery system. If the country wants to defend itself from an orbital weapons platform, then it needs a launch vehicle that has instant readiness to strike the target before it unleashes its weapons. This characteristic requires extensive maintenance and crew training. Second, the ASAT system must have the ability to track the target and guide it to interception. Depending on the threat, a country might require an exhaustive system of surface, aerial, and space-based surveillance and tracking systems. Location is very important in this respect. An ASAT weapon on the ground may not be in position at a particular time to track a target or launch an attack. Third, a direct ascent system must include sufficient command and control capabilities to direct the attack on the target. This capability must include a secure means to order a launch crew to deploy its weapon or provide guidance updates to the ASAT before and after launch. Fourth, after launch, the ASAT needs a means to intercept its target to place it within an effective range of its weapon. This capability can be very difficult to achieve. Fifth, the ASAT weapon must have sufficient "kill" capability to disable or destroy the target. Sixth, the country must have the ability to determine if the target has been rendered useless or requires another attack. The state may immediately need to launch another weapon or assign two or more ASATs against the target to ensure its destruction. Failure of any of these components or capabilities may doom the ASAT operation.

Two particular ASAT characteristics are extremely critical for a successful mission: tracking and interception. If the ASAT's objective is to get close enough to either explode a conventional device or strike the target, then it must find the target. However, this assumes that the ASAT weapon has the ability to correctly identify the target. Suppose an adversary launches a weapons platform into orbit. Any launch produces some space debris that can hamper the correct determination of the true target. A space system might have components like a shroud, a final stage, fasteners, and other parts that may alter target identification by shielding the satellite or affecting detection via infrared signature. A foe might also decide purposely to introduce devices to confuse any tracking system. Suppose a state decides to launch a multiple orbiting bombardment system. Satellite designers might introduce a system that has a reduced radar signature by physical design or coating it with stealth material that would prolong the time and effort to find the target. Additionally, they could also launch a decoy or have replicas that simulate the true satellite. Engineers could also introduce an electronic jammer as a countermeasure or produce chaff, material that can hide a satellite behind a wall of radar reflective material. In either case, the targeted device may gain sufficient time to escape detection or at least have time to accomplish its mission of space bombardment. Another possible option to avoid detection is to maneuver. Most satellite systems have some rudimentary means to alter their orbital paths. This can lead to increased problems of detection, tracking, and interception of the target. Finally, a satellite maker might include a defensive system that could destroy the ASAT. A simple rocket-propelled explosive or kinetic device could demolish the ASAT. A state could also construct satellite constellations with redundant capabilities that would require many ASAT attacks to destroy them.

Another important consideration for ASAT effectiveness is the type of weapon used to eliminate the satellite. Specifically, the weapon could be conventional or nuclear. In the early 1960s, the United States experimented with high altitude nuclear bursts over the Pacific and South Atlantic Oceans. Scientists overseeing the Project Fishbowl series of tests over the Pacific inadvertently discovered that a nuclear device produced sufficient electromagnetic pulse (EMP) to affect a satellite's operating capability.[5] One test, Starfish Prime, damaged three satellites after the United States exploded a 1.4 megaton device at an altitude of about 248 miles (about 400 kilometers). This finding was the basis for the U.S. development of a direct ascent nuclear-armed ASAT system using two Thor ballistic missiles based on Johnston Island.

EMP from x-rays, gamma rays, and neutrons directly affects a satellite's electronics through burnout, but trapped radiation also has long-term consequences. EMP can damage or make inoperable electronic components by introducing stray voltage or currents to conductors that are attached to an electrical system. For example, satellite antennas or solar panels could receive a sharp surge in electrical or magnetic fields created by a nuclear explosion. If the components are unprotected from EMP, lacking shielding, filters, or devices to shunt unwarranted voltages, then a nuclear ASAT can destroy a satellite immediately and create relatively long-lived radiation belts that can affect the lives of other low-Earth orbiting satellites. EMP from a nuclear device can provide a very effective means to destroy or disable a wide range of satellites. However, if the attacking state itself relies on unhardened space assets too, then it might also suffer catastrophic failure of its own or other neutral countries' satellites. Additionally, unintended damage to electrical systems on the Earth's surface would become devastating to all advanced economies. Depending on the size of the weapon and height of the burst, EMP damage would result over a wide line-of- sight range. Any detonation above 19 miles (30 kilometers) would create highly ionized EMP fields that would spread over large areas.[6] For example, a sufficient yield, high altitude burst of about 500 kilometers could cover the entire continental United States in EMP.[7]

Some of the most lucrative satellite targets reside in very low-Earth orbit (LEO) that might entice the use of a nuclear ASAT. If a state uses a relatively low-yield 50-kiloton device launched to explode at an altitude of 250 kilometers, it could create many of the conditions cited above. After only two months all satellites that are "unhardened" in LEO would cease to operate.[8] Additionally, increased EMP can disrupt radio transmissions on the surface and in space, blind sensors on higher orbiting satellites, affect ground-based radars, and create long-term effects in space. A Teledesic-type communications satellite, with limited hardness, at an orbital altitude of 1,350 kilometers that was designed for a 10-year life, would have a greatly reduced life of 1.4 months. Over time, satellites within 500 to 2,000 kilometers would become inoperable.

Conventional weapons can take many forms. An ASAT device can take the form of a kinetic impact, chemical, or jamming weapon. A kinetic impact weapon simply causes structural damage to the target either by using a projectile to hit the satellite or using the whole vehicle to strike the object. These types of weapons require precise interception of their intended targets. Like the proposed anti-ballistic missile vehicle being designed by the United States, a kinetic impact weapon needs to track, discriminate, intercept, and hit the target. Perhaps an ASAT weapon will have an easier task to track its objective since the target will follow a relatively known orbit and period for years. Moreover, a satellite is much more fragile than a ballistic missile's warhead, which is designed to withstand atmospheric reentry. However, once the ASAT sets its path to hit its target, unless it has sufficient maneuvering capability, it may have only one shot. One problem that encompasses all ASAT weapons involves the destruction of the target and potential reentry of the fragments into the Earth's atmosphere. If the satellite has a nuclear weapon or has large quantities of chemical fuel to operate a laser, it might create severe collateral damage upon reentry. Compounding this problem is that a satellite travels at great speeds. For example, a satellite in LEO approaches a speed of about 17,000 miles per hour (27,000 kilometers per hour), while one in an elliptical Molniya orbit has an even greater velocity at 23,000 miles per hour (37,000 kilometers per hour) at its nearest approach to Earth at 200 miles (320 kilometers).[9] Indeed, an effective ASAT system would need the capability to intercept all of these satellites.

Since space is a vacuum, a kinetic intercept vehicle or projectile needs to destroy the target by collision and cannot use concussive force. If the ASAT is not sufficiently accurate to create a head-on intercept, shooting several projectiles or creating a field of shredded metal via an explosive charge could provide a sufficient cloud to strike the target if the ASAT gets in range. In either case, like EMP, there are unintended consequences. Debris from any collisions, kinetic impact vehicle, or projectiles, might create a field that endangers other satellites. Unlike EMP, which will eventually dissipate, this debris might stay in orbit for years. A chemical spray or reactant material could also damage a satellite sufficiently to render it useless. Chemical sprays on camera lenses or on sensitive areas like solar arrays could also make satellites lose their functionality. ASATs could also take the form of a strong radio-frequency that could disable or interfere with particular satellites in close proximity. Jamming a satellite might entail the use of retransmitted false commands or signals to confuse satellite components and could force it to malfunction on a temporary or permanent basis. Chemical and jamming devices, although more benign than a kinetic impact weapon, must still have the exacting interception capabilities.

Throughout history, a state wishing to destroy another country's military capability has relied on surprise to ensure that it swiftly and successfully attains that goal. Direct ascent ASATs, depending on their method of attack, may require a powerful booster system. Unless the system is maintained on mission-ready status around the clock, launch crews might require extensive preparation to prepare the vehicle for launch, giving the target state sufficient warning time to maneuver satellites to avoid the attack. Additionally, if the aggressor has only a limited number of ASATs, the target country could take actions to eliminate its ASAT capability or threaten to escalate the situation in ways that could deter the planned attack. This condition could change if a state can develop a system that has ready aircraft to launch an ASAT into a sub-orbital trajectory to intercept satellites in LEO.

Orbital ASATs

Since 1967, nearly 100 countries have signed and ratified the Outer Space Treaty. This treaty banned the permanent orbiting or stationing of weapons of mass destruction (WMD) in space. Fears of orbiting nuclear bombardment systems raining surprise attacks on the Earth's surface and the accidental reentry of a WMD motivated many countries to approve the treaty. Nuclear-armed, permanently orbiting ASATs that could explode their warheads and destroy their targets via EMP were banned. Since 1960s-era technology limited precision guidance of many weapons of the era, conventional weapons were largely ignored. Today, improved technology has allowed weapons miniaturization and a host of advances to make orbital conventional weapons possible. These weapons would not violate the Outer Space Treaty. Orbital ASATs can take many forms. Such weapons might be a space mine, an orbiting interceptor that destroys its target by kinetic impact or space-to-space projectiles (e.g., a missile, or a space-based gun).

A state could launch a device that acts as a co-orbital interceptor or stays permanently in orbit. A co-orbital space interceptor has many of the problems of a direct ascent ASAT. These devices could use a nuclear or conventional type of warhead to eliminate their targets. Unless the country is willing to violate the Outer Space Treaty to destroy a satellite, with all of the consequences, it would probably use a conventional warhead. Normally, a state would launch this device into orbit, and then the ASAT would need time to catch up to its target. This process might take an orbit or two and several hours for the task to be accomplished. Presumably, an adversary would observe the launch and ASAT attack and it could institute countermeasures (e.g., moving a satellite out of harm's way). The ASAT might run out of maneuvering capability to catch its intended goal of disabling the space vehicle. Allegedly, the Soviet Union fielded a conventionally armed satellite destroyer in the early 1970s. The device had the capability to explode several rounds of metal shards into its intended victim to ensure its success. In 1983, then-Secretary of Defense Caspar Weinberger proclaimed that the Soviets had made the system operational in 1971 with two launch pads at the Tyuratam (Baikonur) launch complex.[10] These systems were powered by a liquid-fuelled SS-9 Scrap intercontinental ballistic missile. The launch weight of a typical SS-9 was 420,000 pounds (about 190,000 kilograms).[11] In comparison, a direct ascent ballistic missile, like the American Thor, weighed considerably less, only 110,000 pounds (about 49,500 kilograms).[12] The cost, launch support, and ability of a rival to detect pre-launch activities would rapidly increase under these circumstances. A variation of this approach would involve a country putting the ASAT into a parking orbit to engage a satellite in a medium-, high-, or geosynchronous orbit. This would normally require an even larger booster, entailing an extensive and expensive preparation to launch and thus losing a valuable source of surprise.

A permanently stationed orbiting ASAT would require some enhanced systems. These weapons need to withstand the relatively harsh environment of space for an extended period. They might require great hardening to protect critical systems against temperature and radiation hazards. Depending on the type of ASAT weapon, it could require a weapons support system (e.g., guidance system and movable weapon housing for projectiles). Additionally, the ASAT would need a secure, reliable communications system that would allow ground controllers to activate and engage the ASAT system. This is especially true if one has decided to station WMD in orbit. Unlike a direct ascent weapon, orbital systems may require rearming of projectiles or weapons replacement. A state that uses an orbital weapons platform has a limited capacity to fire weapons or even maneuver them into position. Orbital ASATs may need to maneuver to intercept their targets and might not be able to attack in a timely manner. A state could overcome this problem by deploying ASAT projectiles that could maneuver independently in space. This might require a more sophisticated and expensive vehicle. Likewise, the state could create a constellation of ASAT weapons in space. Again, this prospect makes it an expensive proposition. Additionally, orbital ASAT platforms might themselves become targets for countermeasures. A state could try to move pre-emptively to eliminate this ASAT threat. A state that wants to deploy an ASAT might want to keep the purpose of the vehicle secret. It could use orbital mines that lie in wait for an intended victim. In this case, unknowing satellite owners or users may unintentionally deploy a satellite near these ASATs. If the orbital ASAT takes on the form of an orbital mine, then other states might place satellites into an orbit that blocks the path of such mines (unless they have a maneuver capability) and renders them useless. A space mine could become a hazard if its intended target is no longer a threat.

Most discussions of ASATs include unmanned systems. However, direct ascent or orbital ASATs might include manned systems. A future trans-atmospheric vehicle could allow a country to intercept, inspect, and possibly destroy a satellite. Likewise, a permanently orbiting space station could also find military application as a base to conduct ASAT operations. Although feasible, the expense of developing such a system for purely ASAT operations would likely make this unattractive. However, if technology and threat dictate additional space weaponization missions—such as an orbital bombardment, reconnaissance, and other roles—then ASAT operations might provide this capability as a secondary mission.

