SILVER BULLET?

Asking the Right Questions About Conventional Prompt Global Strike

JAMES M. ACTON

CARNEGIE
ENDOWMENT FOR
INTERNATIONAL PEACE

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Carnegie Endowment for International Peace
1779 Massachusetts Avenue NW
Washington, DC 20036
P: + 202 483 7600
F: + 202 483 1840
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ABOUT THE AUTHOR

James M. Acton is a senior associate in the Nuclear Policy Program at the Carnegie Endowment. A physicist by training, Acton specializes in deterrence, disarmament, nonproliferation, and nuclear energy. He is a member of the Trilateral Commission on Challenges to Deep Cuts and was co-chair of the Next Generation Working Group on U.S.-Russian Arms Control.

Acton's publications span the field of nuclear policy. He is the author of two Adelphi books, *Deterrence During Disarmament: Deep Nuclear Reductions and International Security* and *Abolishing Nuclear Weapons* (with George Perkovich). He wrote, with Mark Hibbs, *Why Fukushima Was Preventable*, a groundbreaking study into the accident's root causes. And his analysis on proliferation threats, including Iran and North Korea, has been widely disseminated by major journals, newspapers, and websites.

Acton has published in the *Bulletin of the Atomic Scientists*, *Foreign Affairs*, the *International Herald Tribune*, *Jane's Intelligence Review*, the *New York Times*, the *Nonproliferation Review*, *Survival*, and the *Washington Quarterly*. He has appeared on CNN's *State of the Union*, NBC *Nightly News*, CBS *Evening News*, and PBS *NewsHour*.

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LIST OF ACRONYMS

Weapon Systems and Programs

AHW: Advanced Hypersonic Weapon

AMaRV: Advanced Maneuvering Reentry Vehicle

CPGS: Conventional Prompt Global Strike

CTM: Conventional Trident Modification

E2: Enhanced Effectiveness

FALCON: Force Application and Launch From Continental United States

HTV: Hypersonic Technology Vehicle

LETB: Life Extension Test Bed

SLIRBM: Sea-Launched Intermediate-Range Ballistic Missile

SWERVE: Sandia Winged Energetic Reentry Vehicle Experiment

Others

A2/AD: anti-access/area-denial

ASAT: antisatellite

DARPA: Defense Advanced Research Projects Agency

FY: fiscal year

GAO: Government Accountability Office

ICBM: intercontinental ballistic missile

ISR: intelligence, surveillance, and reconnaissance

MaRV: maneuvering reentry vehicle

New START: New Strategic Arms Reduction Treaty

NRC: National Research Council of the U.S. National Academies

SLBM: sea-launched ballistic missile

SSBN: nuclear-powered, ballistic missile submarine (ship, submersible, ballistic, nuclear)

SSGN: SSBN converted to carry cruise missiles (ship, submersible, guided, nuclear)

START I: Strategic Arms Reduction Treaty I

SUMMARY

The development of non-nuclear weapons that can strike distant targets in a short period of time has been a U.S. goal for more than a decade. Advocates argue that such Conventional Prompt Global Strike (CPGS) weapons could be used to counter antisatellite weapons or sophisticated defensive capabilities; deny a new proliferator the ability to employ its nuclear arsenal; and kill high-value terrorists. Critics worry that CPGS weapons could create serious strategic risks, most notably of escalation—including to the nuclear level—in a conflict.

The U.S. Department of Defense has explored a number of CPGS technologies but has yet to decide on a preferred option, let alone acquire or deploy it. While the U.S. Congress has disapproved of particular plans, it has generally agreed with the importance of acquiring the capability. With some CPGS technologies reaching maturity and an acquisition decision approaching, the time is right for a national debate about the benefits and risks of CPGS.

The Cost-Benefit Analysis

- The U.S. Department of Defense has not yet decided for which missions CPGS might be acquired.
- Potential missions for CPGS have varying weapon requirements according to the need for promptness and tactical surprise; the required range of the weapon; and the target's characteristics and defenses.

- Each candidate CPGS weapon has different military strengths and weaknesses; which would be "best" depends upon the scenario.
- The United States is pursuing three separate pathways to develop CPGS weapons: land- or sea-based rocket-launched hypersonic gliders (boost-glide weapons); sea-based ballistic missiles; and air-launched hypersonic cruise missiles.
- The military effectiveness of these weapons would depend critically upon potential adversaries' countermeasures, including early-warning systems; interference with weapons' GPS navigation systems; air and missile defenses; and the mobility or burial of targets.
- Non-prompt alternatives to CPGS include stealth technology and forward-deployed weapons. Depending on the scenario, these alternatives could carry a lower risk of failing to fulfill military requirements.
- Enabling capabilities would be absolutely essential to the effectiveness of CPGS weapons. To date, however, command and control; intelligence, surveillance, and reconnaissance; and battle damage assessment have been neglected.
- CPGS weapons would likely enhance deterrence and simultaneously increase the risk of escalation in a conflict.
- The most discussed strategic risk is the possibility that a CPGS weapon could be mistaken for a nuclear weapon (warhead ambiguity). Concern about this risk originated with plans to replace the nuclear warheads on ballistic missiles with conventional weapons. Other escalation risks are, however, more serious.
- Non-ballistic CPGS weapons, which are highly maneuverable, could possibly lead an observing state to wrongly conclude that an incoming weapon was heading for its territory (destination ambiguity).
- A state could mistakenly believe that its nuclear forces were under attack when its conventional forces were really the target (target ambiguity). This situation could arise, for instance, if a state's nuclear and conventional assets were "entangled" because of dual-use command-and-control systems.
- A state that feared its critical weapon systems—particularly nuclear weapons—were vulnerable to a preemptive CPGS strike could feel pressure to use or threaten to use those weapons first (crisis instability).

- All potential CPGS weapons have some desirable and some undesirable characteristics from the perspective of mitigating strategic risks. Boost-glide weapons, for instance, would have non-ballistic trajectories, tending to reduce warhead ambiguity. However, because they are maneuverable and untrackable after the boost phase, their destination would be unpredictable, exacerbating all escalatory risks.
- Russia and China, both developing CPGS-like technologies, have concerns about the U.S. program, and Washington is committed to easing them. Their concerns relate to all U.S. high-precision conventional weapons, not just CPGS.

Key Recommendations and Findings for the United States

A scenario-based approach to CPGS acquisition would maximize value for money. Before embarking on the acquisition process, the Department of Defense should decide upon the specific missions for which CPGS weapons might be acquired in order to identify clear military requirements.

A comparison of the ability of CPGS weapons and non-prompt alternatives to meet mission requirements is needed to determine whether to procure CPGS weapons at all. This comparison has been absent from the debate. It should account for the relative costs and the implications of potential countermeasures.

CPGS acquisition decisions should take into account the need for U.S. enabling capabilities. The continued failure to consider this issue could lead the United States to procure CPGS weapons incapable of fulfilling mission requirements.

The debate about the strategic ramifications of CPGS should include the full range of risks and benefits. Warhead ambiguity does not pose the biggest escalation risk in a conflict with Russia or China. All risks should be weighed against the potential benefit of enhanced deterrence.

The negative characteristics of boost-glide weapons for managing escalation in a conflict should be recognized. These risks are serious and have been overlooked.

Whatever CPGS technology the United States chooses, it should pursue cooperative confidence-building measures with Russia and China. Cooperative measures, which could be treaty based or politically binding, would more effectively mitigate the strategic risks posed by all CPGS technologies than unilateral measures.

INTRODUCTION

In May 2003, the U.S. Department of Defense formally initiated efforts to acquire high-precision conventional weapons capable of striking targets around the globe within "minutes or hours."[1] Almost a decade later, it has yet to decide upon a preferred technological solution for Conventional Prompt Global Strike (CPGS), let alone acquire or deploy it. Recent testing successes have, however, put a long-delayed acquisition decision firmly back on the agenda. This decision would probably prove controversial under any circumstances. But, as it comes at a time when budgetary austerity and a fluid security environment are exerting opposing pressures on military spending, it is likely to be particularly fraught. This confluence of factors makes the time right for a careful and sober assessment of the potential benefits and risks of CPGS.

The delays in acquiring a CPGS capability have not been for want of trying. In 2006, in its Quadrennial Defense Review, the administration of President George W. Bush announced its intention to deploy the Conventional Trident Modification, consisting of conventional warheads placed on submarine-launched ballistic missiles that are currently used to deliver nuclear warheads. It hoped to gain an initial operational capability within two years at a cost of less than $200 million.[2] The U.S. Congress opposed this plan, ostensibly because of warhead ambiguity—the risk of an adversary's mistaking a deployed CPGS weapon for a nuclear one and launching a nuclear response.

The Pentagon subsequently shifted its focus to the development of much more technically sophisticated non-ballistic systems, which remain in research and development. All of these systems carry multibillion-dollar price tags, and none is likely to become operational until next decade at the earliest.

In spite of the expanding time frame and costs, the administration of President Barack Obama has continued to support the CPGS program—a research and development program funded from a dedicated account within the budget of the Office of the Secretary of Defense. And, while Congress has disapproved of particular plans, it has generally agreed with the importance of acquiring the capability. Moreover, geopolitical trends over the last few years have handed proponents of CPGS some powerful arguments. The spread of advanced defensive systems, frequently referred to as anti-access/area-denial capabilities, that could threaten U.S. freedom of movement in key theaters is now a major military challenge, and there is growing support for the notion that CPGS could help counteract this threat. Other developments, including the North Korean and Iranian nuclear and ballistic missile programs and China's evolving antisatellite capability, also provide rationales for CPGS.

Although progress in research and development has been uneven, there are also signs that the technology is maturing. In November 2011, the first test of one prototype CPGS system, the Advanced Hypersonic Weapon, was deemed fully successful. More recently, in May 2013, a hypersonic cruise missile demonstrator, X-51A WaveRider, enjoyed its second successful test in four attempts. (The X-51A program was funded separately from the CPGS program but has similar goals.)

Critical decisions about CPGS will be made in the next two to three years. The United States must decide which systems—if any—to acquire, which immature technologies are sufficiently promising to merit further research and development funding, and which pathways should be abandoned. In parallel, the U.S. administration will also have to decide whether and how to invest in the enabling capabilities needed to support CPGS, most notably intelligence, surveillance, and reconnaissance.

Even at a time of rising defense budgets, CPGS acquisition decisions would be expected to receive close scrutiny from Congress, as its handling of the Conventional Trident Modification plan exemplifies. For the foreseeable future, however, severe downward pressures on the defense budget will force lawmakers to choose between competing programs, heightening the probable degree of scrutiny. Indeed, CPGS has not been immune to the budgetary pressures now felt across the U.S. government. Obama's latest budget, released in April 2013, calls for reductions in CPGS funding by about 40 percent compared to the previous year and restructures the program significantly. If sequestration—across-the-board spending cuts imposed in early 2013 under the Budget Control Act of 2011—is not rolled back, the affordability of the entire program may be called into question.

The last time CPGS was seriously debated was in the mid-2000s, when the Bush administration announced plans for the Conventional Trident Modification. Much has changed. Then, public debate focused on the potential counterterrorism role of CPGS; today, its advocates tend to focus on state-centric threats. The technology is also different. Plans to put non-nuclear warheads on existing ballistic missiles have been dropped, and instead work is focused on developing a number of more sophisticated—and costly—technologies. All of the options under consideration are more expensive than the Conventional Trident Modification, some by as much as a factor of ten or twenty.