Directed Energy Weapons

The United States has successfully developed an airborne laser capable of destroying ballistic missiles in flight (albeit currently at very limited range). After years of design, testing, evaluating, and conducting research on issues ranging from optics to atmospheric interference, the U.S. Air Force has significantly advanced its directed energy weapons (DEWs) technology. DEWs can extend the range of an ASAT's destructive capacity and can swiftly destroy components of a satellite at the speed of light. DEWs that use a low-powered laser could damage a sensor that operates at the same wavelength as its intended target, have a particular low-powered laser amplified by that sensor, and be used against a satellite at almost any altitude.[13] If the Air Force can employ such a weapon on an airborne platform and strike a missile in the upper atmosphere, then could it do so against a target in space? Would a space-based laser be far behind? DEWs offer many advantages, but offer new concerns for ASAT use. These weapons do provide a way to destroy a number of weapons in a relatively short time, compared to having to use multiple direct ascent or interceptor weapons.

DEWs can take many forms. A state could deploy a laser, focused radio-frequency, or particle beam device from a ground station or an airborne—or even space-based—platform. These weapons could damage sensitive components on a satellite or, in the case of a photo reconnaissance satellite, severely damage the electro-optical sensors of the vehicle. DEWs, like other ASATs, must have the capability to track their targets, but they must also have the unique ability to concentrate their beams at sufficient ranges and aim them to a greater precision than most ASATs. Also, DEWs might require time to disable or destroy a component, depending on the power and wavelength of the energy propagated on the target. The target's design and construction materials, the angle of attack, and a host of other factors can also reduce a DEW's effectiveness. An adversary could coat a satellite with reflective material to mitigate the absorption of energy and avoid potential damage. DEWs also require a large quantity of corrosive fuel or energy to produce a weapons-grade beam. Military engineers could build a ground-based DEW near an energy source, such as a nuclear power plant, or construct a huge reservoir of chemical fuel. Ground-based DEWs can support large laser or particle beams, but they are in fixed locations and heavy cloud cover might obscure operations by distorting the focus and concentration of the weapon. They are also subject to conventional attack by surface and aerial forces.

A space-based or airborne weapon would probably use a multi-megawatt chemical-powered laser. This characteristic would require these systems to carry a limited quantity of chemical fuel that would limit their operational capability to a few shots. Additionally, an orbiting system does not have a capability to refuel easily. A space-based system would also require a large, segmented primary mirror to aim the laser and focus the beam. The mirror would need to be approximately 12 meters (about 40 feet) across. A weapons-grade mirror has never been constructed with these dimensions.[14] An eight-meter diameter mirror might weigh anywhere from 6,000 to 7,000 pounds alone.

DEW operations require an extensive amount of support personnel and equipment. Moving the operation into space, assuming an unmanned system, would also require a large amount of sophisticated automated support systems with redundancies. Such a system, which includes the weapon, fuel, mirror, and support elements, might tax current space-lift capabilities. One source estimates that a space-based laser would weigh about 70,000 pounds.[15] The most powerful U.S. space-lift asset, the Space Shuttle no longer carries military payloads. Regardless, it only carries a maximum payload of only 55,000 pounds into an orbit of about 174 to 260 miles.[16] The largest expendable launch vehicle, Titan IV, might push a 39,000 pound payload into a 115-mile LEO or a much smaller 4,000-pound payload into a polar orbit.[17] Unless the United States builds a higher capacity space launch booster, improves technology relative to weight savings, or delivers the orbiting weapon in segments, it cannot deploy such an ASAT in the near future. Still, a space-based laser requires less energy than ground-based systems, since it does not need the energy required to penetrate the atmosphere and into space. The weapon also is mobile, assuming it has a maneuvering capability.

Airborne lasers have some advantages over space-based lasers. Airborne systems can refuel their DEW weapon and deploy to various areas around the world, unlike ground-based systems. The current airborne laser, deployed on a Boeing 747, can carry a crew that operates and maintains the laser during flight and could take corrective actions under unexpected circumstances. However, an airborne laser is susceptible to a problem inherent in all aerial systems: inclement weather. Once airborne, the aircraft carrying a DEW could potentially fly above the bad weather. Additionally, like ground-based DEWs, aerial DEWs are subject to attack from the surface or to aerial interception.

Conclusion

In the near future, national and international reliance on capabilities that require space platforms to perform critical actions will increasingly make such space assets targets in a conflict. There are several means potential aggressors might employ to achieve their goals. Countries could use ASATs to disrupt services temporarily or destroy them. Direct ascent weapons, orbital systems, and DEWs are only a few of the most notable ASATs that a state might develop and deploy. However, like most weapons, particular ASATs have limitations that scientists and engineers may eventually overcome. A serious look at ASATs by policymakers will need to consider the technical conclusions addressed in this study. Many of these considerations are the result of unintended consequences that may limit any contemplated use of ASATs, but—in the context of a major conflict—these problems may seem trivial. On the other hand, in a small-scale contingency or conflict, the use of ASATs and some of their consequences may force an escalation of actions that may widen and deepen a conflict or strongly hint at a reconsideration of ASAT use.

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1 The United States Air Force developed a direct ascent ASAT that used a nuclear-armed Thor ballistic missile on Johnston Island from 1964 to the early 1970s. The U.S. Army also operated a single, nuclear- armed Nike-Zeus missile on Kwajalein Island from 1963 to 1966. Another weapon that was later developed, but not deployed, was a kinetic kill vehicle delivered via a rocket launched by an F-15 fighter.

2 James Oberg, *Space Power Theory* (Washington, DC: U.S. Government Printing Office, 1999), p. 149.

3 Donald H. Rumsfeld, *Report of the Commission to Assess United States National Security Space Management and Organization*, Public Law 106-65, Washington, DC, January 11, 2001, p. 27.

4 A state can also deny satellite use to another state, if it relies on commercial assets, through pressuring the owner to withhold services to that state or by buying up services at a premium.

5 Paul B. Stares, *The Militarization of Space: U.S. Policy, 1945-1984* (Ithaca, NY: Cornell University Press, 1985), p. 108.

6 Samuel Glasstone and Philip J. Dolan, *The Effects of Nuclear Weapons* (Washington, DC: Departments of Defense and Energy, 1977), p. 47.

7 Electronics and Systems Directorate, *HEMP Electronic Pulse* (Washington, DC: Defense Special Weapons Agency, undated).

8 Defense Special Weapons Agency, Electronics and Systems Directorate briefing "Region-by-Region Assessment Potential Effects of High Altitude Nuclear

Bursts in the India-Pakistan Theater," May 13, 1998.
[9] David Hobbs, *Space Warfare* (New York: Prentice Hall Press, 1986), p. 84.
[10] Caspar Weinberger, *Soviet Military Power, 1983* (Washington, DC: Office of the Secretary of Defense, 1983), p. 55.
[11] David Miller, *The Cold War A Military History* (New York: St. Martin's Press, 1998), Appendix 8, Soviet Land-based Strategic Missiles: 1966-1190, p. 407.
[12] John Gibson, *The History of the US Nuclear Arsenal* (Greenwich, CT: Brompton Books, 1989), p. 36.
[13] *Threats to US Military Access to Space* (Wright-Patterson AFB, OH: National Air Intelligence Center, 1998), p. 15.
[14] David R. Tanks, *National Missile Defense: Policy Issues and Technological Capabilities* (Washington, DC: The Institute for Foreign Policy Analysis, 2000), section 5.14.
[15] Ibid., section 5.15.
[16] Aerospace Industries Association, *Aerospace Facts and Figures 2001/2002* (Washington, DC: Aerospace Industries Association, 2002), "US Space Launch Vehicles," p. 65.
[17] Ibid.

Prospects for "Non-Offensive" Defenses in Space

BY PHILLIP J. BAINES

When the Galaxy IV communication satellite in a geostationary orbit 36,000 kilometers (km) above the United States failed catastrophically in May 1998, an estimated 80 to 90 percent of the 40 million U.S. pager customers were affected by the disruption. Internet access via the satellite was severed as well. Television feeds and news wire service transmissions were also affected.[1] The failure of the onboard attitude control subsystem of the PanAmSat satellite was a rare occurrence but not an unexpected one given the harsh natural environment in which satellites operate, thousands of kilometers away from the nearest repairmen on the Earth. If such disruptions could happen in the absence of man-made threats to satellites, what would be the implication for national security were such disruptions to be caused by hostile acts? Given the U.S. reliance on its space systems for national security, would the United States (as some have argued) face a future "space Pearl Harbor" if it did not first acquire the means to protect its space systems from deliberate harm? How should any space-reliant nation best protect its space systems? Does the fundamental nature of outer space and the current threat environment favor instead so-called "non-offensive" defenses, such as hardening and redundancy, or should "offensive" defenses—ones capable of shooting back— be pursued, whether such weapons are based on the Earth or ultimately in outer space? This analysis seeks to prepare the ground for the complex policy choices that lie ahead by examining the various technical and cost issues involved.

First, this study defines a space system as consisting of three segments: the space segment containing satellites that provide a variety of services to users; the ground segment, consisting of facilities that control the operations or exploit the services of the space segment, and the electromagnetic links that connect the space segment to its ground segment in both directions. Each of these segments is vulnerable to a variety of terrestrially based threats. The possibility also exists for the emergence of space-based threats to artificial satellites in the absence of an international legal instrument effectively banning such developments. Secondly, the study elaborates the current and future threat environment in order to lay the basis for a subsequent discussion of defensive strategies to protect space systems against these threats. Non-offensive defenses with an emphasis on the space segment are the subject of the following section of the paper. Finally, the study tries to answer the question implicit in the title, addressing technological readiness, relative costs, and the architectural dimensions of the issue. The analysis concludes that non-offensive defenses in use today already help protect satellites from the current threat environment. Further prudent investments in relevant space technologies and architectures for the future can also make these systems secure against evolving man-made threats. The study suggests that the threat of military operations against the terrestrial infrastructure necessary to conduct offensive operations in outer space, using existing terrestrial means, may also be sufficient to deter hostile actions against satellites.

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Space Systems Overview

Space systems today provides essential services in the domains of meteorology, navigation, communication, remote sensing, and scientific discovery to civil and commercial segments of our increasingly international society. Military space activities add critical early warning, command, control, communications, computers, intelligence, surveillance and reconnaissance (C^4ISR) missions upon which space-faring powers rely for their national security. These important missions are accomplished by artificial satellites launched into low-Earth orbits (LEO, less than 2,000 km in altitude), medium-Earth orbits (MEO, approximately 20,000 km in altitude), and geostationary Earth orbits (GEO, approximately 36,000 km in altitude). Actual weapons themselves, as best anyone knows, have yet to be stationed permanently in any of these orbits.

LEO orbits are closer to the surface of the Earth and are therefore primarily used for intelligence, remote sensing, meteorology, and scientific discovery missions. Satellites can be located in orbital planes highly inclined with respect to the equator of the Earth (90 degrees inclination), allowing them to view the entire surface of the Earth using orbits that repeat their coverage pattern exactly after a given number of orbits. The periods of these orbits are typically less than two hours. The U.S. Keyhole-11 satellite is an example of a reconnaissance system deployed in LEO in order to produce very high resolution images necessary for strategic military intelligence. MEO orbits are often used for meteorology, early warning, communications, and navigation systems.[2] A constellation of 24 Global Positioning System (GPS) satellites deployed equally in six inclined orbital planes (55 degrees inclination) occupy this region of outer space to provide accurate three-dimensional position and time signals to commercial, civil, and military end-users located around the globe. Geostationary satellites in circular orbits above the equator (0 degrees inclination) have an orbital period equal to the sidereal rotation of the Earth and therefore appear to remain fixed in the sky to an observer located on the Earth. Satellites in LEO and MEO orbits, in contrast, may be visible overhead for durations anywhere between seven minutes and 10 hours. The U.S. Defense Satellite Communication System (DSCS) III satellite is an example of a secure military communication satellite system deployed in GEO.

All space systems require ground stations for telemetry, tracking, and command (TT&C) of the satellites in the space system. Telemetry relays data pertaining to the health and status of the satellite to the mission control facility. Tracking yields positional and temporal observations from which current and future locations of a satellite can be calculated. Satellites in LEO and MEO may try to maintain in-orbit positions within one kilometer of where they should be, whereas satellites in GEO will typically maintain positions within several hundred kilometers of their nominal locations. The command function provides a means for guidance, navigation, and control of a satellite in its orbit during normal operations and periodic orbit maintenance maneuvers. Prime and redundant TT&C systems are the norm for space systems, given the need to ensure reliable control of the satellites at all times in the context of expected failures. These TT&C facilities may be fixed, transportable, or mobile. Some satellites require contact with a mission control facility at least once per day and some require continuous contact, otherwise the satellite will leave its normal mode of operations for a "safe-hold" mode. The safe-hold mode is a mode of operations specifically designed to permit subsequent recovery attempts by ground controllers after a satellite experiences a serious anomalous malfunction. Some satellites have an autonomous mode of operations that can function without contact from a TT&C station for an extended period of time. Ground stations for exploitation of the satellite services may range from a small hand-held GPS receiver for navigation or a mobile phone for communication services, through transportable data reception facilities for early warning or remote sensing missions, to giant fixed Earth stations serving as gateways for large volumes of international transoceanic communication comprising data, telephony, and television signals.