In a 2008 report mandated by Congress, the National Research Council of the U.S. National Academies endorsed the Conventional Trident Modification but stated that "any longer-term, more versatile option will be a far more expensive national investment that the committee believes . . . must be put into the broader context of the nation's strategic strike policy and national security strategy."[3] All of the CPGS technologies currently under consideration are those "longer-term, more versatile options." Yet, "the broader context of the nation's strategic strike policy and national security strategy" is largely absent from what limited public discussion there is about CPGS. This report aims to fill that gap.

BROADENING THE DEBATE

Currently, there is no consensus about what missions CPGS weapons might be used to accomplish. As discussed in chapter 1, although various roles for the technology have been proposed, from countering nuclear threats to overcoming advanced defenses, and their merits are quietly debated within the Pentagon, no decisions have yet been made. These doctrinal choices need to be made before acquisition decisions because the potential missions for CPGS have quite different requirements.

To complicate matters further, the CPGS systems under consideration, which are summarized in chapter 2, have different military strengths and weaknesses. This point has not been widely appreciated. Much of the literature on CPGS appears to assume that different CPGS technologies represent equally effective means of accomplishing the same military ends. In reality, however, all the candidate technologies have their own distinctive sets of weaknesses and vulnerabilities.

As a result, assessing the military effectiveness of potential CPGS weapons, which is done in chapter 3, requires an analysis of these technologies in the context of specific missions against specific adversaries and specific countermeasures. Indeed, a similar analysis is also required to determine whether CPGS weapons would, in fact, provide significant benefits compared to non-prompt alternatives, such as stealth technology. Moreover, the military effectiveness of CPGS capabilities would depend not only on the weapons themselves but also on the enabling capabilities put in place to facilitate their operation. Consideration of these capabilities has been notably absent from most discussions of CPGS.

Similar foreign weapon programs also tend to be ignored within debates about CPGS. However, these programs—Russia's and China's in particular—have the potential to impact U.S. procurement decisions and are discussed in chapter 4.

The international ramifications of CPGS, explored in chapter 5, are another area in which the existing debate has failed to encompass the full range of relevant issues. The potential escalation risks of CPGS have been debated intensely but narrowly, with a near-exclusive focus—at least within the United States—on the problem of warhead ambiguity. However, CPGS poses other, less discussed risks, such as target ambiguity. To give but one example of this risk, Chinese nuclear and conventional missiles are believed to share the same command-and-control system. In a crisis, Beijing could misinterpret a CPGS strike designed to deny it control of its conventional missiles—particularly its anti-ship ballistic missiles—as an attack aimed at denying it control of its nuclear weapons, significantly increasing the risks of escalation.[4]

Finally, the ways in which the acquisition of CPGS by the United States might affect the behavior of potential adversaries in peacetime also demands attention. Some of those effects could be beneficial to U.S. security; others might be detrimental. For example, potential adversaries could become more likely to acquire similar systems, but they may also be more deterred from initiating acts of aggression against the United States or its allies.

It is time to broaden the debate surrounding CPGS. More research and testing may be needed before recommendations can be made about which CPGS systems the United States should acquire or, indeed, if it should acquire any at all. But it is possible to start asking the right questions.

DEFINING CONVENTIONAL PROMPT GLOBAL STRIKE

There is no hard-and-fast definition of Conventional Prompt Global Strike. It is most often defined, including by senior U.S. officials, in terms of high-precision conventional weapons capable of striking a target anywhere in the world within one hour's time of the decision to launch.[5]

However, there have recently been media reports of a wholesale reassessment of the program's requirements.[6] A maximum flight time of one hour appears to be more of a guideline than a firm requirement. Moreover, the CPGS program is currently sponsoring only a single system with truly global range, the Hypersonic Technology Vehicle-2, which attracts only minimal funding. Indeed, senior Department of Defense officials have stated that their focus is currently on developing shorter-range weapons for regional operations.[7]

In private, some officials have started to refer to the concept as "Conventional Prompt Strike," omitting the word "global." But since the term "Conventional Prompt Global Strike" still appears in official documents and is very widely used, this report also uses it, even at the risk of being forced to employ such ungainly terms as "non-global CPGS weapons."[8]

In the absence of a clear definition for CPGS, this report focuses on the development of hypersonic long-range conventional weapons. Hypersonic is usually defined—as it is here—as Mach 5 or above (that is, at least five times faster than the speed of sound). The threshold for "long range" is taken as 1,500 km (930 mi.), which is roughly the range of the most far-reaching conventional missile the United States currently possesses (a variant of the Tomahawk cruise missile). Hypersonic cruise missiles, the development of which is funded through the U.S. Air Force research and development budget, might also be able to fulfill these requirements.

HYPERSONIC LONG-RANGE STRIKE: A TECHNOLOGICAL PRIMER

U.S. intercontinental ballistic missiles and sea-launched ballistic missiles are capable of creating prompt effects at great distances. The nuclear warheads that they currently deliver are unguided after being dispensed; they simply fall under the influence of gravity (indeed, this is the meaning of the word "ballistic"). How close one actually approaches its aim point depends on a number of factors, including the effect of local weather conditions as the warhead reenters the atmosphere in its final seconds of flight. Typically, modern ballistic missiles are reported to have accuracies of around 100 m (330 ft.).[9]

For conventional warheads mounted on long-range ballistic missiles to be militarily effective, much greater accuracy is needed because their destructive capabilities are not nearly as significant as those of nuclear warheads. Indeed, for a CPGS weapon to be militarily effective, it must be delivered to within of a few meters of its aim point.[10]

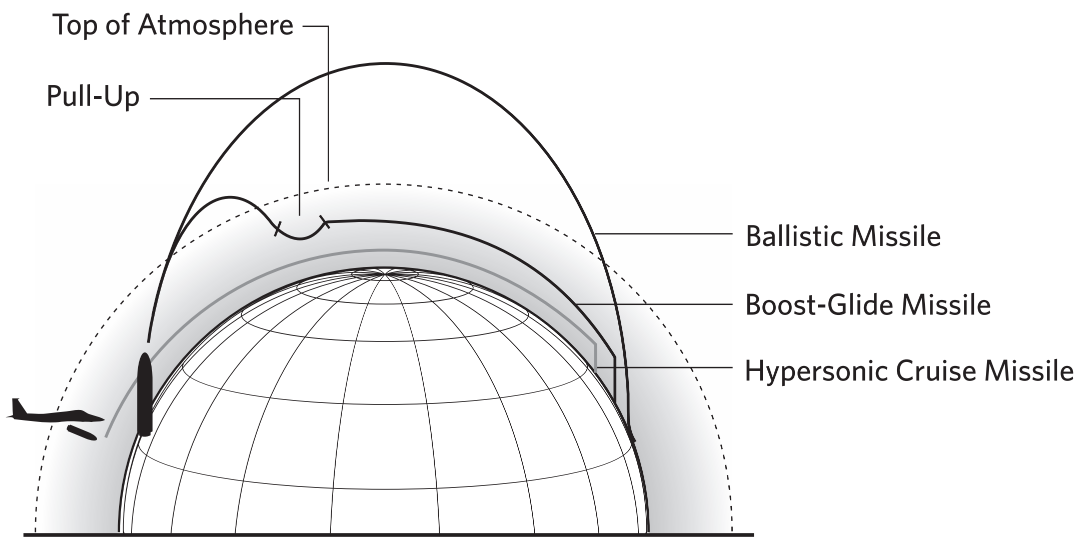
The simplest approach to enhancing accuracy is to use a steerable reentry vehicle, that is, a reentry vehicle equipped with a guidance system and flaps that allow it to steer through the atmosphere toward its aim point. Ballistic missiles armed with such reentry vehicles are known as terminally guided ballistic missiles.

A more ambitious but more versatile approach is to use a hypersonic gliding reentry vehicle that can stay aloft for significant distances (current nuclear-armed reentry vehicles are designed to plummet through the atmosphere as quickly as possible). Hypersonic boost-glide vehicles are launched by missile and designed to reenter the atmosphere shortly afterward.[11] They are unpowered after the boost phase, but—like the space shuttle on reentry or a paper plane—they are shaped to generate aerodynamic lift. This lift allows them to glide for perhaps thousands of kilometers.

An alternative approach to hypersonic long-range strike is the cruise missile. Like gliders, cruise missiles generate aerodynamic lift; unlike gliders, they are powered throughout their flight. All but a few short-range cruise missiles are equipped with engines that burn oxygen from the atmosphere and, for this reason, are often referred to as "air breathers." In contrast to today's ballistic missiles, which possess the speed but not the accuracy for the prompt delivery of conventional weapons over long distances, cruise missiles currently have the required accuracy but not the speed. Figure 1 compares the trajectory of a terminally guided ballistic missile, a boost-glide system, and a cruise missile.

FIGURE 1

Schematic Diagram of Generic Trajectories for Boost-Glide Missiles, Terminally Guided Ballistic Missiles, and Hypersonic Cruise Missiles



Not drawn to scale.

“WHY NOT? RELATIVELY CHEAP AND MAY BE JUST WHAT WE NEED SOME DAY.”

— A 1995 RAND study on the possibility of using existing intercontinental ballistic missiles and sea-launched ballistic missiles to deliver non-nuclear warheads.[1]

A MISSILE IN SEARCH OF A MISSION: WHY IS THE UNITED STATES DEVELOPING CPGS?

KEY INSIGHTS

The U.S. Department of Defense has not yet made any doctrinal decisions about the missions for which Conventional Prompt Global Strike (CPGS) weapons might be acquired. Missions under consideration include

- Denying a new nuclear proliferator the ability to employ its nuclear arsenal
- Destroying or disabling antisatellite capabilities
- Countering anti-access/area-denial capabilities
- Killing high-value terrorists and disrupting terrorist operations

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Each of these missions has distinctive weapon requirements. These requirements differ according to

- The need for promptness (a short time between the decision to use a weapon and its effect on the target) and/or tactical surprise (little or no warning of an incoming strike is provided to the adversary)
- The required range of the weapon, which would decrease if there is likely to be sufficient strategic warning of a conflict for forces to be deployed forward

- The type and effectiveness of defenses
- The targets' characteristics

There is little evidence that the United States is considering acquiring CPGS weapons for possible use against Russian or Chinese nuclear forces (although their use against Chinese conventional forces is being considered).

Discussions of using CPGS to hold high-value, distant, fleeting, well-defended targets at risk that are not based on specific scenarios tend to obscure important differences between missions. A scenario-based approach is more likely to increase the military value derived from CPGS systems relative to their costs.