The electromagnetic links to and from the satellite may be based in the radio frequency or optical portions of the electromagnetic spectrum. Signals transmitted from the ground station to the satellite are known as uplink signals. Signals transmitted from the satellite to the ground stations are called downlink signals. Since signal strength or power varies inversely with the square of the range of transmission, uplink signals are relatively strong at the ground and relatively weak at the satellite, while the reverse is true for the downlink signals. All links are susceptible to interference, whether intentional or not, with laser links considered the most secure from interference. Antennas operating in the radio frequency portion of the electromagnetic spectrum cannot produce as tightly focused a beam as can optical systems operating in the visible or infrared portions of the spectrum. Radio frequency antennas also produce side-lobes on either side of the main beam that can be exploited for electronic warfare, including the jamming of signals transmitted or received by such systems. Higher radio frequency antennas produce smaller and tighter beams than lower radio frequency antennas and thus may be more secure against the probability of an intercept by hostile forces. Given the variance of signal power with range, downlink jammers might best be located on the Earth, whereas uplink jammers may be advantageous if deployed in outer space.

Space systems require space launch vehicles or refurbished intercontinental range ballistic missiles to launch artificial satellites into useful orbits. Over the years a variety of launch vehicles and upper stages have entered service to meet this need for space lift. Table 1 estimates the burn-out velocity of ballistic missiles, missile defense interceptors, and demonstrated anti-satellite (ASAT) weapon systems, as well as the characteristic velocities for artificial satellites in LEO, MEO, and GEO. The characteristic velocity is the linear sum of the magnitude of velocities imparted by maneuvers to place a satellite into its desired orbital position and is characteristic of the amount of energy that it takes to insert it in that location. Table 2 provides the performance capabilities of some current launch vehicles and historical ASAT weapon systems.[3] It is evident from these tables that artificial satellites are physically secure from direct attack due to their altitude above the Earth's gravity well and their speed of motion, since very large rockets are required to reach very high altitudes. This is in contrast to land-, sea- and air-based military systems that may face proximate or stand-off threats from terrestrially based weapon systems.

Launch campaigns starting with the delivery of satellites at the launch sites to the ignition of the space launch vehicles are not instantaneous activities. Much time is required to perform final checks and tests of both the satellites and the launch vehicles prior to their launch. This time line varies from a couple of days to several months depending on the space launch vehicle. Table 3 is indicative of launch readiness for several U.S. space launch vehicles.[4] The time needed to reuse the same launch facility could be comparable to these time lines for the larger space launch vehicles and could be shorter for the air-launched varieties. The implication of Table 3 is that launch preparation activities for the launch of heavy payloads, or of payloads to destinations beyond LEO, would be visible to reconnaissance assets well in advance of their launches. The simultaneous launch of heavy vehicles to attack a constellation of satellites would also be difficult to mount in a short period of time given the limited number of launch sites possessing the complex infrastructure needed to handle these large space launch vehicles. These inherent delays could offer terrestrial counterforce opportunities to protect space assets. Furthermore, unless this performance for space lift is improved, replacement times for degraded or destroyed satellites may also be lengthy.

In addition to these timelines, current satellites typically require 90 days of in-orbit testing prior to their entry into service. Without design improvements, reconstitution periods for satellites or satellite constellations could be prolonged further. LEO satellites may be designed for mission lives between two and seven years while MEO and GEO satellites may be designed to last between 10 and 15 years in-orbit without repair, after which they will need to be replaced. Space-based interceptors, should this threat emerge, would have to be replaced on a comparable schedule to provide an adequate state of operational readiness. Ballistic missiles carrying a nuclear deterrent are terrestrially based in part because of the physical security required to protect these strategic systems, the elimination of timing delays caused by an orbital weapon being at the wrong position within its orbit to strike a target within a specified period of time, and the launch and operational costs of basing a weapon in outer space that is not readily accessible for periodic repairs or upgrades. Orbital nuclear weapons are also prohibited by the 1967 Outer Space Treaty.

The Threat Environment for Space Systems

The space and ground segments of a space system and the electromagnetic links connecting them are vulnerable to a variety of threats. The greatest threats to space systems are in fact not to the space segment itself but are rather the physical, electronic, and information warfare threats faced by the personnel, facilities, and equipment comprising the ground segment and the links to and from the space segment. The ground segment of space systems are vulnerable to the full gamut of land-, sea-, and air-based military threats, conventional and nuclear. This segment of the space system is also vulnerable to unconventional threats, such as those that might arise from hackers and terrorists. Launch vehicles and the infrastructure necessary to place satellites in orbit are also particularly vulnerable given, in many cases, the siting of spaceports upon the coasts of space-faring states. Conversely, separated by vast distances from potential weapons and the large vehicles required to reach artificial satellites, the space segment of these systems currently face a rather low level of

Table 1
Burn-Out Velocities of Select Launch Vehicles, Ballistic Missiles, Anti-Satellite Weapons and Characteristic Velocities of Selected Orbits

Launch Vehicle or Orbit	Altitude (km)	Burn Out or Characteristic Velocity (km/s)
Short Range Ballistic Missile[1] (0 to 1,100 km range)	400	3.1
Medium Range Ballistic Missile[1] (1,100 to 2,750 km)	750	4.7
Intermediate Range Ballistic Missile[1] (2,750 to 5,500 km)	1,200	6.0
Intercontinental Range Ballistic Missile[1] (5,500 to 11,000+ km)	1,500	7.3
Point Missile Defense Interceptor[2]	200	1 to 2
Theatre Missile Defense Interceptor[3, 4]	750	3 to 6
National Missile Defense Interceptor[3, 4]	1,500	7 to 9
U.S. Direct Ascent ASAT[2, 5]	1,000	4
U.S.S.R. Co-orbital Polyot ASAT[5]	2,000	8
Circular Low Earth Orbit, i = 28.5E, (LEO)	185	7.8
Circular Low Earth Orbit, i = 90E, (POLAR)	800	8.1
Geostationary Transfer Orbit, i = 28.5E, (GTO)	185 x 35,786	10.3
Circular Semi-Synchronous Orbit, i = 55.0E, (MEO)	20,222	11.3
Circular Geostationary Orbit, i = 0.0E, (GEO), Equatorial Launch	35,786	11.7
Theoretical Escape Velocity (Surface of the Earth)	Infinity	11.2

i = inclination

[1] Approximation calculated after R. Bate, D. D. Mueller, and J. E. White, *Fundamentals of Astrodynamics* (New York: Dover Publications Inc., 1971) pp. 277-320 for a symmetric launch and re-entry profile.
[2] Approximation calculated after P. Sutton, *Rocket Propulsion Elements*, 3rd ed. (New York: John Wiley & Sons, 1963) pp. 116-149 for a vertical rocket.
[3] U.S. Ballistic Missile Defense Office, "U.S. Ballistic Missile Defense Program Focus," BMDO Fact Sheet 96-001, March 1997.
[4] M. A. Taverna and A. Natavi, "Fresh Look at BMD," *Aviation Week and Space Technology*, March 31, 2003, pp. 54-55.
[5] R. L. Garwin, K. Gottfried, and D. L. Hafner, "Antisatellite Weapons," *Scientific American* 250 (June 1984), pp. 45-55.

direct threat and this has had a bearing on the non-offensive defenses employed to date. Nevertheless, with concerns mounting over the survivability of space-based components of ballistic missile defense systems and the increased reliance of the United States on space for its national security, this section of the study briefly surveys the threats to space systems, dwelling particularly on threats to satellites, in preparation for a subsequent discussion of non-offensive defenses for space systems.

Threats to space systems can include: nuclear weapons; conventional weapons; directed energy weapons; electronic warfare; and physical, personnel, and information operations. Each threat capable of action against a satellite is discussed in turn.

Table 2
Performance of Selected Launch Vehicles[1]

Vehicle	Upper Stage	Payload Mass LEO (kg)	Payload Mass GTO (kg)	Payload Mass GEO (kg)	Payload Mass POLAR (kg)	Launch Site	Vehicle Mass[3] (tonnes)	Vehicle Length[3] (m)
Pegasus	—	455	125	—	265	Air	19.0	15.5
Taurus	—	1,450	375	—	1,180	Vandenberg, Cape Kennedy	73.0	27.9
Delta II 7925	PAM-D	5,045	1,820	910	3,830	Vandenberg, Cape Kennedy	231.9	38.1
Atlas II	Centaur	6,395	2,680	570	5,400	Cape Kennedy	187.6	47.5
Titan IVB	— IUS	17,700 —	— 6,350	— 2,380	14,110 —	Vandenberg, Cape Kennedy	943.1	44.0
Space Shuttle	PAM-D IUS	— —	1,300 5,900	— 2,360	— —	Cape Kennedy	2,029.6	56.0
MHV ASAT[2]	—	—	—	—	15 suborbital	Air	1.2	5.4
Polyot ASAT[3]	—	—	—	—	1,400 co-orbital	Baikonur	182.0	39.7

[1] W. J. Larson and J. R. Wertz, eds., Space Mission Analysis and Design (Second Edition) (Dordrecht: Kluwer Academic Publishers, 1992), pp. 674-675.
[2] D. Hobbs, *Space Warfare* (New York: Prentice Hall Press, 1986), pp. 84-97.
[3] www.astronautix.com

Nuclear Weapons

Nuclear weapons pose a severe threat to space systems. Aside from the targeting of the ground segments or launch infrastructure by the current inventory of intercontinental ballistic missiles, direct-ascent nuclear anti-satellite weapons could constitute a formidable threat to artificial satellites. Such systems owe their development to early nuclear test experiments conducted prior to the 1963 Limited Test Ban Treaty prohibiting all nuclear test explosions in outer space. The Starfish Prime nuclear test of July 9, 1962, by the United States illustrated the vulnerability of unhardened satellites. That test, a 1.4 megaton device exploded at a 400-km altitude above Johnston Island in the Pacific Ocean, caused the failure of six or seven satellites within seven months when electrons became trapped in the Earth's geomagnetic field.[5] The yield and the accuracy of a nuclear weapon detonated in space will determine the lethality of the weapon's explosion. Subsequent U.S. Squanto Terror or Project 437 ASAT tests using Thor intermediate-range ballistic missiles armed with simulated nuclear weapons were considered a success if they passed within 9 km (5 nautical miles) of their intended satellite targets. By 1965, some shots of this test series approached the targets as close as 1.6 km.[6]

Approximately 80 percent of all the energy from a nuclear weapon detonated in outer space appears in the form of X-rays. Other important effects include small amounts of gamma radiation and neutrons, as well as small fractions in residual radioactivity and in the kinetic energy of bomb debris. In addition to these primary effects, an electromagnetic pulse (EMP) is also caused by nuclear weapon detonations in space. Here X-rays and gamma rays impinge on the upper atmosphere of the Earth creating an electron flux that re-radiates its energy in the radio-frequency (RF) portion of the electromagnetic spectrum. As this RF energy arrives at the system, it induces currents and voltages that may damage or destroy electronic systems not hardened against these effects. System-generated electromagnetic pulse is an additional phenomenon caused when X-rays and gamma-rays hit a satellite or an internal component, thereby creating an internal flux of electrons whose interactions can create large currents and voltages that may damage sensitive components inside the satellite.[7]

Long after the detonation of a nuclear weapon in outer space, electrons created by the weapon would join the naturally occurring radiation in the Van Allen belts. The electron flux may increase by many orders of magnitude for a significant length of time, thus increasing the absorbed dose in unshielded materials as the satellite repeatedly traverses the Van Allen belts. Satellites not specifically designed for operations after detonation of a nuclear weapon may fail quickly in this enhanced radiation environment due to a rapid accumulation of total ionizing dose on the critical electronic parts of a satellite. According to one prominent report, satellites hardened to twice the natural radiation environment in LEO would fail within two to four months of the detonation of a 10-kiloton nuclear weapon over Japan at a 150-km altitude.[8]

Table 3
Launch Vehicle Readiness and Indicative Costs

Launch Vehicle	Time to Launch[1]	Costs[2]
Pegasus	2 days	$11M (1994)
Taurus	5 days	$20M (1999)
Delta 7925	23 days	$60M (1990)
Atlas II	55 days	$85M (1994)
Titan IV	100 days	$432M (1999)
Space Shuttle	150 days	$245M (1988)

[1] Anon., "Space Modular Systems," available at www.au.af.mil.
[2] U.S. dollars; www.astronautix.com.

Replacement satellites hardened to just 7 kilorads and destined for lower (800 km) orbits would fail rapidly if launched less than a year from the nuclear event. Replacements launched 18 months after the fact would enjoy near-normal lifetimes. The Globalstar constellation of 48 satellites plus four in-orbit spare satellites (assumed to be radiation hardened to 65 kilorads, or two times the natural radiation of a 1,400-km orbit), could be reconstituted six months after a nuclear event and enjoy a near-normal lifespan.[9] Geostationary satellites, in contrast, are typically hardened to 200 kilorads of natural radiation accumulated over their design life.

Finally, a nuclear weapon detonated in outer space will affect the adsorption of radio-frequencies by the Earth's atmosphere, especially between 60 and 80 km in altitude. Higher frequency transmissions are less susceptible to this effect than lower frequency transmissions.[10]

Russia, the United States, China, the states forming the European Space Agency (ESA), Ukraine, India, Israel and Japan all possess space launch vehicles capable of launching a nuclear warhead into orbit. In addition to these countries, Pakistan, Iran, North Korea, and Saudi Arabia possess medium-range ballistic missiles that could lob a nuclear warhead into outer space.[11] Not all of these states, of course, are known to possess such warheads. In addition, hostile acts can be deterred with the consequences of a robust response to such aggression. The likelihood of a terrorist acquiring both a nuclear weapon and a ballistic missile to explode it for its EMP effects is judged by U.S. Air Force General (ret.) Robert T. Marsh to be "so unlikely and difficult to achieve that I do not believe it warrants serious concern at this time."[12] Historically, both the United States and the former Soviet Union have demonstrated nuclear-tipped anti-satellite or ballistic missile defense interceptors. As ASAT weapons, nuclear weapons have several strategic, political, and legal disadvantages; they can only be used at the nuclear level of conflict and when they are used they may damage unhardened friendly and neutral satellites at ranges that can be very large. EMP effects can also harm the critical information and electronic infrastructure of industrial societies on Earth within the line of sight of the nuclear detonation. Finally, orbital nuclear weapons would contravene Article IV of the 1967 Outer Space Treaty; testing of nuclear weapons in outer space would contravene the 1963 Limited Test Ban Treaty; and exploding a nuclear warhead in outer space to modify the space environment for military purposes would be at odds with the 1977 Environmental Modification Convention.

Conventional Weapons

Artificial satellites could be threatened by conventional ASAT weapons consisting of air- or land-based direct-ascent kinetic energy kill interceptors, land-based short duration co-orbital explosive pellet interceptors, and long duration orbital anti-satellite weapons.[13] While the direct-ascent kinetic energy kill and the co-orbital explosive pellet ASAT weapon systems have been demonstrated by the United States and the former Soviet Union respectively, neither system is operationally deployed today, and both states have observed a voluntary ASAT test moratorium since 1985. As best anyone can glean from open source information, long duration orbital space mine ASAT systems are so far limited to the conceptual stage of development.

The U.S. F-15 launched direct-ascent Miniature Homing Vehicle ASAT weapon underwent a single test against a satellite target in 1985. It successfully demonstrated a hit-to-kill technology using a thermal infrared homing device. This system was never deployed operationally. More recent development of a dedicated kinetic-energy anti-satellite (KEASAT) system in the United States has never advanced to the integrated flight testing phase due to congressional and presidential funding decisions, as well as certain military resistance. The production of space debris that would accompany the direct application of military force in outer space could adversely impact U.S. assured use of outer space and therefore is working as a restraint against such developments. Terrestrially-based exo-atmospheric hit-to-kill interceptors of the currently proposed U.S. ballistic missile defense (BMD) system will also have an inherent, but thus far untested capability against satellites in LEO. Most BMD weapon technologies would in fact likely be useful in an ASAT role well before they reached the levels of power and precision needed for BMD.

Testing of the Soviet Tsyklon-launched Polyot short-duration co-orbital ASAT system began in 1968 and ended in 1982. This system used a SS-9 (R-36) intercontinental ballistic missile to launch a chaser satellite on a one- or two-orbit rendezvous trajectory, which when proximate enough, exploded a package of pellets at the target satellite. Up to 1981, the U.S. Air Force judged the Soviet tests successful if the explosive pellet warhead interceptor passed with 1 km of its target. After 1981, however, approaches within 9 km have been judged successful.[14] Overall, the Soviet co-orbital ASAT system had only a 50 percent success rate. Tests incorporating the radar homing sensor have had a 64 per cent success rate while all tests with an infrared/optical homing sensor seem to have failed. All interceptions have taken place at altitudes of less than 2,000 km, although some U.S. analysts claimed the Soviet system could attack satellites as high as 5,000 km.[15]

A long-duration orbital ASAT is a weapon launched into a storage orbit for an extended period of time before it maneuvers to engage a target satellite. Such an ASAT may be stand-alone or covertly embedded in a host satellite with a different and other innocent purpose.

A "Nearsat" is a satellite that would trail another satellite and explode either on command or when itself attacked to inflict harm on its quarry. A "Farsat" is a satellite parked in a storage orbit away from its target that maneuvers to engage the target on command. Space mines are parked in orbits that intersect the target's orbit and are detonated during a periodic close encounter. Of the three major space powers, it has been reported in the press that China is developing a "parasitic mine" to challenge U.S. space superiority.[16] Orbital interceptors of the Farsat and Nearsat variety would require the demonstration of a rendezvous capability with a non-cooperative target. To date, only the United States and Russia have demonstrated rendezvous and capture with manmade objects, while Japan and ESA have demonstrated rendezvous of spacecraft with celestial objects. Nearsats of the type China is reportedly developing would also require demonstration of non-cooperative automated rendezvous and capture in space that the United States has yet to perform.[17]

The correlation of orbits selected for Nearsats, Farsats, and space mines in relation to their maneuverable satellite quarries dispersed in constellations would likely reveal the deployment of these types of weapons well before their intended use. In a 1988 Office of Technology Assessment report on the survivability of the Strategic Defense Initiative (SDI), it was concluded that much more analysis would be needed to clarify the viability of space mines as a threat to the system.[18] The same report, however, also determined that the survivability of SDI implied unilateral control of certain sectors of space. Such control would be necessary to enforce "keep-out" zones against Soviet ASAT weapons or space mines during and after U.S. deployment of a space-based SDI system. For this reason, space-based kinetic energy interceptors were postulated to both defend critical SDI assets against ASAT weapons and attack ballistic missiles in the boost and post-boost phases. In the United States, experiments have recently been proposed for as early as 2008 to test space-based kinetic-energy boost phase intercepts of ballistic missiles that could possibly be used in such a counterspace role.[19]

Directed Energy Weapons (DEWs)

DEWs focus intense beams of electromagnetic energy or neutral particles to disrupt, deny, degrade, or destroy their targets from a distance. Fixed land-based high-energy laser (HEL) technology capable of degrading or destroying the sensitive components of satellites is available to the United States and Russia, as each of these countries continues research into advanced ballistic missile defense technologies. The United States has a high-power laser test facility at White Sands, New Mexico, and another at China Lake, California, while Russia has two Soviet-era experimental facilities at Sary Shagan, which it now must lease from Kazakhstan. As part of its missile defense program, the United States is developing an airborne laser testbed mounted on a Boeing 747. It plans to test this system against a ballistic missile in fiscal year 2004-05 as part of the block 2004 deployment of the missile defense program. Space-based variants of HEL systems are at least a decade away from deployment. The U.S. integrated flight experiment for demonstration of a space-based laser, originally scheduled for 2012, was recently canceled. China may already possess the capability to degrade or damage optical sensors on satellites under certain specific conditions and analysts believe that Beijing could probably develop ground-based ASAT weapons that could destroy satellites in the future.[20] Lower-power lasers, such as those used for precision tracking of satellites, may be used to disrupt or deny the use of sensitive optics on an unhardened imaging satellite. As many as 30 states may already be able to use low-power lasers to blind sensors on satellites.[21]

For engagement ranges of several hundred kilometers, the HEL laser spot size will be as large as the satellite itself. To degrade or destroy a satellite, the laser beam will need to hold steady long enough to deposit sufficient energy on the target. Depending on the incident flux level and the pointing stability, this dwell time could be several seconds to several minutes in duration.[22] HELs damage a satellite by overheating it and melting its "skin" or by tearing its skin as a result of the mechanical impulse that pulse radiation can generate on a target surface. Denial or disruption of artificial satellites requires significantly less powerful lasers.

High-power microwave (HPM) weapons are devices capable of producing intense, damaging beams of microwave radio frequency radiation. HPM generators could be used to overload and damage satellite electronic equipment. These generators could be land-based or space-based. The proximity of a space-based HPM to its target holds a range and atmospheric adsorption advantage over a terrestrial-based HPM. Space-based HPM systems will have to compete with space-based HELs for future deployment decisions, however, since both types of systems are heavy and expensive. Target satellites may also be hardened to greater certainty against HPM weapons than against HELs or neutral particle beams (NPBs).[23] NPB weapons, which may only be space-based, are considered to be more distant weapon developments than HEL weapon systems.

Electronic Warfare (EW)

Domination of the electromagnetic spectrum is a crucial component of modern military operations. EW can be defined as the use of the electromagnetic spectrum to deceive, disrupt, deny, degrade, or destroy an adversary's combat capability or to protect friendly combat capability from such harm. Electronic warfare has three fundamental subdivisions that are applicable to communication and non-communications (e.g., radar) EW.[24] Electronic support (ES, formerly electronic support measures) is the division of EW involving actions tasked by, or under the direct control of an operational commander to search for, intercept, identify, and locate sources of intentionally and unintentionally radiated electromagnetic energy for the purposes of immediate threat recognition and construction of an electronic order of battle. Electronic attack (EA) is the division of EW involving the use of electromagnetic energy to attack personnel, facilities, or equipment with the intent of deceiving, denying, disrupting, degrading, or destroying adversary combat capability. EA comprises jamming, electronic deception, and neutralization or negation. Jamming is the use of electromagnetic energy to prevent a radio receiver from receiving its intended signal and to disrupt (partially) or deny (totally) service on a temporary and reversible basis. Electronic deception involves the use of false or misleading transmissions to confuse an adversary. Neutralization describes the use of very high levels of electromagnetic energy to degrade or destroy electronic equipment on a permanent basis. Electronic protection (EP) comprises those actions taken to protect personnel, facilities, and equipment from any effects of friendly or adversary employment of EW that deceives, disrupts, denies degrades, or destroys friendly combat capability. Optical analogues to traditional radio frequency or electronic warfare exist as military systems increasingly make use of laser technology for communication, light detection and ranging (lidar), or imaging. Land-, sea-, and air-based EW techniques can be applied to the ground segment and links to and from the space segment of space systems. The transformation of airborne jammers to spaceborne jammers could be just one small development step away, as the U.S. Space Command Long-Range Plan, for example, identifies a spaceborne jammer capability as an important item for its future inventory.[25]

Non-Offensive Defenses

Given the expression of the threat environment above, it is possible to postulate non-offensive defense strategies to mitigate this environment for the ground, space, and link segments of a space system. With respect to the space segment of space systems, non-offensive defense measures include: denial and deception; maneuvering; hardening and shielding; electronic attack and protection; redundancy and reconstitution; and dispersion and deployment. The next section discusses each topic in turn and provides examples to illustrate current practices.

Denial and Deception

Denial and deception form a powerful strategy for the protection of space assets. Denial is the collection of means and methods useful to prevent an adversary from gaining valid information from its intelligence sources. Deception is the collection of means and methods useful to mislead an adversary into believing false information collected by its intelligence apparatus. One example of denial applied to satellite survivability is the classification of orbital element information collected by space surveillance networks. These orbital elements are necessary to predicting the future location of satellites from their past observed positions. While the United States possesses the world's best space surveillance network, it naturally does not publish the orbital elements for its classified satellites, as this information could be used by adversaries in their denial and deception activities. There was a time when NORAD two-line orbital elements for all non-U.S. satellites were made available on the Internet. Today, official dissemination of this information is limited to those with a genuine need to know and new visualization programs have been developed by NASA to satisfy the public's curiosity with regard to the location of satellites without divulging these data.[26] A variety of non-governmental organizations and hobbyists have stepped in to fill the void, but their information does not carry the accreditation of the U.S. Space Command. This denial practice makes it more difficult for potentially hostile nations to track friendly satellites from among 8,000 other space objects without investing in their own expensive surveillance network.

Another denial technique in current use is the reduction of electro-optical and electromagnetic signatures for artificial satellites. Prior to 1990, GEO communication satellites would be covered with gold-anodized kapton thermal blankets to protect the spacecraft from the extreme heat and cold of outer space. Since 1990, many of these thermal blankets have been supplanted with black carbon-impregnated kapton thermal blankets to improve the surface conductivity of these satellites and to reduce their optical signatures. This change makes it harder to track satellites with optical sensors and raises the cost of space surveillance networks needed to obtain the orbital element information necessary to attack such satellites. Similarly, the use of radar absorption materials can be postulated for critical LEO satellites in the future. Signature denial measures can be designed into the configuration of an artificial satellite to keep heat sources hidden from terrestrial observation and to reflect radar energy in directions other than those returning to the source of illumination. Operating a satellite at very low altitudes can make a satellite difficult to detect using space-based infrared sensors that must view it against the radiant Earth or Earth limb background. Miniaturization of satellites can also help hide missions from observation by space surveillance networks.