While the term "Conventional Prompt Global Strike," coined during the administration of President George W. Bush, may be relatively new, the concept it represents is not. As the accuracy of intercontinental ballistic missiles (ICBMs) increased during the Cold War, it became effectively inevitable that the possibility of using them to deliver conventional weapons would be explored.[2] Advisers to the U.S. military appear to have first suggested conventional ICBMs in the mid-1970s. For example, a 1975 study by the RAND Corporation for the U.S. Air Force raised the possibility of developing highly accurate guidance systems for ICBMs so that "the smallest possible yield, *or even conventional explosives*, can be employed where conditions dictate or permit" (emphasis added).[3]

The RAND study is notable not only for mentioning the concept of a conventional ICBM but also for propounding a rationale that was reiterated by government advisers for over three decades. The study's basic theme is that ICBMs risk becoming obsolete if "they are considered simply as one of three different ways [along with sea-launched ballistic missiles and heavy bombers] of doing the same job."[4] The authors argued, however, that ICBMs could be modified, at relatively low cost, into highly accurate, lower-yield weapons to allow "effective and flexible targeting with minimum collateral damage."[5] The desire to "leverage" existing nuclear capabilities cheaply to create more usable and versatile weapons has been an important driver of advocacy for the development of long-range hypersonic weapons.[6]

In 1995, another RAND study examined the future of U.S. nuclear forces after the end of the Cold War. It posed a familiar question: "Can strategic delivery systems, many of which may otherwise be destroyed in the [Strategic Arms Reduction Treaty I (START I)] build-down, find cost effective applications as nonnuclear delivery systems?"[7] It considered the possibility of using ICBMs and sea-launched ballistic missiles (SLBMs) to deliver conventional warheads, reaching the conclusion, "why not? Relatively cheap and may be just what we need some day."[8]

Nearly a decade later, in 2004, this logic was echoed in a report by the Defense Science Board (which, while not a statement of official policy, can sometimes reflect and/or shape official thinking). It advocated placing conventional warheads on existing nuclear delivery systems, noting that because the missiles had already been built, "large sunk costs can be leveraged."[9] In particular, following the logic of both RAND studies, it argued for using Peacekeeper/MX ICBMs in this way since their "planned retirement [in 2005] . . . provides an opportunity for a highly leveraged option."[10]

A variant of these ideas was finally adopted as official U.S. policy in 2006, more than thirty years after the 1975 RAND study, following much advocacy and many government-sponsored technical studies. In its Quadrennial Defense Review of that year, the Bush administration elevated the development of conventional long-range ballistic missiles to a national policy goal with its plan to place conventional warheads on Trident D5 SLBMs.[11] This plan was never implemented in the face of congressional opposition and efforts are now focused on the much more expensive task of developing entirely new delivery systems. Nonetheless, the origins of CPGS still resonate. Because the CPGS program was, for a long time, driven by "technological opportunism," the development of technology has, so far, outpaced developments in doctrine.[12] Indeed, in August 2012, Madelyn R. Creedon, the assistant secretary of defense for global strategic affairs, acknowledged that the United States was "still early in the development of the policy to go with" the technology.[13]

The slow pace of policy development does not mean there are no potential roles that CPGS could fill. A number of potential missions for CPGS have been proposed, ranging from killing terrorists at the "low end" to destroying nuclear-armed mobile missiles at the "high end." However, the distinct requirements of different potential missions tend to be obscured by talking generally about defeating distant, time-critical, high-value targets, as U.S. government officials tend to do (at least in public). Unless CPGS is developed to meet specific missions, the technology risks remaining, in the words of a defense contractor, a "missile in search of a mission." It is unlikely that such a program could survive the present budgetary environment.

THE NUCLEAR THREAT

Since the concept of hypersonic long-range conventional weapons originated with the idea of adapting nuclear delivery systems to carry conventional warheads, it is unsurprising that the first targets proposed for such weapons were the "strategic" targets that nuclear weapons were—and still are—used to hold at risk. The 1975 RAND study is a case in point.[14] The U.S.-government-sponsored Long Range Research and Development Planning Program, which published its study in that same year, also advocated the development of long-range conventional ballistic missiles in its final report.[15] The list of potential targets included not only Soviet military targets, such as airfields, submarine bases, and mobile missiles, but also war-supporting industrial facilities, such as oil refineries and steel production plants,[16] all of which were included in contemporary nuclear targeting plans.[17] Slightly over a decade later, in 1988, the Commission on Integrated Long-Term Strategy, appointed by President Ronald Reagan, noted that "[a]s accuracy improves, the nuclear yield needed to destroy hardened military targets also drops dramatically, to the point where conventional warheads could do the job with some of today's cruise missiles and—in the next decade—with some ICBMs."[18] Nonetheless, there is no evidence that the United States actually pursued the development of long-range conventional ballistic missiles during the Cold War.

With the end of the Cold War, the long-running debate about whether conventional forces could contribute to strategic deterrence shifted decisively. The focus of U.S. threat perceptions moved from a global conflict against the Soviet Union to "regional aggression" by states such as "Iraq, North Korea, or even Libya."[19] In such scenarios, Cold War strategist Paul Nitze argued in a famous 1994 *Washington Post* op-ed, "any sort of nuclear weapon would be politically or militarily impractical."[20] He saw "strategic, high-precision conventional weapons" as a potential solution. Simultaneously, fears of proliferation were growing, prompting U.S. strategists to begin to think through the challenges of fighting a regional war against a nuclear-armed adversary.[21] To try to nullify the nuclear threat, some analysts argued for the development of conventional weapons capable of denying the adversary the ability to employ its nuclear forces.

In 1994, for instance, RAND analyst Marc Dean Millot, called for the United States to develop "highly-responsive and accurate offensive weapon systems to destroy enemy nuclear forces."[22] Mirroring the logic from Nitze's op-ed (which had appeared just a few months earlier), Millot argued that, in combating a regional adversary, conventional, not nuclear, weapons were needed because U.S. leaders "should not be self-deterred from using the capability because they or their allies are unwilling to conduct nuclear operations."[23]

Denying a new proliferator (as opposed to the Cold War nuclear adversaries of Russia and China), the ability to use its nuclear weapons might be termed the **counternuclear** mission. The term "counternuclear" is preferred to "counterforce" because the former emphasizes that the probable target set is larger than just an adversary's extant nuclear forces and may include, for example, command and control, leadership, and nuclear warhead production and storage facilities. (Indeed, U.S. strategic targeting plans have *always* had much larger target sets than just an adversary's nuclear forces.[24]) To try to defeat attacks, many potential counternuclear targets are heavily fortified, often by burial, and are referred to as "hard and deeply buried targets." Others, including many types of ballistic missiles, are mobile.

The idea of using conventional weapons for the counternuclear mission was picked up within the U.S. government even before Nitze wrote his op-ed. In December 1993, Secretary of Defense Les Aspin launched the Defense Counterproliferation Initiative.[25] Among the goals he identified at its outset was the development of non-nuclear technology for destroying hard and deeply buried targets. The following year, a concrete step along the development pathway was taken when U.S. Strategic Command and U.S. Air Combat Command formally identified a military requirement for weapons capable of holding such targets at risk by issuing a Mission Need Statement intended to catalyze research and development efforts.[26]

A wide variety of weapon systems—most of which were neither hypersonic nor long range—were seen as having a role in conducting counternuclear strikes against new proliferators.[27] However, conventional ICBMs and SLBMs were seen as one arrow in the counternuclear quiver. Because of the extremely high speeds at which they reenter the atmosphere, their use as penetrators to defeat hard and deeply buried targets was explored.[28] Their rapid travel times also led to the suggestion that, especially if equipped with a maneuvering warhead, they could be used to hold mobile missiles at risk.[29]

The 1990s saw the start of official efforts to study and conduct research and development into long-range conventional ballistic missiles. In the early to middle part of the decade, the U.S. Navy Systems Project Office explored the option of delivering conventional warheads with Trident C4 sea-launched ballistic missiles.[30] More significantly, the Pentagon also funded the Missile Technology Demonstration, designed to test the ability of a ballistic missile to penetrate hard rock. The third and final test, conducted in September 1998, saw the reentry vehicle penetrate to a depth of over 13 m (or 44 ft., which is sufficient to reach some, but by no means all, deeply buried targets).[31]

Following these experiments, in December 1998, the Air Force Research Laboratory issued a Request for Proposals to industry for a conventional ICBM penetrator warhead capable of defeating hard and deeply buried targets.[32] While none of these programs appear to have led to acquisition efforts, they do demonstrate that the U.S. government was exploring conventional ICBMs and SLBMs before the Bush administration formally initiated the CPGS program.

The concept of a Conventional Prompt Global Strike capability fit very naturally with thinking in the Bush administration's Pentagon. In its 2001 Quadrennial Defense Review, the Bush administration expressed its intention to move away from traditional threat-based planning to a capabilities-based approach that emphasized the unpredictability of international relations and the consequent importance of being able to defeat an adversary regardless of "who the adversary might be and where a war might occur."[33] Within this framework, there was a natural attraction to long-range high-precision conventional weapons capable of hitting a target anywhere in the world within a short period of time. Indeed, the importance of "long-range precision strike" was emphasized in the 2001 Quadrennial Defense Review as a critical component of a capabilities-based approach.[34] Subsequently, the 2001 Nuclear Posture Review further developed this idea in the form of a "new triad," the "first leg" of which consisted of "new non-nuclear strategic capabilities," combined with the "Cold War triad" of nuclear delivery systems.[35] Hard and deeply buried facilities were once again identified as a particularly important target for these new conventional capabilities.

In 2003, a new mission, Global Strike—"the ability to rapidly plan and deliver limited-duration and extended-range attacks to achieve precision effects against highly valued adversary assets"[36]—was defined and assigned to U.S. Strategic Command.[37] (To avoid confusion, it is important to note that Conventional Prompt Global Strike is a subset of Global Strike, which also includes nuclear and "non-prompt" conventional attacks, as well as non-kinetic actions, such as cyberattacks and electronic attacks, that do not involve delivering physical ordnance to a target.) Subsequently, in May 2003, the U.S. Air Force issued the Mission Need Statement for Prompt Global Strike that has formed the basis of procurement efforts to date.[38]

Although the first years of the Bush administration saw many potential missions for CPGS proposed, the counternuclear mission always remained a core justification.[39] For instance, funds were acquired through the Defense Emergency Response Fund in the fiscal year (FY) 2003 budget to develop a steerable reentry vehicle for the Trident D5 ballistic missile with the goal of developing a penetrator to "destroy hardened underground targets, like command and control bunkers and storage sites found in Iraq and North Korea."[40] Justifying the need for this capability, Peter C. W. Flory, assistant secretary of defense for international security policy, argued that:

> in a regional crisis against an adversary armed with [weapons of mass destruction], the credibility of our deterrent may turn on our ability to threaten highly-valued assets of importance to that state's leadership while minimizing collateral damage. These assets may include [weapons of mass destruction], missiles, command and control facilities, or

> leadership bunkers, any one of which may be protected in hard or deeply-buried facilities.[41]

(This statement also illustrates that, periodically, the counternuclear mission has been framed in somewhat broader terms as a counter–"weapon of mass destruction" mission, allowing for the possibility of CPGS strikes against chemical- and biological-weapon-related assets and facilities too.[42])

Counternuclear strikes have remained an important justification for CPGS during the administration of President Barack Obama. In what is, perhaps, the administration's most comprehensive policy statement on CPGS—the report it submitted to the U.S. Congress pursuant to the Senate's Resolution of Advice and Consent to Ratification of the New Strategic Arms Reduction Treaty (New START)—it was explicit about a continuing interest in the counternuclear mission:

> CPGS systems could offer a number of benefits, including reinforcing deterrence of States like North Korea and Iran. . . . Such capabilities would increase the options available to the President in time of crisis and conflict, including specifically the ability to hold at risk key high-value targets such as [weapon of mass destruction] facilities and ballistic missiles with rapidly executed, high-precision attacks.[43]

Similarly, a 2009 report by the Defense Science Board analyzed the feasibility of a conventional counternuclear strike against a "regional adversary" possessing ten nuclear-armed mobile missiles and three underground facilities used for missile support and the storage of spare warheads.[44] While this report was much less optimistic about the feasibility of such a strike than the report by the same body published five years earlier, it suggests that counternuclear strikes are still being considered as a potential mission for CPGS.[45]

Whenever the Bush or Obama administrations have mentioned a specific target for a CPGS counternuclear strike, it has almost invariably been North Korea or Iran, or if such specificity was inappropriate, "rogue states" or "regional adversaries." However, both Russia and China (which are referred to as "near-peer competitors" in U.S. military jargon) have expressed serious concerns that, in a deep crisis, the United States might attack their nuclear forces with CPGS or other non-prompt high-precision conventional weapons. There is very little evidence that the U.S. government is considering CPGS for strikes against Russian or Chinese nuclear forces, or that this purpose has ever attracted significant governmental support, even if it has, very occasionally, been advocated by officials (see the box, "How Much Interest Is There in Directly "Substituting" Nuclear Weapons With CPGS Capabilities?" on p. 29). In fact, there is equally little evidence that Washington is considering CPGS strikes against Russia for any reason. By contrast, some potential missions for CPGS other than the counternuclear mission might involve strikes on China. But it is Chinese conventional forces, not Chinese nuclear forces, that would be the targets of such strikes.

TERRORISM

During the Cold War and the 1990s, conventional ballistic missiles were not considered for use against nonstate actors. The terrorist attacks of September 11, 2001, however, influenced U.S. defense thinking in many areas, including about potential roles for long-range conventional strike weapons. For example, the 2008 report on CPGS by the National Research Council (NRC) of the U.S. National Academies and Defense Science Board studies in 2004 and 2009, along with other notable reports on strategic strike, have connected **counterterrorism** missions with hypersonic long-range conventional capabilities.[46]

The archetypal scenario invoked for the use of CPGS weapons against nonstate actors is a meeting of terrorist leaders. The NRC advances two reasons why long-range hypersonic weapons might be needed in this scenario.[47] First, it argues that, since the exact time and place of the meeting may not be known until the last minute, the United States might have very little time to plan and execute an attack, placing a premium on weapon speed. Second, it argues that if the United States conducts the attack with non-prompt weapons, such as cruise missiles, the target could be forewarned in the time taken for the weapon to arrive. To illustrate this point, it gives the example of a failed 1998 cruise missile attack against Osama bin Laden in Afghanistan. The National Research Council cites a source that argues that the Pakistani Navy may have detected the missiles in flight, resulting in a warning that reached the intended target beforehand.[48] Other analyses have disputed this version of events, arguing that bin Laden probably decided to skip the meeting days beforehand after an associate of his was arrested.[49]

This particular attack aside, the general difficulty of killing bin Laden in the late 1990s seems to have influenced thinking within the Bush administration about the potential value of CPGS more broadly. In 2006, for instance, in justifying the need for CPGS at a hearing of the Senate Armed Services Committee, Flory pointed to "the difficulty that President Clinton and his people had dealing with the Osama bin Laden threat," and the way that their efforts were beset by "concerns about boots on the ground, concerns about basing access, concerns about overflight, concerns about timing."[50] He argued that the Conventional Trident Modification could help fill the "gap" where "traditional options for one reason or the other do not work or do not give [the president] a risk benefit calculation that is acceptable."[51]

Other counterterrorism scenarios have been advanced as well. The Defense Science Board has considered the possibility of a terrorist group acquiring a "weapon of mass destruction" that is being carried in "a large backpack," which the United States "has no more than 24–48 hours to attack or capture . . . before it is moved and perhaps lost."[52] And some have argued that CPGS weapons could be useful for interdicting the transport of nuclear material by a terrorist group or the "transfer of WMD from rogue state to terrorists."[53]

There is a perception among some legislators and analysts that counterterrorism is the primary purpose of CPGS.[54] That perception is almost certainly incorrect. While U.S. officials, particularly during the Bush administration but also during the Obama administration, have certainly mentioned counterterrorism applications of CPGS on multiple occasions, these references have not been as common as mentions of other uses, especially the counternuclear mission. Given that the kind of counterterrorism strikes for which CPGS might be acquired are relatively uncontroversial, at least compared to other potential applications, there is good reason to suppose that the relative scarcity of official public mentions reflects private thinking within the U.S. government.

ASYMMETRIC THREATS

Over the course of the last decade, the focus of U.S. defense planning has shifted from counterterrorism and counterinsurgency back toward interstate warfare. As the recent "rebalance" to Asia exemplifies, concerns about the possibility of conflict with China are particularly prominent. In fact, these concerns emerged during the latter years of the Clinton administration and the very early years of the Bush administration, though they were eclipsed for a while after September 11, 2001, by substate threats.

The principal challenge facing the United States in interstate warfare is overcoming potential adversaries' "asymmetric" capabilities that are intended to exploit specific U.S. weaknesses and hence prevent the United States from employing its overwhelming conventional strength decisively. CPGS has been proposed as a potential way of neutralizing two such asymmetric threats: antisatellite (ASAT) weapons and anti-access/area-denial (A2/AD) capabilities.

ASAT Weapons

Satellites are a key enabler of contemporary U.S. military operations because of their critical role in many facets of warfare including communications, navigation, and surveillance. U.S. concern about antisatellite weapons is primarily focused on China (although concern is also sometimes expressed about Russia).[55] Beijing is believed to be developing various

ASAT weapons and some Chinese military writings stress the potential value of antisatellite operations against the United States.[56]

China successfully tested a hit-to-kill ASAT weapon against one of its own satellites at an altitude of 850 km (530 mi.) on January 11, 2007, thus demonstrating some capability to target U.S. satellites that orbit relatively close to the earth, such as reconnaissance satellites.[57] China may also have tested ASAT technology capable of interception at much higher altitudes on May 13, 2013, when it launched a rocket to an altitude of about 10,000 km (6,200 mi.), although no actual interception took place.[58] Such a test would be most significant as a step toward being able to target U.S. satellites, including Global Positioning System (GPS) satellites and missile early-warning satellites, that orbit at even higher altitudes. Moreover, China's successful ballistic defense missile test of January 11, 2010, demonstrated hit-to-kill technology that could be used in ASAT applications.[59] (Indeed, on February 20, 2008, the United States used a ballistic missile defense interceptor to destroy an American satellite that was falling back to earth and, according to the U.S. government, posed a danger to people.[60])

U.S. officials publicly suggested that CPGS could be useful for combatting Chinese ASAT capabilities from at least as early as 2005.[61] However, the issue came to the fore in the aftermath of China's 2007 ASAT weapon test. Shortly after that test, in a hearing of the House Armed Services Committee, James Cartwright, the commander of U.S. Strategic Command, was asked to give examples of specific scenarios in which the United States might consider using a CPGS weapon. In his reply, he stated:

> let us take as an example the recent ASAT test. If the target is deep and you want to go in there and ensure there cannot be a second launch, then having a conventional capability against something that was launched that was conventional in nature, as the ASAT is, that seems to me to be an appropriate target to defend our interests in space.[62]

Chinese ASAT missiles themselves are presumably one potential target in the **counter-ASAT** mission. At least some (and possibly all) of these weapons are mobile, including the ASAT weapon used in China's January 2007 test.[63] Other potential ASAT-related targets, such as radars or facilities that can be used to disable satellites with lasers, are fixed. These fixed facilities appear to be located "deep" within China (along with, perhaps, some or all of the ASAT missiles). For instance, according to a study by the Center for Strategic and Budgetary Assessments, there is an ASAT facility in western China near Xinjiang.[64] This site is over 2,500 km (1,600 mi.) from the nearest coastline, placing it beyond the reach of existing sea-launched cruise missiles. It is within range of air-delivered weapons—but only if the aircraft used to deliver them can survive Chinese air defenses.

References to the counter-ASAT mission became less frequent after 2007. Cartwright's successor at U.S. Strategic Command, General Kevin Chilton, brought the subject up before the House Armed Services Committee again in 2008, emphasizing the unattractiveness of the nuclear alternative:

> Let us hypothesize there is a nation that were to field a robust anti-satellite capability, akin to the capability we saw demonstrated by the Chinese, and let us say that nation were to attack our satellites. . . . And so when the phone rings on the STRATCOM Commander's desk on that scenario, because he is in charge of defending space, and the President says, "General Chilton, make them stop," today, I can offer him a nuclear option. A country has attacked our space assets, but no American has died in this scenario. I am not saying that that would not be the option chosen, but wouldn't it be also nice to have a Prompt Global Conventional Strike capability in the quiver to be able to offer that to the President to make them stop? And that is where I think this concept has its greatest strength.[65]

One year later, in April 2009, a leaked Pentagon report to Congress that was obtained by Global Security Newswire also included the "pending employment of an antisatellite weapon" as a possible application of CPGS.[66] Since then, however, the counter-ASAT mission does not appear to have been mentioned, in the context of CPGS, by an administration official. Looking in from the outside, it is impossible to tell whether this scarcity is a result of a lack of support within the U.S. government for acquiring CPGS weapons for this mission or whether there is more widespread support but the mission is too sensitive to discuss publicly.[67]

Anti-Access/Area-Denial Systems

The proliferation of anti-access/area-denial systems is another challenge that has recently risen to the fore of U.S. defense planning. Potential adversaries' anti-access capabilities are designed to prevent American forces from entering a theater of operations by holding fixed bases, such as ports and airfields, and mobile assets, such as ships, at risk. Area-denial capabilities are intended to hinder the movement of U.S. forces in contested areas, prevent it or make it prohibitively costly. A2/AD capabilities are, of course, not new. Air defenses, land mines, and sea mines are all examples.

China, in particular, is at the cutting edge of developing A2/AD capabilities targeted against the United States. Its development of maneuverable medium-range ballistic missiles (themselves non-global CPGS-like systems), including DF-21D for the purpose of targeting U.S. aircraft carriers and DF-21C for holding land-based targets at risk, has elicited considerable concern within the United States.[68] Yet, these missiles are just one element among a wide range of capabilities for A2/AD operations, or "counterintervention" operations as Chinese military strategists term them. Other elements include kinetic capabilities (such as cruise missiles and short-range ballistic missiles), non-kinetic capabilities (such as cyber and electronic warfare systems), anti-space capabilities (which are both kinetic and non-kinetic) and supporting systems such as radars, and command and control.[69]

Unlike antisatellite weapons, however, A2/AD capabilities of concern are not restricted to China. Iran, which is developing a "'hybrid' A2/AD strategy that mixes advanced technology with guerrilla tactics,"[70] is another challenge and one that, in some ways, may be more urgent than China's because a U.S.-Iran conflict is—and could well remain—more likely than a U.S.-China conflict.

The 2010 Quadrennial Defense Review singled out the development of A2/AD capabilities in China, Iran, and North Korea, and announced the development of an Air/Sea Battle Concept to provide guidance for operational plans to combat these threats.[71] One key element of this multifaceted approach is the ability to strike deeply within an opponent's territory. The Joint Operational Access Concept, published in January 2012, indicates that the targets of such strikes might include "critical hostile elements, such as logistics and command and control nodes, long-range firing units, and strategic and operational reserves."[72]

A range of strike assets would unquestionably be needed for the **defense suppression** mission, but both officials and official documents have indicated that CPGS *might* have a role to play. Clearly, the ability to penetrate defenses is a prerequisite for conducting defense suppression attacks successfully. The high speed of CPGS weapons would offer some advantages in this regard. Most significantly, the 2010 Quadrennial Defense Review, in its discussion of the long-range strike systems needed to combat A2/AD capabilities, states that the Department of Defense "plans to experiment with conventional prompt global strike prototypes." In a similar vein, Michael Schiffer, then deputy assistant secretary of defense for East Asia, stated in a March 2011 congressional hearing that "to counter competitors' anti-access/area denial investments . . . we are examining such technologies as prompt global strike capabilities."[73] Given the title of the hearing was "Long-Term Readiness Challenges in the Pacific," there seems little doubt that the primary competitor he had in mind was China.