Deception is another effective passive space protection measure. Satellites are not all regarded as equally threatening. Communications satellites are far less threatening than reconnaissance satellites and reconnaissance satellites are far less threatening than space-based ASAT weapons. No artificial satellite would be more threatening than a space-based laser capable of reaching through the atmosphere to destroy targets on the Earth. This mission differentiation would afford an opportunity for one satellite to try to mask itself as another, or to carry an unrelated piggyback payload on its platform. Critical payloads could then be made more survivable by hiding in the operational shadows of the primary mission. Nuclear detonation detection and location sensors, for example, have flown on navigation satellites as well as on early warning satellites.

The operational status of a satellite is as important to an adversary as the type of satellite and the mission it performs, since "dead" satellites do not need to be negated. Consequently, satellites that play possum hold some potential for the survivability of critical satellite systems.

One illustration of this technique is thought to have occurred when the United States first replaced photographic return film satellites with electronic imaging satellites and began using satellite-to-satellite relay links to hide earlier overseas satellite-to-ground station transmissions. It is believed that the Soviet Union thought that this mission had failed shortly after the launch when the satellite did not return film capsules. Similarly, satellites that are decommissioned before they fail catastrophically may be resurrected at a later date. It is also conceivable that reportedly failed satellites may never have failed at all.

The use of decoys is another classic deception technique to increase the survivability of critical military missions. Decoys can force an enemy to waste firepower on false targets or to withhold fire for fear of doing so. To be effective, decoys must be sufficiently realistic to the space surveillance network of a potential adversary. Decoy satellites do not appear to have been deployed as yet given the rather sparse threat environment. Decoys can be expensive and do not result in any additional capability. Therefore, inactive redundant versions capable of later activation may be a preferred approach for space system survivability.

Hardening and Shielding

For each type of ASAT weapon, there exist defensive hardening techniques that can reduce the range at which the weapon is effective. Hardening of a space system's elements is the single most effective action that can be taken to improve its survivability.[27] The aim of nuclear hardening is to prevent harm from a distance so that an opponent must get close to each satellite in order to destroy it. The Milstar and DSCS III communications satellites, the GPS navigation satellites, and the Defense Support Program (DSP) early warning satellites are all examples of U.S. satellites that are hardened to withstand nuclear attacks. Satellites may be hardened to withstand the effects of nuclear weapons by avoiding reliance on photovoltaic cells for power (solar cells are vulnerable to X-rays and the enhanced radiation produced by high-altitude nuclear weapon detonations) or by covering more radiation resistant solar cell types with fused silica. Selecting radiation hardened components to build fault-tolerant designs and shielding them against electrons and protons are effective hardening means that must be carried out to some extent in any event, given the natural radiation environment. Gamma radiation is particularly penetrating but constitutes little of the total energy of a nuclear explosion in outer space. X-ray hardening is therefore performed on many existing military satellites, to the degree sufficient to reduce the prompt radiation dose to levels approximately equal that of the gamma radiation.

To prevent damage from high-altitude EMP effects, metal shields can keep the radiation from entering the satellite cavities. Good external grounding, interconnection of all conducting parts and surfaces, surge arresters, and the elimination of sensitive components are typical hardening techniques. System-generated EMP (SGEMP) effects can also be quite harmful to unhardened spacecraft. Faraday, magnetic and electro-optic shielding, and fault-tolerant electronic designs are possible hardening measures against such effects. Internal surfaces may also be coated with low atomic number paints to reduce internal electron emission into cavities. Input and output circuits and terminals can be protected with various devices such as zener diodes, lowpass filters, and bandpass filters to limit current or clamp voltages caused by SGEMP.

Circumvention is also an important hardening strategy for high-altitude nuclear weapon detonations. Circumvention consists of partitioning the satellite design into those functions that must operate during a transient nuclear weapon effect from those functions that do not need to operate throughout that event. When the prompt nuclear event is detected by onboard sensors, protection circuits for non-essential functions can be "switched in" for the subsequent secondary effects of a nuclear detonation in outer space. When the prompt nuclear event has transpired, these protection circuits can be "switched out" as appropriate to return to normal operation. Component hardening and fault-tolerant designs are then used for all those functions that must survive the initial high dose rate event of a nuclear weapon explosion. This hardening strategy can be less expensive than hardening all of the satellite to operate throughout the full effects of a high-altitude nuclear weapon explosion.

Directed radio-frequency (RF) weapons generate a beam of RF energy intense enough to damage or interfere with satellite electronics. A satellite's antenna tuned to receive a frequency the weapon radiates will amplify the received radiation to the sensitive electronics in the satellite's interior. It can thus damage unprotected amplifiers or downconverters in the front end of a receiver. Antenna-nulling techniques, over-voltage, and over-current protection circuits harden satellites against high-power microwave threats. Switching incoming signals to a dissipating load instead of an active receiver can protect the satellite at the cost of a temporary service interruption. Planar array antennas are more adept at antenna-nulling than horn and reflector antennas, but this ability comes at the expense of increased cost and mass. The DSCS III satellite, for example, uses a planar array antenna system. The aforementioned techniques for hardening satellites against nuclear weapon effects, such as EMP, can also harden a satellite against high-power microwave weapons. Autonomous satellite operations will meanwhile increase the survivability of satellites in the event a ground control station or the control signal uplinks to a satellite are interfered with for extended periods. Mobile ground stations are also survivability features for space systems.[28]

Hardening against laser weapons could become more important as this emerging threat evolves. Survivability methods can include optical shutters or special filters to protect sensitive imaging sensors from intense laser illumination produced by terrestrial facilities. The use of multiple frequencies is another hardening technique. The sensors on the early-warning DSP satellites, for example, use two thermal bands to detect missile launches in the presence of a laser threat capable of jamming only one of the two bands.[29] Off-nadir viewing capabilities for imaging satellites means an adversary on the ground illuminating a satellite from directly below will not necessarily affect the data collection by an overhead satellite. Illumination warning sensors on satellites could also geo-locate the source of illumination and relay these co-ordinates for a terrestrial counterforce response. A satellite may also use GPS signals or additional light-baffled star trackers to ascertain its attitude in addition to its normal reliance on the Earth and sun sensors of its attitude control subsystem. In the future, satellites may incorporate ablative coatings and mount structurally isolated or dampened shields exterior to the main spacecraft body, as well as utilize spin stabilization to protect these satellites from HEL effects. These are similar to the countermeasures that ballistic missiles might employ in a threat environment containing boost phase air- or space-based laser BMD systems.[30]

Hardening against neutral particle beams (NPBs) could draw from techniques developed for nuclear hardening that would have preceded the long development of these types of exotic weapons. Relatively little shield mass would be required to protect a satellite from a beam of low-energy particles (up to 100 Mev), but the shield mass would rise sharply if particles were produced by more powerful NPBs.[31]

Mechanical shielding using so-called "multiple Whipple bumper" technology,[32] developed for the International Space Station against micro-meteoroid and space debris hazards,[33] as well as the technology developed by NASA, ESA, and the National Space Development Agency of Japan for comet missions, could be adapted for use to shield satellites from explosive pellets of co-orbital ASAT weapon systems. Additional shielding may be employed around the satellite batteries and onboard propellant system to protect these vital subsystems from catastrophic damage. Re-routing of critical wire harnesses are additional design recommendations for enhancing spacecraft survivability against the damage caused by space debris. Repairable or replaceable solar arrays employed within a space infrastructure that includes in-orbit robotic servicing could also contribute to satellite survivability. Given the difficulty of shielding against hypervelocity impacts of kinetic- energy kill interceptors weighing 15 kilograms or more, satellite maneuverability may be a more promising defensive strategy as the shielding mass could be spent on rocket fuel to avoid being hit by an approaching interceptor.

Maneuvering

Satellites may maneuver in order to complicate enemy surveillance and targeting or to evade enemy fire. A maneuver is an action in outer space that changes the orbital elements of the satellite. In the current threat environment, satellites other than some reconnaissance satellites are not known to carry fuel for maneuvers to evade deliberate attack. All operational satellites possess a planned amount of fuel to maintain their orbital positions in the face of disturbances caused by natural phenomena.

Satellite orbits are predictable in the absence of maneuvers performed in the interval between observations. This makes reconnaissance satellites particularly susceptible to denial and deception activities by those who do not wish to be observed or those who wish to deceive the observer with decoys. To overcome this limitation, such satellites may perform periodic maneuvers to re-establish the surprise of overflight observation, which may be effective given current limitations in major space surveillance networks, including those of the United States, Russia, and China. With more than 8,500 man-made objects and about 500 active satellites in orbit, space tracking systems do not simultaneously track all objects in orbit; rather, the space objects are observed on a "duty cycle" basis. If the duty cycle is not real-time observation, it is possible for space objects to disappear until new observations re-establish contact. Inclement weather can also affect the optical observation of satellites from the ground. Satellites that can avoid observation cannot be targeted by terrestrially-based direct ascent or co-orbital satellites. Similarly, counterforce operations taken against terrestrial space surveillance networks can confound an enemy by denying access to the information necessary to guide the orbital interceptors to their targets.

It is not a viable strategy to perform maneuvers to avoid LEO orbital passes over fixed terrestrial ASAT weapon sites, since multiple engagement opportunities can accrue every day. Mobile direct ascent ASAT weapons or ballistic missile defense systems can further reduce the effectiveness of this type of evasive maneuvering by dispersing the systems in a manner unknown to the satellite operator. In order to evade an interceptor continuously, whether direct ascent or co-orbital, a satellite will need to have an acceleration capability and a velocity change capability about equal to that of the interceptor, more or less depending on initial positions and velocities. Maximizing the acceleration and velocity change parameters of a satellite to perform evasive maneuvers can be attained at the expense of the payload. Because an interceptor's mass can be made quite small, it could, however, be difficult or costly to design a satellite that could perform its mission effectively as well as evade specialized ASAT interceptors. Table 4 illustrates this further with mass and fuel mass fractions for a terrestrially based ASAT system, a verification satellite designed for co-orbital rendezvous (Paxsat A), and a previous generation communication satellite. It is evident from the Intelsat V and the Paxsat A comparison that a useful payload mass can be carried by a heavier satellite loaded with fuel for maneuvering, but only at the cost of procuring a larger launch vehicle. Separately, limited orbital maneuvers have been performed by spacecraft in LEO, notably the Space Shuttle and the International Space Station, to evade orbital debris. In the future, orbital transfer vehicles (upper stages designed for long duration in-orbit operations), when docked with critical satellites, could be employed to provide a refillable evasive maneuver capability for satellites.

Once a direct ascent or co-orbital ASAT interceptor has been launched toward a satellite located in LEO, MEO, or GEO, the weapon has committed a significant amount of its finite fuel to arrive at a given place at a given time. This commitment of the interceptor may be exploited by the target satellite (e.g., by evasive maneuver) given the time of flight required to reach it. The times of flight for select orbit transfers are illustrated in Table 5. These times represent minimum energy (or so-called Hohmann) transfers, and faster intercept times may be obtained at the expense of more rocket fuel to transit on faster trajectories.

As an extreme example of this delay, the co-orbital approach of the terrestrial Soviet ASAT weapon meant that launch needed to wait until the longitude of the launch site matched that of the target satellite's orbital plane, an event that happened only twice per day. This introduced an average lag of six hours between the decision to attack a LEO satellite and the launch of the interceptor. Typical launch campaigns from ignition of the space launch vehicle to placing satellites into the proper orbital slot can also take several revolutions of the elliptical transfer orbit to phase the transfer orbit with the desired injection point of the operational orbit. It is not unusual for satellite launch campaigns to the geostationary orbit to last a couple of days. Similarly, given an orbital interceptor that is fuel restricted, a period of time will need to pass for the orbit of the satellite interceptor to align with that of the target satellite. These phasing and time of flight intervals may permit the target satellite to take evasive maneuvers that could in turn raise the cost of maneuvers for the interceptor.