Given the very high unit cost of CPGS weapons, their use would have to be relatively restricted. Even a deployment capable of striking hundreds of targets, which was advocated by the Defense Science Board in 2004 but is probably significantly larger than anything being contemplated today,[74] could deliver only a small fraction of the total firepower expended in a major military campaign, especially one involving the suppression of A2/AD capabilities. Advocates of using CPGS argue that their limited use early in a conflict could have a disproportionate effect by disabling or destroying key defensive systems, enabling follow-up attacks by less survivable U.S. forces.[75]

A number of statements by senior U.S. officials indicate a potential interest in using CPGS in exactly this way. In 2009, for instance, Chilton stated that CPGS weapons could be employed "to disable an adversary's command-and-control capability as the leading edge of a broader combat operation."[76] In 2006, Cartwright identified "radars, and integrated air defense components" as potential targets for CPGS strikes.[77] Even as far back as 2005, a draft study plan for the Prompt Global Strike Analysis of Alternatives discussed, at length, the significance of anti-access capabilities.[78] While no study plan—let alone a draft—should be regarded as a statement of U.S. policy, the document does suggest that the Pentagon started to consider CPGS for defense suppression before such discussions surfaced more prominently during the Obama administration.[79]

Today the Pentagon still seems to be considering such uses. The most authoritative statement on defense policy issued to date during the Obama administration—the 2010 Quadrennial Defense Review—makes it clear that the Pentagon has not yet taken any final decision about whether CPGS weapons might be suitable for countering A2/AD capabilities. In fact, the decision is not simply a binary choice about whether to endorse or exclude their use for this purpose. Depending on the cost-benefit analysis, the Pentagon could, for example, endorse their usefulness against regional adversaries, such as Iran, but not against near-peer competitors, such as China.

IDENTIFYING MISSION REQUIREMENTS

Officials in both the Bush and Obama administrations have often not distinguished between different potential missions for CPGS, preferring instead to talk generally about the need to hold distant, time-critical, highly defended, fleeting targets at risk. The lumping together of terrorists with other "fleeting targets," such as mobile missiles, is a particularly stark example.[80] Part of this tendency toward abstraction surely results from the difficulty that all governments face in discussing politically sensitive scenarios in public. But, it also originated with the Bush administration's preference for a capabilities-based planning approach and so appears to have influenced behind-the-scenes thinking too. In 2007, for example, Brian R. Green, deputy assistant secretary of defense for strategic capabilities, stated baldly that "we prefer actually in our shop not to talk about specific scenarios" for CPGS.[81]

There are two problems with this approach. First, it ignores important differences in weapon requirements for each of the four potential missions for CPGS. In fact, from the perspective of weapon requirements, the counternuclear and counter-ASAT missions can usefully be subdivided into preemptive cases (in which the United States believes an attack is imminent and seeks to preempt it) and retaliatory cases (in which an adversary has struck first and the United States seeks to prevent further attacks). Second, a capabilities-based approach ignores the differences between potential CPGS technologies. These technologies have different military strengths and weaknesses; how effective any particular technology might prove would depend on the specifics of the scenario.

The ability of candidate CPGS technologies to meet mission requirements is analyzed in chapter 3. Here, the nature of those requirements is the focus. Clearly, the ideal weapon would have any number of attributes; the National Research Council identified no fewer than fifteen, ranging from volume of fire to value for capability evolution.[82] However, the potential deficiencies of existing systems are at the heart of the issue. After all, in acquisition decisions, a critical aspect of the cost-benefit analysis is—or at least ought to be—whether a new weapon would permit the United States to successfully prosecute military missions that it cannot with existing systems. Advocates of CPGS identify four areas that need improvement: weapon speed, range, ability to penetrate defenses, and ability to cause sufficient damage to the target set.

Weapon Speed

The most fundamental argument advanced for CPGS is that existing weapons may be too slow for time-critical missions. But a focus on weapon speed tends to obscure a crucial distinction between **promptness** and **tactical surprise**. The distinction between promptness and tactical surprise is important because some CPGS missions require promptness whereas others require tactical surprise (a few may even require both).

Prompt weapons are capable of reaching their targets a short time after an employment decision is made. Tactical surprise requires that an adversary gain little or no warning of an incoming strike. Tactical surprise can, in turn, be distinguished from strategic surprise, which refers to the absence of warning of a conflict. The Arab-Israeli Wars in 1967 and 1973 illustrate the difference between tactical and strategic surprise. In 1967, both sides were expecting a war, but Israel achieved tactical surprise with an unanticipated preemptive air offensive. In 1973, the Arab attack represented strategic surprise because Israel was not expecting a war.

Promptness is neither necessary nor sufficient to achieve tactical surprise. For instance, if an adversary can detect the launch of a prompt weapon, such as a ballistic missile, it might still gain a useful margin of warning. Conversely, tactical surprise can sometimes be achieved with non-prompt weapons, such as subsonic cruise missiles or bombers that may take hours to reach their targets but are sufficiently stealthy to avoid providing an adversary with a tactically useful margin of warning.

To capitalize upon time-sensitive intelligence about, say, the location of a meeting of terrorists or the transport of radiological material, promptness may be required. Of course, if the terrorists detect an attack in progress they could foil it by relocating. But, in reality, the target would most likely be forewarned by breaches in operational security rather than by detecting an incoming weapon. Consequently, from the perspective of *weapon requirements*, promptness rather than surprise is the primary consideration for counterterrorism missions. (The failed 1998 cruise missile strike against Osama bin Laden is a case in point.)

In other missions, tactical surprise is likely to be the key weapon requirement. A conflict in which a U.S. president orders defense suppression attacks would almost certainly have been preceded by a crisis lasting days and, much more likely, weeks or even months. (Indeed, official U.S. military doctrine appears to assume that such joint operations would generally be preceded by a crisis.[83]) Tactical surprise could be extremely important in that case since it might deny the adversary enough time to implement countermeasures, such as dispersing mobile assets or alerting defenses, that could help protect the relatively small number of high-value assets that CPGS weapons might be used to strike as part of the "leading edge" of a broader campaign. Whether or not the weapons used were prompt—whether they took one hour or eight hours to reach their targets—would probably be irrelevant. Additionally, since defense suppression attacks would be likely to last for hours—if not days—reducing the travel time of a small number of weapons would be unlikely to make much of a difference to the total duration of the operation.

For other missions, the requirement for promptness or tactical surprise is likely to depend on whether the U.S. attack is preemptive or retaliatory. For instance, if the United States were to make a preemptive counternuclear strike then tactical surprise would likely be a key requirement because, once again, any such strike would probably be preceded by a prolonged crisis. (In theory, if the United States were worried that the adversary was just a few hours away from authorizing a nuclear strike then promptness and tactical surprise would be required. In practice, this scenario would be unlikely to arise but cannot be discounted.) By contrast, if an adversary were to use nuclear weapons first and the United States wished to deny it the ability to conduct further attacks then there could be a real advantage to using a faster weapon that reduced the time needed for a response by just a few hours. In this case, promptness rather than surprise would be likely to be the key requirement. Indeed, in a retaliatory scenario, the adversary would surely expect an immediate U.S. response probably making tactical surprise impossible.

Weapon Range

Clearly, the required range of a weapon depends on the details of the scenario: the location of the target, the location of available U.S. weapons, and the "strategic depth" of the target state (strategic depth depends on both geography and the effect of defenses in forcing U.S. platforms to operate from greater distances). An additional issue, repeatedly emphasized by various U.S. officials, is the political, logistical, and expense challenges of forward basing. As a result, in the words of Cartwright, "it is unlikely we can or will have forces in every place we need them at the crucial moment."[84] This concern was a significant part of the Bush administration's argument that weapons capable of hitting a target anywhere in the world from the continental United States were required.[85]

That said, perhaps the single most important factor in determining the required range of a weapon is whether sufficient *strategic* warning time is likely to be available for the United States to deploy forces. The more planning time the United States has, the further afield it can deploy its resources, enabling the use of shorter-range weapons. The opportunity to strike a terrorist leader could conceivably arise without much warning. By contrast, the United States would have strategic warning of a serious conflict against a nation-state—certainly one in which antisatellite weapons might be used or defense suppression attacks ordered—because such a conflict would, in all probability, be preceded by a crisis lasting days, or more likely weeks.

Whether the United States is capable of capitalizing on warning time to forward-deploy strike assets depends, in part, on how easy those assets are to deploy. In this regard, sea-based assets have an advantage over land-based ones. Nonetheless, in general, the probable availability of strategic warning increases the utility of shorter-range weapons.

Defense Penetration

Another key argument for CPGS is the need to penetrate highly defended airspaces.[86] Certainly, all other things being equal, the high speeds of CPGS weapons would increase the difficulty of intercepting them. However, CPGS systems might be vulnerable to other types of defenses, such as GPS jamming. The level of defenses is likely to vary significantly between scenarios. For instance, while the states against which the United States might launch counternuclear strikes (such as North Korea and possibly Iran in the future) have some defenses, these pale in comparison to those that would be faced in defense suppression attacks against China.

Ability to Inflict Sufficient Damage to the Target Set

A final issue is the ability to cause "sufficient damage" to the target set. Existing conventional weapons have a limited ability to hold at risk certain types of targets, in particular those that are hard or deeply buried and those that are mobile. Proponents argue that CPGS weapons could more effectively hold these targets at risk.

Possible targets for CPGS strikes include an adversary's weapon systems and high-value enabling assets needed to support those systems. In some cases, destruction of the weapons themselves would be critical. For instance, in a counternuclear strike, the United States would clearly want to destroy the adversary's nuclear-armed missiles (whether or not it also targeted command and control) in case launch authorization had been predelegated or to limit damage if the conflict continued. By contrast, in a defense suppression attack, the destruction of a few key enabling assets, such as radars, could be an acceptable alternative to attacking the mobile conventional ballistic missiles used in A2/AD operations (though the United States might still try to target both).

Likewise, the definition of "sufficient damage" depends on the scenario. In some scenarios, such as a preemptive attack on mobile nuclear-armed missiles, destroying a weapon irreversibly and with high probability would probably be required. In other scenarios, a "functional kill," in which the asset was prevented from performing its function but was not physically destroyed, might suffice. For instance, if an adversary were to attack a U.S. satellite, it might be sufficient to cut off communications to remaining ASAT weapons (although, once again, physical destruction would presumably be preferable).

Different Missions, Different Requirements

Table 1 summarizes the differences in requirements between the different potential missions for CPGS. For a "typical" example of each mission, this table summarizes (i) whether promptness or tactical surprise is required; (ii) the probable level of defenses; (iii) whether strategic warning is likely to be available; and (iv) the nature of the target set.

Unquestionably, a more granular analysis could identify plenty of atypical scenarios. Nonetheless, this table makes the key point that in different scenarios, weapon requirements can be very different. This, in turn, underlines the need for a scenario-based approach to CPGS acquisition decisions. A more abstract capabilities-based approach is unlikely to give adequate weight to the differences between different missions or between different potential weapons.

TABLE 1

Analysis of Reference Scenarios for Different Missions Proposed for Conventional Prompt Global Strike

MISSION	REFERENCE SCENARIO	PROMPTNESS OR TACTICAL SURPRISE?
Counterterrorism	The United States receives intelligence about the location of a meeting of terrorist leaders and wishes to attack them.	Promptness
Pre-emptive counternuclear	The United States believes that the use of nuclear weapons by North Korea or a nuclear-armed Iran is imminent and decides to strike first.	Tactical surprise (or conceivably both)
Retaliatory counternuclear	The United States seeks to prevent further attacks after North Korea or a nuclear-armed Iran uses a nuclear weapon.	Promptness
Preemptive counter-ASAT	The United States believes that the use of ASAT weapons by China is imminent and wishes to defeat them preemptively.	Tactical surprise (or conceivably both)
Retaliatory counter-ASAT	The United States seeks to prevent further attacks after China uses ASAT weapons.	Promptness
Defense suppression	The United States seeks to nullify Chinese A2/AD capabilities at the start of a conflict.	Tactical surprise

Key: ASAT=antisatellite weapon; A2/AD=anti-access/area-denial

a Depending on the scenario, the air defenses of the country in which the terrorists are located could be relevant. It is conceivable, therefore, that more advanced defenses could be encountered in a counterterrorism mission.

b As the killing of Osama bin Laden exemplifies, strategic warning in a counterterrorism scenario is eminently possible.

c Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, U.S. Department of Defense, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, March 2009, 81, www.acq.osd.mil/dsb/reports/ADA498403.pdf.

d An adversary's use of nuclear or ASAT weapons is very likely to be proceeded by a crisis, even if there is little or no tactical warning.

e Jim Wolf, "China Poses Risk to Key U.S. Satellites: Top General," Reuters, April 11, 2007, www.reuters.com/article/2007/04/11/us-space-usa-china-idUSN1125395120070411.

f Jan van Tol with Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), 59, www.csbaonline.org/wp-content/uploads/2010/05/2010.05.18-AirSea-Battle.pdf.

g Van Tol et al., *AirSea Battle*, 19.

h Van Tol et al., *AirSea Battle*, 59 and 65.

PROBABLE DEFENSIVE CAPABILITIES	STRATEGIC WARNING?	CHARACTERIZATION OF POSSIBLE TARGETS
None or basic[a]	Possibly[b]	Mobile individuals
Basic	Very likely	Mobile nuclear-armed missiles; hard and buried warhead storage sites[c]
Basic	Very likely[d]	As above
Advanced	Very likely	Mobile ASAT missiles;[e] fixed infrastructure, including soft targets (e.g., large radars and laser facilities[f]) and buried targets (e.g., command and control[g])
Advanced	Very likely[d]	As above
Advanced	Very likely	Mobile conventional missiles; fixed supporting infrastructure, including soft targets (e.g. large radars[h]) and buried targets (e.g., command and control[g])

CONCLUSIONS AND RECOMMENDATIONS

U.S. officials acknowledge that the development of CPGS doctrine is still at an early stage—quite an admission considering that the technology was first considered in the mid-1970s, that research and development efforts have been under way since the 1990s, and that the first acquisition attempt was made almost a decade ago. One consistency has been a lack of interest in acquiring CPGS systems to conduct strikes against Russian and Chinese nuclear forces, which is significant given the concerns expressed by Moscow and Beijing about these weapons.

The slow development of doctrine is, in large part, a result of the program's history. The origin of CPGS lies in the idea of using ICBMs and SLBMs that would otherwise be dismantled to deliver conventional warheads at relatively low cost. Although this concept has now been abandoned, the original impetus behind the development of long-range hypersonic conventional weapons came more from technological opportunism than a clear mission need. During the Bush administration, some officials exacerbated this dynamic by discouraging the discussion of specific scenarios and instead advocating abstract thinking in terms of decontextualized high-value, very distant, highly defended, fleeting targets.

None of this necessarily implies that there is no useful role for CPGS weapons to fill. What it does imply is that because of the differences between potential missions—as table 1 demonstrates—a scenario-based approach is likely to be a more productive way of thinking through the acquisition process. It cannot be overemphasized that what is presented in the table is in many ways a simplification and that some potential scenarios may have different requirements. But, because CPGS is neither without costs nor risks, these exceptions actually constitute an argument for performing a more granular analysis of the potential scenarios, not for a return to more a more abstract capabilities-based approach.

In this regard, it is notable that the 2009 Defense Science Board Report on *Time Critical Conventional Strike From Strategic Standoff*, which is based on highly detailed scenarios, reached quite different conclusions from other reports (including a 2004 report by the same body). Among this report's many distinctive conclusions, the most significant is, perhaps, that

> none of the scenarios [considered in the report] exposes a need for "one hour, global range delivery." On close examination, there appears to be nothing unique or compelling about one hour. The operationally relevant meaning of "time urgent" is far more nuanced, and varies from minutes to many hours.[87]

This conclusion is certainly consistent with the argument that, in scenarios requiring tactical surprise, travel times longer than an hour are unproblematic if a weapon can avoid detection en route. It is also consistent with the argument, advanced in chapter 3, that, in order to destroy mobile targets, one hour may be too long.

In public, the Obama administration has been as abstract as the Bush administration in its discussions of CPGS. It is hard to gauge whether private discussions are more concrete. But recommendations can nevertheless be made based on available information:

1. If it is not already doing so, the Department of Defense should adopt a scenario-based approach for developing doctrine for and making acquisition decisions about Conventional Prompt Global Strike.

The Department of Defense should justify its funding requests—for both research and development, and acquisition—with reference to particular missions and, to the extent possible in public, concrete scenarios.

2. Congress should continue to press the Department of Defense to explain its thinking about the potential roles for CPGS. In addition, before funding any CPGS acquisition request, Congress should require the Department of Defense to produce an unclassified statement on the specific missions for which CPGS might be acquired.

Without a clear picture of the potential missions for CPGS, neither Congress nor the U.S. public would be in a position to make an informed decision about whether to support CPGS acquisition plans.

HOW MUCH INTEREST IS THERE IN DIRECTLY "SUBSTITUTING" NUCLEAR WEAPONS WITH CPGS CAPABILITIES?

Tied to the CPGS program is a fairly widespread belief that the United States seeks to "substitute" nuclear with conventional weapons, in the sense of using the latter rather than the former to hold a large number of targets in strategic war plans at risk. This concept has been hailed in some quarters, including by some disarmament advocates. It has also met with considerable criticism in others, including from an unlikely coalition of U.S. "nuclear hawks," who worry about weakening deterrence, and many Russian and Chinese strategists, who fear that the United States would be more willing to enact strategic war plans that do not require nuclear use. This debate probably starts from a false premise, however. There is actually relatively little evidence for serious, high-level interest within the U.S. government for large-scale substitution, although there is a stated interest in developing non-nuclear strike options for at least some scenarios *in addition to* the nuclear options.

U.S. doctrine and some statements by senior government officials are sometimes cited as evidence for an interest in direct substitution.[88] For instance, the 2001 Nuclear Posture Review reportedly states that "[t]he addition of non-nuclear strike forces—including conventional strike and information operations—means that the U.S. will be less dependent than it has been in the past on nuclear forces to provide its offensive deterrent capability."[89] In a similar vein, Obama stated to the *New York Times* in 2010 that CPGS was part of an effort "to move towards less emphasis on nuclear weapons."[90]

There are two ways to interpret such statements. They are certainly consistent with an interest in direct substitution. But, reducing reliance on nuclear weapons by strengthening conventional forces does *not* necessarily imply substitution. If CPGS capabilities are viewed as a way to help ensure U.S. conventional superiority in general purpose forces (by, for example, neutralizing an adversary's anti-access/area-denial capabilities), they could reduce the need for the United States to rely on nuclear weapons as a hedge against a loss of its conventional advantage. As such, CPGS weapons could help make the United States less reliant on nuclear weapons without actually acting as a substitute for them in strategic war plans. Which interpretation the framers of the above statements had in mind is unclear. Rather, the point is that reducing reliance on nuclear weapons and substituting for them can be conceptually distinct.

Periodically, there have been unambiguous calls for direct substitution. In 1976, no less a nuclear strategist than Albert Wohlstetter argued that "the remarkable improvements in accuracy and control in prospect will permit non-nuclear weapons to replace nuclear ones in a wide range of contingencies."[91] More recently, some high-level officials—most notably Cartwright—have made similar statements. For instance, in testimony to the House Armed Services Committee in 2007, Cartwright argued that "we need to increase our other capabilities as alternatives and replacements for the drawdown of the nuclear weapons that we have in our stockpile."[92] In testimony to the Senate a week later, he went further and argued that this process was already under way—at least in rather limited circumstances—stating that

> [w]e used cruise missile-delivered nuclear weapons to hold at risk integrated air defenses targets/weapons. We really do not need to do that with nuclear weapons any more. The conventional cruise missiles that we have are survivable, they are precise. They can address these targets. So we have been able to offload some of those targets, and that has allowed us to stay on track in the reduction of operationally-deployed nuclear weapons.[93]

Cartwright's support for substitution has, however, been strongly contested. In 2010, for example, Chilton did not dispute the possibility of holding more strategic targets at risk with conventional weapons but disagreed over the implications of doing so:

> we have to be careful when we start talking about one-for-one substitutions of conventional weapons for nuclear weapons, because when it

> comes to the deterrence mission—not the warfighting mission necessarily, but the deterrence mission—the nuclear weapon has a deterrent factor that far exceeds a conventional threat.[94]

Today, this view appears to be the dominant one in the Obama administration. Indeed, in a June 2013 report to Congress on U.S. nuclear employment strategy that announced the Department of Defense was "planning for non-nuclear strike options," the Obama administration emphasized that these options "are not a substitute for nuclear weapons." This statement presumably means that nuclear options will continue to be available to give a president the choice of whether to employ conventional or nuclear weapons.[95] Meanwhile, no official has recently argued, for example, that significant further nuclear reductions should be brought about by direct substitution or that the United States should consider CPGS (or any other high-precision conventional weapon system for that matter) to hold Russian or Chinese nuclear forces at risk.

Instead, most proponents of CPGS tend to argue that long-range high-precision conventional weapons would be useful in situations in which the use of nuclear weapons would not be credible. Or, as a U.S. naval officer said bluntly about counterterrorism missions in 2002, "we are not going to launch a strategic nuclear missile in response to a tactical terrorist strike, and the terrorists know it."[96] Similarly, the use of conventional weapons for the counternuclear mission started to be seriously considered from the early 1990s onward precisely because of fears that the use of nuclear weapons against regional adversaries would lack credibility.[97] In fact, given that the proliferation activities of North Korea and Iran are highlighted in the Obama administration's recent report to Congress, counternuclear strikes against these states may well be one of the missions for which the Department of Defense is exploring non-nuclear strike options.[98]

In the final analysis, it is hard to argue that the United States really sees CPGS as a substitute for nuclear weapons if the scenarios that motivate U.S. interest in the former are those in which use of the latter would lack credibility and if the United States continues to plan for a nuclear option in those scenarios. "Supplement" is probably a better description than "substitute."[99]

“DARPA HYPERSONIC VEHICLE ADVANCES TECHNICAL KNOWLEDGE.”