Even with these advantages, however, a target satellite could out-maneuver or outrun the interceptor only if it has budgeted fuel for such evasive operations and only if it were designed from the outset to include the rocket engines and structural designs, especially those for solar arrays, reinforced to withstand the accelerations of the evasive maneuvers. Retrievable solar arrays have been developed for past spacecraft missions, notably the Olympus mission of the European Space Agency and the Hubble Space Telescope mission of NASA. In-orbit refuelling options such as the Orbital Express mission of DARPA and orbital transfer vehicles (space tugs) also under current development may present new opportunities for satellite survivability based on enhanced satellite mobility, modularity, and robotic servicing capabilities.[34]

Electronic Attack and Protection

Satellites that are approached by anti-satellite weapon systems may use a number of airborne decoys and analogues to confound the terminal homing device of the interceptor. These include passive and active measures. If the terminal homing vehicle uses radar, the target satellite may explode a volume of chaff in which to hide. Should the volume of the chaff be larger than the satellite, an ASAT interceptor may miss the target satellite. Similarly, flares mimicking the thermal dissipation of a target satel-

Table 4
Mass Fractions for a Land-Based ASAT, a Maneuverable Verification Satellite and a Geostationary Communication Satellite

	U.S. ASAT	PAXSAT A[1]	INTELSAT V[2]
(A) Payload Mass	15 kg	273 kg	234 kg
(B) Fuel Mass	1,000 (est.)	3,000 kg	861 kg needed for the apogee kick motor 173 kg needed for station-keeping on-orbit
(C) Total Mass at Launch	1,200 kg	4,466 kg	1,869 kg 1,008 kg Beginning of Life (BOL)
Payload Mass Fraction (A/C)	1%	6%	13%
Fuel Mass Fraction (B/C)	83%	67%	55% 17% BOL
Delta-Velocity (capability for orbit changes)	4 km/s (est.)	3 km/s	2.3 km/s total 0.5 km/s BOL

[1]Anon., "PAXSAT A Study of the Feasibility of a Spacecraft-Based System to Determine the Presence of Weapons in Space," Spar Aerospace Limited Brochure, Montreal, November 1984.
[2] B.N. Agrawal, *Design of Geosynchronous Spacecraft* (Englewood Cliffs, NJ: Prentice-Hall Inc., 1986), pp. 37-39.

lite may divert an interceptor that uses a rudimentary thermal imaging sensor. Electronic and optical countermeasures need not be restricted to passive means alone. Satellites could use or deploy active emitters to spoof or jam the homing device of the ASAT interceptor. Spoofing refers to transmitting signals that lead the interceptor to a virtual target instead of tracking the real target. Both radar and lidar (light) means have been developed for terrestrial use and these could be space-qualified as necessary to defeat future anti-satellite weapon threats. While such measures may begin to take on the characteristics of offensive weapons, it may be possible to define space-based weapons in terms of aperture-power-range thresholds, as had been done, for example, to distinguish air defense versus ballistic missile defense radars within the 1972 ABM Treaty context.

Redundancy and Reconstitution

Space is a harsh environment in which on-site repairs are not usually cost-effective at the present time. Satellites therefore eschew single point failures in their designs to the maximum practical extent. Prime and redundant electronics are typically used on all current spacecraft to enhance service reliability. Redundancy is not just practiced within a satellite. Most GEO communications satellites are bought in pairs and separately launched into orbit to provide system-level redundancy. The proliferation of satellites as in-orbit spares will increase the survivability of the space system against attack as a whole and significantly raise the cost of destroying a functional capability. Given a launch-on-demand infrastructure, on-ground spares can also be launched into orbit to reconstitute a satellite system negated by ASAT weapon activity. Table 3, however, illustrates that launch-on-demand is not a current global capability for large satellites, but could be achieved for smaller satellites if the necessary investments are made in this type of infrastructure. Proliferating satellites may not preserve the functioning of a constellation of satellites, however, if the spares can be identified and negated after being brought on-line. Consequently, the use of spares is made more attractive if an enemy's terrestrial ASAT operations can be negated by terrestrial counterforce operations.

Dispersion and Deployment

Dispersion is a well-practiced art in terrestrial conflict and the same can be made true for space. The deployment and

Table 5
Time of Flight for Select Minimum Energy Orbit Transfer Maneuvers

Maneuvers	Time of Flight
U.S. Direct Ascent ASAT	15 minutes (est. based on visibility)
Former Soviet Union Co-Orbital ASAT	3 hours (2 orbit intercept)
Launch to Burnout of an ICBM[1]	3 to 5 minutes up to 400 km altitude
Launch to Injection of a Delta Launch Vehicle[2]	27.5 minutes up to 185 km altitude
LEO Parking to LEO Operational (185 km to 800 km)	0.8 hours
LEO Parking to MEO Operational (185 km to 20,222 km)	3.0 hours
LEO Parking to GEO Transfer Orbit (185 km to 35,736 km)	5.2 hours

[1] U.S. Congress, Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control*, OTA-ISC-281 (Washington, DC: U.S. Government Printing Office, September 1985).
[2] G. Maral and M. Bousquet, *Satellite Communications Systems*, (New York: John Wiley & Sons, 1982), pp. 306.

use of constellations of satellites increase the number of targets that must be negated to eliminate a system capability. Constellations can also use the Earth as a shield from the effects of nuclear weapon bursts in outer space. Consequently, constellations are more survivable than solitary spacecraft. A prime example of a constellation is the Iridium mobile communication satellite system consisting of 66 satellites and seven in-orbit spare satellites. Other concepts including the Skybridge and Teledesic broadband communication satellites are also promising developments.[35] The satellite-to-satellite link capabilities of these constellations will help mitigate susceptibility to EW jamming threats as compared to systems involving extensive space-to-ground linkages.

Modular satellites can also contribute to system survivability. In this case, the function of a larger satellite may be performed by numerous small satellites. A prime example might be a future replacement for a sophisticated radar satellite. Instead of putting coarse and fine resolution synthetic aperture radar payloads on one large satellite, new capabilities in terms of timeliness and surveillance effectiveness may be attained by flying a fine resolution sensor separately from and following a coarse resolution sensor. This way, the targets on the ground may be detected in the first instance and classified with the pass of the second satellite. Should an ASAT attack eliminate one of these satellites, the system would still have the benefit of the other.

Higher altitude orbits may be used to avoid the direct ascent capabilities of terrestrial ASAT weapons without necessarily diminishing capabilities. For example, the development of larger aperture optics for astrophysical scientific research could be applied to the reconnaissance missions of the future. The so-called Next Generation Space Telescope,[36] with a mirror aperture of six meters diameter, has a mirror 2.5 times larger than that of the Hubble Space Telescope. Placing larger diameter optics in higher orbits can increase satellite survivability by using orbits higher than the ceilings of air-launched ASAT weapons. Launching larger diameter optics into Molniya-type orbits can also improve satellite survivability by exploiting the increased velocity of the low-perigee pass, making the satellite harder (and more expensive) to hit.

Lower-altitude orbits may also be used to survive ASAT weapons without necessarily degrading performance. If a space maneuver vehicle[37] or military spaceplane were to fly at an altitude of 100 km instead of the normal photo-reconnaissance altitude of 300 km, then the diameter of the optics in the bay of the vehicle could be one-third that of the photo-reconnaissance satellite without any loss in resolution. Use of a space maneuver vehicle could also gain an element of surprise because it is not confined to a predictable orbit. Such a vehicle might also exploit an ambiguity in interceptor homing technology by flying at altitudes too high for endo-atmospheric interceptors but too low for exo-atmospheric interceptors. A military spaceplane will also have wings that can be used for orbital plane change maneuvers instead of fuel-expensive inclination changes performed by rocket burns. Space maneuver vehicles would be launch-on-demand, repairable, up-gradable and reusable assets. They could also be used to reconstitute small satellite constellations. Dispersal of such vehicles would also reduce the risk to launch infrastructure counterforce operations.

Alternate means could also be practised at the system-of-systems level. Here, choosing the right mix in terrestrial and space technologies and capabilities could introduce redundancy and eliminate over-reliance upon any single domain of the aerospace continuum. Land-, sea- and air-based mobile communications and intelligence assets deployed in the theater of operations, for example, could offset or supplement reliance upon space assets in times of hostility. Unmanned air vehicles and air-to-air data links show particular promise in this regard, as increased procurements will bring down current costs.

Electromagnetic Links

The experience of terrestrial systems in electronic warfare has migrated to space systems. Current state-of-the-art military communications satellites, Milstar, for example, use frequency agility or hopping, extra-high and super-high frequency links and satellite-to-satellite crosslinks to ensure the survivability of these assets from peacetime through nuclear war. Beam-nulling for anti-jamming purposes, as, for example, used on the DSCS III military communication satellite system, also contributes to protecting the links against electronic attack.

Ground Segment

Mission control facilities and user terminals for critical military satellite assets are hardened to survive nuclear engagements. Hardening against EMP effects and having redundant and dispersed assets contribute to this survivability. Physical security, personnel security, and information assurance means (such as firewalls, encryption, and air gaps between external communication lines and the computer system commanding the satellites) are prudent investments in today's threat environment.[38] The mobility of some assets further assists in meeting the challenge. Terrestrially-based electronic attack and electronic support capabilities provide additional levels of defense for critical space systems of major space-faring nations.

Are Non-Offensive Defenses for Real?

The answer to this question depends on the threat environment in which it is asked. Currently, the threat environment is comparatively low for the space segment of critical military systems and satellite survivability has thus far been applied at levels appropriate to such a threat level. Hardening against nuclear and electronic warfare threats and use of high- altitude orbits, as well as increasing maneuvering fuel budgets for LEO satellites, have all contributed to satellite survivability. The continued absence of a threat would enable the current practice to hold. This survivability, however, has come with an attendant cost, as Milstar satellites cost $800 million each.[39] Table 6 illustrates satellite survivability options, including an indication of costs and effectiveness for non-offensive defense strategies.

The threat environment is not static. The development of new threats, including the possible deployment of space-based weapons, as well as advances in miniaturization and maneuvering technology or a shift in reliance on military systems to commercial systems could alter this threat perception in one direction or another. Evolution is also the norm in the development of technologies and system improvements necessary for some of the non-offensive defenses to be fully exploited for survivable space systems. In order to protect space systems in new environments, improvements must be made in the space surveillance networks of the major space-faring powers. Near real-time, 24 hours per day, seven days per week surveillance is required for all space activities, including space surveillance assets deployed in outer space. Improved systems are needed not only to detect and track objects but also to collect in-orbit intelligence sufficient for technical analysis to discern the evolution of threats. This may require co-orbital observation as well as fly-by observations. Space activities must be monitored in order to detect threats well in advance of an actual attack on space objects. On-board satellite monitoring and reporting devices must be developed to discern attack conditions from natural phenomena. Many of these developments have been identified in the Long-Range Plan for the U.S. Space Command and in the Joint Warfighting Science and Technology Plan.[40]

Table 6
Satellite Survivability Options[1]

Option	Cost	Effectiveness	Features
Satellite hardening	2-5% of total cost of a satellite	Very good	Trapped electron shielding, prompt radiation shielding, latchup screening, radiation tolerant electronics, degraded electronic part de-ratings Example: Milstar
Redundant nodes	Cost of one node times the number of nodes	Good	Essential functions performed by two or more nodes (e.g. satellites with overlapping coverage but separated by greater than one lethal diameter range) Example: Iridium
Onboard decoys	1-10% of total cost of satellite	Good, depending upon type of threat guidance	Credible decoys simulating both radar and optical signatures of the satellite; decoys are launched when an attack is detected (detection system is required) Example: not used
Maneuver capability	10-20% of total cost of a satellite	Good, depending upon type of threat guidance	Thrust levels depend on satellite altitude (warning time), nature of threat, threat detection efficiency; additional satellite weight for high acceleration Example: reconnaissance satellites
Autonomous operations	3-8% of total cost of satellite	Protects against loss of ground station	Autonomous orbit control (e.g., station-keeping for GEO orbits), momentum control, redundant unit control (fault detection), and substitution Example: GPS
Mobile ground control stations	2 to 3 times the total cost of a large ground station	Very good; provides very survivable ground control station network	Multiple mobile ground control stations; while one is tearing down, one is setting up, and one is changing its location; survivability is achieved by physical location uncertainty Example: GPS and DSP satellites
Onboard attack reporting system	1-5% of total cost of a satellite	Essential for total system survivability	System records or reports time, intensity, direction of all potentially hostile events; allows an appropriate military response Example: under development

[1] W. J. Larson and J. R. Wertz, eds., Space Mission Analysis and Design (Second Edition) (Dordrecht: Kluwer Academic Publishers, 1992), p. 228.

For maneuvering defense mechanisms to be made truly effective, the command and control of critical satellite systems will need to be improved to make better use of the situational awareness created by an improved space surveillance network. Emergent technology demonstrations such as DARPA's Orbital Express Refillable/Upgradable spacecraft and the Autonomous Space Transfer and Robotic Orbital (ASTRO) vehicle needs to be encouraged, as these maneuvering, refuelling, and robotic servicing technologies can improve the survivability of space systems.[41] Boeing's Space Maneuver Vehicle (X-37) also holds great promise in improving the survivability of critical space systems by providing a multi-mission platform truly capable of launch-on-demand.[42,43] The further development of space tug systems, such as long-lived orbital transfer vehicles, can also improve the survivability of critical space systems without necessarily requiring the application of force from outer space.

Conclusion

Examples of denial and deception, hardening and shielding, electronic attack and protection, redundancy and reconstitution, and dispersion and deployment decisions are all in evidence in existing space systems to meet the challenges of the current threat environment. Advances in constellation architectures, in-orbit servicing, and improved launch readiness for small satellites can all contribute to more survivable space systems. As these developments progress, architectural decisions will need to be taken to ensure that a robust space capability is available when it is needed. A mix between terrestrial and space systems for the missions performed in both domains will need to be properly balanced. A choice over whether the military should make use of commercial systems will also loom large, especially when it is unlikely that these systems will be hardened to the same degree as military systems. Architecture decisions are needed with respect to a continuing reliance on "big birds" when perhaps a "flock of canaries" may be more survivable, since space segments consisting of dispersed constellations cannot be neutralized simultaneously and without ample warning.