— Title of Defense Advanced Research Projects Agency press release announcing the August 11, 2011, test of the Hypersonic Technology Vehicle-2. It crashed nine minutes into a planned thirty-minute flight.[1]

A MISSION IN SEARCH OF A MISSILE: WHAT PROGRAMS IS THE UNITED STATES PURSUING FOR CPGS?

KEY INSIGHTS

The United States is pursuing multiple research and development programs that explore prompt long-range conventional strike technologies. Currently the following concepts are under development or consideration:

- Advanced Hypersonic Weapon, an intercontinental glider that could be land- or sea-based (under active development)
- Hypersonic Technology Vehicle-2, a global glider that would be based in the continental United States (recently downgraded to a risk-mitigation program)
- Sea-Launched Intermediate-Range Ballistic Missile, which could carry either a hypersonic glider or a steerable reentry vehicle (currently under consideration)
- High Speed Strike Weapon, a hypersonic cruise missile that would be air-launched and is bureaucratically separate from the Conventional Prompt Global Strike (CPGS) program (a Request for Proposals is expected)

The U.S. Department of Defense hopes to begin the CPGS acquisition process within the next few years, at which point the Obama administration has committed to opening it up to competition.

There are significant differences in the technical risk and cost of the available options:

- If armed with a simple steerable reentry vehicle, the Sea-Launched Intermediate-Range Ballistic Missile could almost certainly be deployed at the lowest cost with the lowest risk.
- The Hypersonic Technology Vehicle-2 and the High Speed Strike Weapon are probably associated with the greatest cost and risk.
- Although the Advanced Hypersonic Weapon is an intermediate case, it probably lies closer, in terms of cost and risk, to these more ambitious options than the Sea-Launched Intermediate-Range Ballistic Missile.

Differences in the amount of time it would take to deploy potential CPGS weapons are much less marked than differences in technical risk and cost.

To date, the U.S. Congress has focused, almost exclusively, on the costs and risks of sea-based systems and has not compared them to the costs and risks of the alternatives.

More than a decade after the U.S. Air Force identified the need for the capability to "strike globally and rapidly with joint conventional forces against high-payoff targets,"[2] a solution has yet to be identified. In this sense, Conventional Prompt Global Strike is still a mission in search of a missile.

Over the course of the last decade, efforts to develop a CPGS capability have slipped progressively further behind schedule. When the administration of President George W. Bush first unveiled its plan for the Conventional Trident Modification (CTM) in 2006, it indicated a goal of fielding the first weapons by 2008.[3] In 2008, the year after Congress had refused funding for the CTM for a second time, U.S. Strategic Command signaled that it hoped to field a boost-glide weapon in 2012.[4] By early 2010, this date had reportedly slipped to 2017.[5] Following flight tests in late 2010, "industry officials" were quoted as saying an initial operational capability would be ready "around 2020."[6] Today, even that estimate seems optimistic.

In spite of these difficulties, research and development efforts have progressed to the point where, over the next two or three years, the Department of Defense is likely to request funds from Congress to acquire one or more weapon systems (and, possibly, to continue research and development efforts). Any request will almost certainly be subject to considerable scrutiny by Congress, and—if the debate over the CTM is any indication—by analysts and activists, too. This scrutiny ought to be based on a relatively detailed understanding of the various candidate technologies, their financial costs, and the technical risk associated with them—that is, the chance that the program will fail to meet its goals on time and budget.

OVERVIEW OF THE OPTIONS

There are three basic approaches to long-range prompt conventional strike: terminally guided ballistic missiles, boost-glide weapons, and hypersonic cruise missiles (see the box "Hypersonic Long-Range Strike: A Technological Primer," on p. 5). The United States is currently exploring all three options.

Clearly, many attributes relevant to assessing a weapon (its maximum payload and range, the time required to reach a target, and so on) depend upon the details of its design. Still, there some important overarching differences between these technologies based on four characteristics:

- **Range** determines whether systems can be deployed in the continental United States or must be forward-based to reach potential targets.
- **Midcourse maneuverability** allows a weapon to steer around any state that has not granted overflight rights or which it is undesirable to overfly.
- **Terminal maneuverability** allows a delivery system to slow down in order to dispense certain kinds of munitions or, more ambitiously, to be redirected to defeat a moving target. Systems with very limited terminal maneuverability may not be able to defeat targets that are protected by terrain, such those located on the far side of a mountain from the launch site of a missile.
- Whether a weapon is **ballistic over the majority of the trajectory** determines whether it is accountable under the New Strategic Arms Reduction Treaty (New START)—if most of a long-range missile's flightpath is ballistic, it is covered by the treaty's limits and verification regime. The administration of President Barack Obama has also argued that a non-ballistic trajectory "reduce[s] the possibility that the launch of a CPGS system might be misconstrued as the launch of a missile carrying a nuclear weapon."[7]

Table 2 summarizes how the three basic approaches to long-range hypersonic strike differ in terms of these characteristics.

TABLE 2

Key Differences Between the Three Technological Approaches for Conventional Hypersonic Long-Range Strike

	TERMINALLY GUIDED BALLISTIC MISSILES	BOOST-GLIDE WEAPONS	HYPERSONIC CRUISE MISSILES
Maximum range	Intercontinental	Global	Regional
Midcourse maneuverability	Zero	High[b]	High[d]
Terminal maneuverability	Limited or very limited[a]	Medium or high[c]	Medium or high[c]
Ballistic over the majority of trajectory?	Yes	No	No

a Whether a terminally guided ballistic missile can defeat a terrain-protected target depends on the exact details of the reentry vehicle. See, for example, Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 106–107, www.nap.edu/catalog.php?record_id=12061.

b For example, one candidate weapon, the Hypersonic Technology Vehicle-2, is designed to have a maximum range of 17,000 km with a cross-range capability of 6,000 km. Jess Sponable, "Reusable Space Systems: 21st Century Technology Challlenges [Sic]," Defense Advanced Research Projects Agency, June 17, 2009, 20, www.nianet.org/getattachment/resources/Education/Continuining-Education/Seminars-and-Colloquia/Seminars-2009/Reusable-Space-Systems,-LaRC,-17-Jun-09.pptx.aspx.

c As discussed further in chapter 3, it is unclear whether hypersonic gliders or hypersonic cruise missiles are capable of the rapid and unpredictable maneuvering necessary to defeat advanced missile defenses by evasion.

d Although quantitative data are not available, air-breathing systems would be expected to have a greater cross-range capability (as a fraction of their total range) than gliding systems. The U.S. National Research Council, for example, describes the cross-range capability of hypersonic cruise missiles as "substantial." Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, Air Force Science and Technology Board, and Commission on Engineering and Technical Systems, National Research Council, *Review and Evaluation of the Air Force Hypersonic Technology Program* (Washington, DC: National Academy Press, 1998), 35, www.nap.edu/catalog.php?record_id=6195.

BALLISTIC AND BOOST-GLIDE TECHNOLOGY

The direction of the complex, multifaceted CPGS program, which is focused on the development of terminally guided ballistic missiles and boost-glide weapons, has been, and continues to be, shaped heavily by the U.S. Congress. This history helps to explain the successes and failures of the program to date as well as its prospects.

CPGS Prehistory

Although terminally guided ballistic missiles and boost-glide weapons have quite different trajectories, they are actually not fundamentally different technologies; rather, they lie at different ends of the spectrum of maneuvering reentry vehicles (MaRVs). The more aerodynamic lift a MaRV generates, relative to the drag it encounters, the farther it is capable of gliding.

The United States first tested a maneuvering reentry vehicle in 1966 (when the focus was exclusively on the delivery of nuclear weapons).[8] Early efforts, such as the Mk-500 "Evader" reentry vehicle, were directed toward using maneuverability to defeat ballistic missile defenses. During the 1970s, this system, which was less accurate than contemporary non-maneuvering warheads, was repeatedly and successfully flight-tested and, had Soviet defenses advanced unexpectedly, units could have been manufactured and ready for deployment in about three-and-a-half years.[9] Subsequent efforts were focused on enhancing accuracy. For the first and only time, the United States deployed a maneuvering reentry vehicle, apparently capable of limited gliding, on the nuclear-armed Pershing II ballistic missile from 1983 to 1991.[10] This missile was over five times more accurate than the Pershing IA missile (taking into account the differences in their ranges), although still too inaccurate, by a factor of five or ten, for the delivery of conventional warheads.[11]

These programs and many others provide experience that is generally useful for CPGS development. However, two programs from before the Bush administration, the Advanced Maneuvering Reentry Vehicle (AMaRV) and the Sandia Winged Energetic Reentry Vehicle Experiment (SWERVE), are particularly important since the technology developed in them is either being used directly in candidate CPGS technologies or has been proposed for use in alternative concepts (see table 3 for a summary of both programs).

TABLE 3

Selected Cancelled U.S. Maneuvering Reentry Vehicle Programs

	AMaRV (ADVANCED MANEUVERING REENTRY VEHICLE)[a]	SWERVE (SANDIA WINGED ENERGETIC REENTRY VEHICLE EXPERIMENT)[c]	E2/LETB (ENHANCED EFFECTIVENESS/ LIFE EXTENSION TEST BED)[d]
Description	Inertially guided glider	Inertially guided [?] glider	The E2 system was a GPS-guided steerable "backpack extension" for Mk 4 re-entry vehicles (carried by most Trident D5 ballistic missiles). The LETB system was an improved design capable of limited gliding.
Number of tests	3 (FY 1980–FY 1981)	3 (1979–1985)	3 (2002, 2005, 2009)[e]
Glide time	< 800 secs.[b]	About 70 secs.	Not applicable
Notes		Stable gliding for at least 70 secs. at Mach 8 was achieved in the third test, implying a glide range of about 170 km.	Accuracy goal of 10 m. Due to a loss of GPS signal in the 2002 test, the reentry vehicle impacted "well off the target" (although "within a few meters" of where the navigation system calculated the target to be). There was also a partial loss of GPS signal in the 2005 test. Its impact on accuracy is not publicly known. No details are publicly available on the outcome of the 2009 test.

Key: FY=fiscal year

These programs are either the predecessor of a CPGS system currently under development or have been proposed as the basis for a CPGS weapon.

a Thomas B. Cochran, William A. Arkin, and Milton M. Hoenig, *Nuclear Weapons Databook*, Volume 1, *U.S. Nuclear Forces and Capabilities* (Cambridge, MA: Ballinger Publishing Company, 1984), 109–110, http://docs.nrdc.org/nuclear/files/nuc_84000001c_01.pdf.

b Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 89, www.nap.edu/catalog.php?record_id=1206, gives 800 secs. as the maximum glide time for a weapon based on AMaRV. It is safe to assume that the original system had a smaller—possibly a much smaller—glide time.

c Kenneth W. Iliff and Mary F. Shafer, *A Comparison of Hypersonic Vehicle Flight and Prediction Results*, Technical Memorandum 104313 (NASA, October 1995), 7 and 29, www.nasa.gov/centers/dryden/pdf/88389main_H-2074.pdf.

d Amy F. Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, CRS Report for Congress, R41464 (Congressional Research Service, February 13, 2012), 8–10 (the latest version of this report is available from www.fas.org/sgp/crs/nuke/R41464.pdf); Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 121–22.

e Personal Communication, senior U.S. official, May 2013.