Protection of space systems must not only examine space segments but also the threats to ground segments and the links between them. Improved launch infrastructure, terrestrial space surveillance, and command and control nodes all need to be examined—lest any single link become the weakest. At the same time, the vulnerability of the ground segments of space systems and the infrastructure necessary to support these ventures will present opportunities to disrupt attacks on space assets by interfering with the ground launch and control operations of hostile space-faring nations. The threat of such military operations against the terrestrial infrastructure needed to wage offensive operations in outer space using existing terrestrial military assets may in fact be sufficient to deter hostile actions taken against satellites.

Clearly, the assured use of outer space is best managed in the absence of space-based threats. If a mix of offense and defense is prudent, terrestrial military means are available for counterforce missions without fielding the instruments of war in outer space. One last non-offensive defensive means to ensure space security may therefore be to negotiate, sign, and ratify a verifiable multilateral treaty banning the deployment of weapons in outer space. The consequence of such deployment may be more crucial than a silenced pager resulting from a single point failure in a non-redundant node of a communications network.

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[1] J. Pelline, "Outage hits pagers, Net access," CNET News.com, May 21, 1998, <http://www.news.com>.
[2] These orbits typically have periods of one-half of a sidereal day (four minutes short of 24 hours approximately).
[3] W.J. Larson and J. R. Wertz, eds., *Space Mission Analysis and Design* (Second Edition) (Dordrecht: Kluwer Academic Publishers, 1992), pp. 676.
[4]Anon., "Space Modular
[7] Larson and Wertz, *Space Mission Analysis and Design*, pp. 215-228.
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[9] Ibid.
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[11] J. Cirincione, "The Declining Ballistic Missile Threat," Testimony of Project Director Joseph Cirincione before a special meeting of the Danish Parliament (the Folketing), April 24, 2003, <http://www.ceip.org>.
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China's Space Program: Emerging Competitor or Potential Partner?

by Brian Harvey

China's space program is one of the least well known in the world. This may well change if, as many people expect, China launches its first manned spaceship in the fall of 2003. By the time of the Beijing Olympics in 2008, there may be two space stations in Earth orbit: the International Space Station—a project of the United States, Russia, Europe, Canada, and Japan—and a Chinese space station. By then, China is also expected to have flown its first unmanned space probe to the Moon. It is also not beyond the realm of possibility that China will send the next manned mission to the Moon. The visionary writer, Arthur C. Clarke, long appreciated the ability of the Chinese to surprise us. In *2010*, his sequel to *2001: A Space Odyssey*, Clarke depicts Russia and the United States mounting a joint expedition to Jupiter. At the last moment, they are overtaken by a Chinese spaceship appropriately called the *Tsien Hsue Shen*, named after the father of the Chinese space program.

This study reviews the history of the Chinese space program and identifies its defining characteristics. The program is then discussed from an international perspective. The conclusion of this study considers the policy environment likely to surround future developments regarding Chinese space activities and possible strategic implications, particularly for the United States.

Early History

China's space progress should, in some respects, not surprise us. Besides China's invention of the rocket in 970, the country is an ancient civilization that developed chemistry, invented the suspension bridge, laid the basis for modern medicine, and made astronomical observations that have stood the test of time. But China's achievements were set back by war and invasion—at the hands of Western countries in the 19th century and by Japanese conquest in the 20th. But the recent origin of the Chinese space program benefited from unexpected U.S. assistance. By the 1930s, China was sending its scientists abroad to study. One of these was Tsien Hsue Shen, the studious sun of an educational official, who went to the United States in 1935.[1]

Tsien graduated with a Ph.D. in mathematics in 1939 from the California Institute for Technology (CalTech). Five fellow CalTech students and associates invited him to join a group interested in what would now be called amateur rocketry. They were a group of experimenters buying up spare parts, assembling them, and setting them off in the nearby desert. Tsien was, in effect, the mathematics advisor to the group, in 1937 writing his first work on rocketry entitled. Their first, often dangerous, experiments were presented to the Institute of Aeronautical Sciences and written about locally in the student press, where Tsien made some bold comments about the possibility of eventually sending rockets 1,200 kilometers (km) into space. Like fellow rocketeers in Germany and the Soviet Union, they soon found attracted funding from the U.S. military, which saw the potential for rockets both to make aircraft fly faster and to fly as ballistic missiles. Military funding rose from $1,000 to $650,000 in five years. By 1942, after the United Sates entered the war, Tsien was working on small solid rocket motors to help aircraft get airborne; shortly afterwards, he helped to draw up plans for a missile program.

Tsien became an assistant professor of aeronautics in 1943. He was one of the co-founders of the famous Jet Propulsion Laboratory (JPL), which subsequently devel-

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oped U.S. unmanned probes of the Moon, the nearby planets, and the outer solar system. He was the first head of research analysis at JPL in 1944. By the following year, he was working in the Pentagon advising the U.S. military on how to harness the latest discoveries in aeronautics and rocketry for the post-war defense forces (he later received a commendation from the U.S. Air Force for this work).

In May 1945, having been given the temporary rank of colonel in the U.S. Air Force, Tsien arrived in Germany to survey Nazi wartime achievements in rocketry, their rocket factories, and secret test sites. On May 5, he met the leading German rocket engineer, Wernher von Braun, who had just surrendered to the Americans. Not long afterwards, the man who was to be his opposite number in the Soviet Union, chief designer Sergei Korolev, was scouring other nearby parts of Germany on an identical mission.

Returning to JPL, Tsien published his wartime technical writing in a book called *Jet Propulsion*. After a stint at MIT in 1946-48 and a brief visit to China in 1947 (to get married), he became the Robert Goddard Professor of Jet Propulsion at CalTech in 1950. He gave a presentation to the American Rocket Society in which he outlined the concept of a transcontinental rocketliner able to fly 400 km above the Earth. His proposal was later covered in *Popular Science*, *Flight*, and *The New York Times*. The following year, he predicted that astronauts would travel to the Moon within 30 years. Some of his rocketplane ideas inspired the U.S. Air Force to develop its spaceplane project of the late 1950s, the Dyna-Soar (standing for "dynamic soaring"), ultimately one of the ancestors of the U.S. Space Shuttle.

But, in 1951, at the height of the McCarthy witch-hunt in the United States, Tsien was accused of being a communist. A period of confusion followed, in the course of which Tsien had his security clearance revoked. He was held alternately in jail, under a form of house arrest, and under surveillance, still unsure of his ultimate fate. The various bureaucratic factions of the U.S. government argued about whether he should be released, jailed, or deported. As they did so, Tsien continued to work, investigating problems of rocket guidance and how computers could steer rockets in their ascent through the atmosphere. But the government impounded his papers and charged that one set comprised secret codes, although further inspection found that they were only standard logarithmic tables.

In a September 1955 agreement between the American and Chinese governments, Tsien and 93 fellow Chinese scientists returned to now-Communist China in exchange for 76 U.S. prisoners-of-war taken during the Korean conflict. Reentering China through Hong Kong, then a British colony, Tsien and his family were warmly greeted in Shenzhen by the Chinese Academy of Sciences and welcomed in a series of homecoming celebrations that culminated in Beijing, just restored as China's capital city. Soon, he visited the Harbin Military Engineering Academy (the circumstances that led him there are not known) and was asked to help China construct its first guided missiles.

The Chinese space program was officially founded in October 1956, exactly a year before Russia's first satellite orbited the Earth, with Tsien as its first director. With the news of *Sputnik*, China's observatories began a program to monitor the satellite in the night skies. Chairman Mao Zedong initiated an ambitious program to get a Chinese satellite into orbit as well. However, Mao's order was eventually frustrated by junior officials, who argued that in a country which did not even make motor cars and where the bicycle was the main means of conveyance, a satellite was too great a leap forward. The space program settled for more modest objectives. China signed a cooperative agreement with the Soviet Union, and the Russians helped the Chinese to reverse engineer the German V-2 rocket. A launching base (Jiuquan) was built in the Mongolian desert to begin test firing the Dong Feng (East Wind) missile.

From the First Satellite to a Lunar Program

Tsien Hsue Shen bided his time, continuing to work on spaceflight issues and putting forward proposals for satellite projects. He cultivated the patronage of Zhou Enlai, who helped spare the Chinese space program from the worst ravages of the Cultural Revolution, which broke out in 1966. China's first satellite, called the *Dong Fang Hong* (the East is Red) eventually made it into orbit in 1970. It was a simple satellite, although at 170 kilograms (kg) the largest first satellite of any of the spacefaring powers. This flight was followed by a scientific satellite and three military electronic reconnaissance satellites. In 1975, China became only the third country in the world to recover a satellite.[2]

China's next project was a second, radical step forward. In an effort to master new technologies and bring modern communications to its vast country, China set the target of mastering modern communications satellites. This, in turn, required the development of liquid-hydrogen-fueled upper stages. A new launching base (Xi Chang) was constructed, nearer to the equator in southwest China. The new rocket was called the Long March 3 family, and it began to put Chinese communications satellites into 24-hour orbit from 1984 onward.[3] Communications satellites became the basis of a series of applications satellites. First of these was the *Feng Yun* series, developed from 1988. *Feng Yun* operates in two versions, the 1 series, which goes into polar orbit and the 2 series, which uses geosynchronous orbit. Polar orbit missions required China to construct a third launch base (Taiyuan). The second applications satellite is the *Beidou* series, which are navigation satellites. The first was launched in October 2000 and the third on May 24, 2003.[4]

Since 1995, China has begun to consider a lunar program. The number of Moon probe studies rose from one in 1995 to three in 1997. Fifty-four have now been completed, the designers methodically ticking off all the elements they must consider in planning such a mission. Contrary to Western claims that China conducts its space program in strict secrecy, these studies can all be accessed through the Internet.[5] China intends to use its Long March 3 series to launch quite sophisticated probes to the Moon and has no intention of emulating the early Soviet *Luna* and U.S. *Pioneer* series. The three missions currently under consideration are for an orbiter, a lander, and a sample return mission. Much work has already gone into the robotics required for the latter.

Manned Spaceflight

But it is through manned flight that China's arrival as a space superpower will most be noticed. Observers only recently learned that China first began to plan for manned spaceflight back in 1966. On March 15, 1971, China became the third country in the world to select a squad of astronauts. Under project *Shuguang* (Dawn), they were to fly into space for several days in a recoverable cabin. However, political support for the project was not sustained, and it was closed down only a few years later.[6]

China returned to the idea of manned flight in 1992. Chinese engineers went shopping in Moscow and sent the first members of their second astronaut squad to the Russian "Star City" facilities for training. A new version of the Long March 2, called the 2F, was adapted to fly a manned space cabin. Manned flight required a considerable investment in infrastructure, and its modernity and sophistication are one of many remarkable features of the present Chinese space program. The project for manned flight necessitated an astronaut training center, a global fleet of tracking ships, a network of overseas tracking stations (in Tarawa, Namibia, and Pakistan), a large vehicle assembly building, a new launch pad at Jiuquan, and a large mission control center. As for the manned spaceship, the *Shenzhou*, it shows every prospect of being versatile and successful. Contrary to what has sometimes been assumed, it is not a copy of the Russian *Soyuz*, although it is inspired by its basic design. *Shenzhou* is larger (it could probably take a crew of four), longer, has more solar panels, and leaves its orbital module behind for maneuverable autonomous flight. *Shenzhou* has now flown unmanned four times, in November 1999 (one-day mission) and in January 2001, March 2002, and December 2002 (all six-day missions). *Shenzhou 5*, due in October 2003, will be the first manned flight. It will be followed by missions for a spacewalk and an eventual docking (we could imagine a mission similar to that of *Soyuz* 4/5 conducted by the Soviets in 1969), leading to a small space laboratory. The next generation of Long March launchers, the Long March 5, will be able to lift a *Salyut/Mir class* space station in 2008.

Main Features of China's Space Program

Several features of the Chinese space program stand out and are worth emphasizing:

- It is a slow and deliberate program. The *Shenzhou* tests have taken four years so far. The Chinese have not been racing anyone, including themselves.
- There has been a strong, even fanatical emphasis on quality control. As one engineer said recently, "We can't afford failures." *Shenzhou 3* was sent back to the shop once and stripped apart a second time because engineers had second thoughts about quality control. The delays cost six months, and no one was punished for them.
- The program has been developed within China. While no one should be naive and imagine that China does not engage in information-collection and standard international industrial espionage, this is an indigenous program developed by domestic know-how. China has been under various forms of technology embargoes since 1949 and much of this regime still persists. When *Dong Fang Hong 1* was launched, Zhou Enlai insisted that the post-launch communiqué include the words "We did this through our own unaided efforts." This remains the case, and suggestions that the Chinese have built their program by stealing blueprints from friends and enemies alike stand in the way of accepting their hard-learned engineering achievements.

- It is a sophisticated program, contrary to some reports. For years, it was asserted in the West that the Chinese used "wooden planks" for heat shields. The techniques involved in manned spaceship design, automatic lunar probes, liquid-hydrogen technology, clocks for navigation satellites, Earth resources imaging, and so on are advanced, just like the fibers and compounds actually used in their heat shields.
- It is not as secret as is often claimed. We know the names of the personnel who are trained and eligible to fly the first manned *Shenzhou* into orbit. By contrast, the names of Gagarin's colleagues, chosen with him in 1960, were not made known until 1986. We have many technical details about Chinese rockets, because the Chinese have published user manuals. Foreigners can visit Xi Chang as tourists, and Western scientists and journalists have been to Jiuquan. The basic details of most Chinese spacecraft are known.
- Chinese rockets have a good safety record. The last launch failure was in 1996, which is more than what can be said about many other space programs.

An International Perspective

Given its current status and activities, it is worth asking how China's space program fits in a broader international perspective. If we define a "space power" as a country or multinational consortium able to put its own satellites into orbit, the world has nine space powers: Russia, the United States, France, Britain, the European Space Agency (ESA), China, Japan, India, and Israel. (Of these, Britain and France no longer have separate national satellite-launching programs, so the current relevant number is really seven.)[7] Table 1 lists the number of launches by the different spacefaring nations.

Table 1
Rocket Launches Worldwide[1]

Nation	Number of Launches
Soviet Union/Russia	2,680
United States	1,255
Europe/ESA	149
China	69
Japan	57
France	10
India	12
Israel	5
Britain	1
Total	4,238

[1] As of January 1, 2003.

China, therefore, accounts for a tiny proportion of world space launches (1.6 percent). However, the proportions are much higher if one takes out the two superpowers—Russia and the United States. Of the 303 launches by other space powers, China then accounts for 20 percent. Even in the broader context, China emerges as the fourth spacefaring power in the world. Except for brief periods early on and in the mid-1990s, Russia has always been the leading spacefaring nation, followed closely by the United States and, some distance behind, Europe. China has come next as the leading *Asian* power in space, ahead even of Japan and India.

Looking at deep space missions (the Moon, Venus, Mars, and beyond), four of the space powers have launched deep space missions: the United States, Russia, Europe, and Japan, but not China. Turning to geosynchronous orbit, only six countries have launchers able to reach 24-hour orbit: the United States, Russia, Europe, China, Japan, and, since 2001, India.

China's Space Budget

Estimating China's space budget has always been problematic. As was the case in the Soviet command economy, financial transfers between organizations are often set at notional amounts. Some costs are clearly subsidized. For example, important functions in the space program were and still are performed with military help (for example, the rocket troops and search and recovery operations). Another consideration is that labor costs in China are exceptionally low. As a result, formal financial estimates of the Chinese space budget have tended to be on the low side in relation to their international competitors.

The Chinese themselves estimate that government support for space activities is worth ¥1.45bn annually, about •154m, which is an implausibly low figure. However, this may simply be the research and development figure, for it is known to exclude launcher operations. Several authoritative Western estimates have been made, some similar to one another. These are in the range of •1.59bn (*Aviation Week & Space Technology*) to •1.68bn (Britain's *Flight International*). A figures of •1.64bn represents a mid-point between the two. In 2002, the Chinese gave a figure for the cost of the manned space program from inception to the completion of the first docking mission as ¥19bn, or about •2.5bn.

Table 2 attempts to estimate world space budgets for 2001, the last year for which fully comparative figures are available. This is an inherently difficult exercise, for several countries do not have published space budgets, and in others it is difficult to separate national from international programs, military from civilian. Exchange rates present a further complication, so this table must be treated with caution.

Although the absolute figures given here are problematic, the *relative* outcomes may be more meaningful. These figures show the United States not only as the largest space spender, but the largest by far. This has always been the case from the very beginning. Europe comes in second, a long distance behind, with Japan following much further behind in turn, but ahead of individual national programs in Europe (the Russian figure is problematic, for its understates the program's huge capital assets). The table places China as the fifth space spender in the world. Its low labor costs put it below the Japanese level—otherwise it would certainly be above.

But China is unlikely to remain this low on the list for long. The planned expansion of the Chinese space program over 2001-05 is so extensive that it will only be achievable with substantial increases in funding. Luan Enjie, director of the China National Space Administration, is quoted as saying that China's space budget will double during this five-year period. Likewise, his deputy, Guo Baozhu, has stated that space spending would "greatly exceed" figures in the previous five-year plan of 1996-2001.

There are no absolutely clear figures available for the numbers of people working in the Chinese space program. The best Western estimates give a figure of 200,000 people directly involved in the space industry. Of these, 100,000 are technical workers drawn from light industry, the army's technical ranks, and polytechnical schools. About 10,000 are graduate research engineers working in 460 institutes connected to the space program. The Chinese space program has been able to choose the top graduates coming out of engineering schools and has been able to attract the country's most talented scientists. Working in the space program is prestigious, although financially unrewarding. A typical mission controller gets only about •2,000 a year, a fraction of what a bright graduate could get in the private sector. Yet, China seems to be able to attract staff without difficulty, likely due to the inherent interest of young scientists and engineers in space activity.

As of summer 2003, the Chinese space program had completed 70 orbital insertion missions, placing 78 satellites in orbit (some on multiple release missions). The recoverable satellite series and international commercial launches have been the largest elements of the program (16 each), followed by geostationary domestic communications satellites (10) and scientific (8). Applications satellites (navigation, meteorology, and Earth resources) are likely to continue in importance, as, of course, will the manned program. A separate space science program has played a very minor role, though the *Shenzhou* orbital module carries a large scientific payload.

Table 2
World Space Budgets

Nation	Budget (millions of Euros)[1]
United States	35,888
Europe	5,865
ESA (2,835)	
National programs (2,297)	
Japan	2,033
China	1,640
Russia	750
India	580

Adapted from Sevig, *European Space Directory, 2002* (Paris: Sevig Press, 2002).

[1] Estimates based on 2001 figures.

Between 1970 and 2003, China launched an average of two rockets per year. The launch rates of the Chinese space program are generally low and have never exceeded six in any given year. In some years (such as 1989), there have been no launches at all. Even in some recent years, launch rates have been quite low (for example, there was only one launch in 2001). Some people have interpreted this as indicating problems, but it is more likely that China had enough applications satellites in orbit at the time to meet its needs and had no urgent need to replace them.

Official Policy: The White Paper

Several questions are of interest to foreign observers. What is China's strategy for space exploration? What future developments are indicated? What specific space goals have been articulated over the years in government economic, defense, and planning statements, documents, and policy papers? Fortunately, there has been considerable information released in these sources, and the highly political—indeed polemical—language of the 1970s has given way to much more pragmatic statements.

Until recently, spaceflight operated within the context of broader plans for scientific development, the most recent being the *National long and medium-term programme for science and technology development, 2000-2020,* adopted in 1996-97. The key elements of this 20-year plan were: the development of communications, meteorological, remote sensing, and other applications satellites; provision of international launcher services at competitive prices; and development of a new launcher capable of putting 20 tons into orbit. More recently, and probably indicating its increased importance, spaceflight development became subject to a national policy statement in its own right.

On November 22, 2000, China published a 13-page White Paper on its future space program. Readers expecting a listing of future launch schedules, dramatic reorganizations, or announcements of exciting new projects were disappointed. Like most government White Papers the world over, the language was bureaucratic, the aspirations general, and some of the statements quite bland. Still, the document provided some useful information.

First, the White Paper recited China's space achievements, articulated over-arching aims, and listed broad lines of development. It recalled how China had to struggle against a "weak infrastructure" and a "relatively backward level of science and technology." It enunciated three broad aims for the space program: exploration, applications, and the promotion of economic development. Space development was set in its broader political context and linked to economic progress, environmental protection, and international cooperation. Internationally, China would make a point of working closely with the other countries of the Asia-Pacific region.

In designing its space policy, China would select a small number of key areas of development and concentrate on them, rather than try to do everything. China would build on its best abilities and concentrate on a limited number of areas and targets according to its strengths. China would combine self-reliance with international cooperation. The short-term priorities of the space program were stated as:

- monitoring of the Earth, atmosphere, and oceans;
- weather forecasting;
- developing independent communications and broadcasting systems with long operating lives, high capacity, and reliability; and
- instituting an independent satellite navigation system.

The long-term priorities of the space program were set out as:

- manned spaceflight;
- improved national space scientific achievement;
- introduction of the next generation of new, low-cost, non-polluting, high-performance rockets;
- development of a national system of remote sensing, ensuring the effective distribution of data throughout the country;
- construction of a new generation of satellites for micro-gravity research, materials science, life sciences, space environmental studies, and astronomy; and
- conduct of preliminary work toward exploration of the Moon and deep space.

The White Paper also articulated a number of what it called "development concepts" to guide the space program over the next number of years. These included the principles that:

- space industry organizations should be encouraged to market their products as widely as possible, both domestically and internationally;
- resources should be made available for tackling key technological problems;
- recruitment of talented people to the space industry should be encouraged, with the aim of building a cadre of young and highly qualified scientists and engineers; and
- the program should continue to emphasize quality control, risk reduction, and skilled management.

The White Paper contained few surprises. It confirmed the impression of a space program that would not try to do everything but would instead concentrate on some key areas in a systematic way. The emphasis on manned flight and a new fleet of launchers was confirmed, although there was no specific mention of a planned space station. There was a renewed commitment to space applications and space science. Missions to the Moon were, for the time being, still something to study rather than to do. Symptomatic of its long-range thinking was the commitment to improved human resources and addressing key technological problems.

Apart from the White Paper, the Chinese space program operates within the context of the national five-year plans introduced by the communist government. The current version is the 10th national five-year plan, covering the years 2001-05. This is frequently quoted as a reference point in Chinese statements, and its key feature was a commitment to unspecified but much increased expenditures on spaceflight. It has a space subsection that describes the goals and blueprint of the civil space program in the period 2001-05, but subordinate to the White Paper. The two most eye-catching objectives of the period were the commitment to a manned flight by 2005 and the launch of an unmanned Moon probe. The program called for preliminary study of lunar exploration and identification of scientific objectives for lunar missions. An ambitious total of 30 spacecraft was promised during the period, almost half the total launched by China altogether up to 2001.

Conclusion

The Chinese space program is moving toward a great breakthrough—manned spaceflight. Although this may be seen in the popular mind as a recent and sudden development, it is in fact the logical culmination of a space program that formally pre-dates *Sputnik*. The program is a small one in the context of the two leading spacefaring nations, but gives China a strong position in Asia. Government policies indicate an ambitious program that will expand in the future, promising missions to the Moon and even farther afield.

Whether the Chinese space program is going to be cooperative or competitive will depend on international dynamics. Opposition from conservative members of the U.S. Congress has blocked Chinese participation to date in the International Space Station (ISS). However, it may be better to invite the Chinese into the ISS rather than, in effect, force them to build their own independent space station. From available information, China is not eager to start a new space race, certainly not one in the military sphere. Yet, if such a race is forced upon it by other space powers, China may develop into a very capable competitor.

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[1] For the story of Tsien Hsue Shen, see Iris Chang, *The Thread of the Silkworm* (New York, Basic Books, 1995).

[2] Ibid.

[3] For an account of the Chinese space program up to 1990, see Zhang Yun, ed., *The Chinese Space Industry Today* (Beijing: China Social Sciences Publishing, 1986), and Chen Hyi, *Into Outer Space* (Beijing: China Pictorial Publishing, 1989), p. 156.

[4] For an account of recent developments, see Phil Clark, "Chinese satellites—status report at the end of 2001," *Journal of the British Interplanetary Society* 55, No. 7/8 (2002).

[5] Paolo Ulivi, "The Chinese planetary programme," at <http://utenti.lycos.it/paoloulivi/chinamoon.tml>.

[6] Mark Wade, *Shuguang 1*, <www.astronautix.com>.

[7] Britain cancelled its launcher program after only one successful mission; France merged its launcher program with ESA's.

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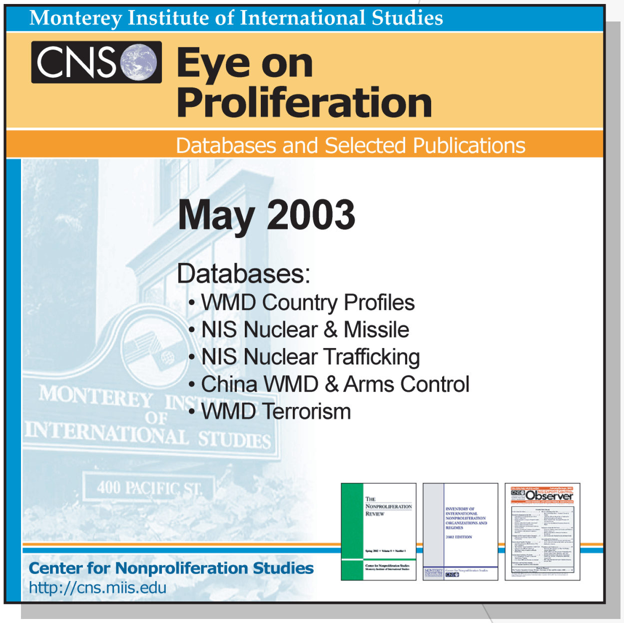

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