The Bush Administration: Laying the Foundations

The simplest and cheapest way to develop a CPGS capability would be to place steerable conventional reentry vehicles on land-based intercontinental ballistic missiles (ICBMs). This option was analyzed during the first term of the Bush administration, with consideration given to the use of Minuteman II ICBMs (which were taken off alert in 1991 and subsequently phased out) and MX/Peacekeeper ICBMs (which were then in the process of being retired).[12] All land-based ICBM options suffer from a range of problems, however, including the overflight of any third countries between the missile and the target, and the potential release of burned-out missile stages over the United States or Canada if existing ICBM sites are used.[13]

At the same time, the possibility of placing conventional warheads on sea-launched ballistic missiles, which do not suffer from these disadvantages, was also explored.[14] In fact, naval systems appear to have rapidly become seen as the only short-term CPGS option and, in 2006, the Bush administration sought funding to place conventional warheads on Trident D5 sea-launched ballistic missiles. This approach leveraged steerable reentry vehicle technology developed in the early 2000s under the Enhanced Effectiveness (E2) program, which subsequently morphed into the Life Extension Test Bed (LETB, also shown in table 3).

At the same time, the Bush administration restarted research and development into boost-glide vehicles. Because of their midcourse maneuverability, these systems could be based in the continental United States without the overflight problems that would afflict conventional ballistic missiles (although to avoid burned-out missile stages falling on land, coastal launch sites would still be needed). In 2003, a few months after the Mission Need Statement for CPGS was issued, the Defense Advanced Research Projects Agency (DARPA) and the U.S. Air Force initiated the FALCON (Force Application and Launch from Continental United States) program. One of FALCON's long-term goals was to develop a land-based boost-glide weapon, deployed in the continental United States, with a range of 17,000 km (10,600 mi.).[15] To this end, the program originally identified the interim goal of developing, by 2010, a less ambitious boost-glide system with a range of 6,000 km (3,700 mi.) that could then be further developed. For this purpose, DARPA selected Lockheed Martin's Common Aero Vehicle, later renamed the **Hypersonic Technology Vehicle** (HTV).[16] Although the HTV concept is informed by the U.S. experience with maneuvering reentry vehicles, it is not the direct descendant of any previously tested design.

When the FALCON program was conceived, boost-glide technology was not seen as an immediate solution for CPGS but rather a "midterm" option. The CTM concept, a less ambitious terminally guided ballistic missile, although reportedly considered by U.S. Strategic Command as "not optimal," was viewed as the only feasible near-term option.[17] In 2007, however, Congress rejected—for a second time—the Bush administration's request for CTM funding, effectively promoting the technology being developed under the FALCON program to the position of front-runner.[18] At roughly the same time, the decision was made not to flight-test the HTV after design flaws were discovered and instead to move straight to the testing of its longer-range successor, the HTV-2. This system remained the preferred candidate until late 2012.

As a risk-mitigation strategy—that is, a way to hedge its bets—Congress also insisted in 2007 that some of the defense-wide account it created to fund all research on CPGS should be spent on the **Advanced Hypersonic Weapon** (AHW), an alternative shorter-range hypersonic glider being developed by the U.S. Army. Unlike the HTV-2, the AHW is the direct technological descendent of a previously tested system, the Sandia Winged Energetic Reentry Vehicle (see table 3). Congress defended this system the following year against efforts by the Bush administration to defund it.

Technically, a third program, the **Conventional Strike Missile**, which aimed to develop and demonstrate a weaponized CPGS system, was also created during the Bush administration in 2006 to be a "midterm" successor to the CTM.[19] From the start, senior U.S. Air Force officials hinted that the technology being developed under the HTV-2 program would be employed in the Conventional Strike Missile.[20] Yet, because of concerns about ambiguity, Congress had prohibited funds from being used to weaponize the HTV-2. As a result, the HTV-2 and Conventional Strike Missile programs had to be kept legally separate.[21] Following an analysis of alternatives completed by the Pentagon in 2008, it was reported that the Conventional Strike Missile demonstration flight, which at that point was planned for 2012, would indeed be a weaponized version of the HTV-2 (how this approach was consistent with congressional prohibitions against weaponizing the HTV-2 is not entirely clear).[22]

The Obama Administration: Putting Theory Into Practice

CPGS efforts during the first term of the Obama administration largely followed the structure created in the Bush administration. In each of its first four budgets, the administration sought funding for the HTV-2 as the lead technology and the AHW as a "risk mitigation path."[23] Congress continued to fund both systems (though not necessarily at the levels requested by the administration).

Significantly, flight tests began during the Obama administration. In 2010 and 2011, two tests of the HTV-2 and one of the AHW were conducted. While the AHW test was fully successful—the glider flew over 3,800 km (2,400 mi.) to its "planned impact location"[24]—the two HTV-2 tests were not. In both cases, the HTV-2 successfully separated from its launch vehicle and achieved between 2 and 3 minutes of aerodynamic flight out of a planned 23 minutes.[25] The missions were both terminated prematurely by onboard safety systems because of different anomalies.

Presumably as a result of these tests, as well as financial pressures, the Obama administration restructured the CPGS program at the end of its first term. The FY 2014 budget request, released in April 2013, continues to foresee robust funding for the AHW at over $600 million across five years, including for two future flight tests.[26] By contrast, the FY 2014 budget request foresees significantly reduced funding for the HTV-2—a mere $12 million across five years—and drops plans for a Conventional Strike Missile demonstration flight.[27] The budget request states that during FY 2012 (which ended on September 30, 2012), the HTV-2 program was "restructured" from a "weaponized . . . demonstration to a risk reduction/technology maturation/test campaign program."[28]

Following the release of the budget, the prospects for the HTV-2 diminished further. In July 2012, presumably at about the same time that the CPGS program was being restructured, the Department of Defense announced that there would be a third HTV-2 flight test as part of a new DARPA program called Integrated Hypersonics, which originally aimed "to develop, mature, and test next-generation technologies needed for global-range, maneuverable, hypersonic flight at Mach 20 and above for missions ranging from space access to survivable, time-critical transport to conventional prompt global strike."[29] However, in July 2013, it was reported that the Integrated Hypersonics program had itself been restructured to focus on shorter-range systems and that plans for another HTV-2 flight test had been cancelled.[30]

It is now clear, therefore, that the AHW is the prime candidate for a deployed CPGS system. If the AHW is to be deployed, decisions must be made about the system's basing mode. The FY 2014 budget request foresees two future test flights—one conducted by the U.S. Army (which also conducted the 2011 flight) and one by the U.S. Navy—suggesting that the AHW could be based either on land (at, for example, Guam and Diego Garcia), on surface ships, or on submarines.[31] More than one basing mode might also be a possibility.

The Obama administration has expressed an interest in other concepts as well. In 2009 and 2010, it requested funding (at a very low level) for a ship-based boost-glide system known as ArcLight that would use a Standard Missile-3 interceptor,[32] though this program appears to have been cancelled. A more significant innovation came in early 2012, when the Pentagon, in setting out its priorities for a fiscally constrained environment, announced its intention to work on the "design of a conventional prompt strike option" for Virginia-class attack submarines.[33] This concept, which is sometimes referred to as the **Sea-Launched Intermediate-Range Ballistic Missile** (SLIRBM), still appears to be under consideration. More recently, Obama administration officials have also publicly mentioned the possibility of basing a variant of this missile on surface ships.[34]

The idea behind this weapon is not new. In the 2000s, a similar concept, the Sea-Launched Global Strike Missile, was conceived in response to criticism of the CTM. Proponents argued that the risks of an adversary's misidentifying a conventional missile as one armed with a nuclear warhead could be reduced by designing a new delivery vehicle with characteristics significantly different from those of the Trident D5.[35] The U.S. Navy proposed basing the missile aboard its four Ohio-class SSGNs (ballistic missile submarines that have been converted to carry conventional cruise missiles).[36] For the reentry vehicle, it proposed using a scaled-up version of the technology developed for the CTM, which had been tested as part of the E2 and LETB programs (see table 3) and would have a very limited glide range of "several hundred miles."[37]

Although Congress had funded the development of a similar missile at low levels in FY 2005 and FY 2006, it balked a much larger funding request in FY 2009 for the development of its reentry vehicle—in large part because the planned concept relied on technology developed for the CTM.[38] Moreover, as a way of preventing CPGS funds from being used in the development of sea-based systems, it insisted in the FY 2009 National Defense Authorization Act that the administration secure Congress' approval for research into any new CPGS concepts.[39] This language appears to have interfered with SLIRBM development.

If work on SLIRBM proceeds, the Pentagon might choose to leverage previous missile research as much as possible. The earlier missile concept, which was designed for Ohio-class submarines, would probably need to be shortened to fit within the smaller Virginia-class hull. A shortened missile, if equipped with a steerable reentry vehicle weighing about 700 kg (1,500 lb.), would probably have a range of around 2,400 km (1,500 mi.) if four missiles were fitted in each tube and 3,700 km (2,300 mi.) with three missiles in each tube (see appendix C for details).[40]

Using the steerable reentry vehicle technology developed for the CTM (or something similar) might, however, be controversial in Congress. By contrast, outfitting SLIRBM with a hypersonic gliding reentry vehicle (such as the AHW, perhaps) might prove more palatable politically and would increase its range substantially, but would also present a greater technical challenge.

To summarize, two programs to develop hypersonic gliders—the Advanced Hypersonic Weapon and the Hypersonic Technology Vehicle-2—are currently being funded (see table 4). The former, which could be based on land or sea, now attracts the vast majority of CPGS funding, while the latter has been downgraded to a risk-mitigation program.

In addition, a separate program to develop a weaponized missile, the Sea-Launched Intermediate-Range Ballistic Missile (see table 5) appears to be under consideration. Also shown is the Conventional Strike Missile. Although this program appears to have been cancelled, it is probably representative of any future weapon based on the HTV-2 (or any other very long-range glider).

TABLE 4

Current Hypersonic Glider Development Programs

	HYPERSONIC TECHNOLOGY VEHICLE-2	ADVANCED HYPERSONIC WEAPON
Maximum planned range (approximate)	17,000 km[a]	8,000 km[a]
Direct predecessor	None	SWERVE
Testing distance	7,600 km[b]	3,800 km[e]
Test 1 outcome	On April 22, 2010, the HTV-2 successfully separated from its launch vehicle allowing the collection of "139 seconds of Mach 22 to Mach 17 aerodynamic data." However, the flight was ended prematurely (about 9 minutes after launch) by an autonomous flight termination system after the vehicle began to rotate uncontrollably.[c]	On November 17, 2011, the AHW completed a "successful" flight test terminating at its "planned impact location."[f]
Test 2 outcome	On August 11, 2011, the HTV-2 successfully achieved "aerodynamically controlled flight . . . for nearly three minutes," but the test was ended automatically (about 9 minutes after launch) when, as a result of heating, "larger than anticipated portions of the vehicle's skin peeled from the aerostructure . . . causing the vehicle to roll abruptly." This problem was unrelated to the anomaly in the first flight.[d]	N/A
Basing mode of weaponized system	Land-based in the continental United States	Ship-based, submarine-based or land-based (possibly in Guam and Diego Garcia)

In the fiscal year (FY) 2014 budget request, the Hypersonic Technology Vehicle-2 (HTV-2) is described as a "risk mitigation" program. Two further tests for the Advanced Hypersonic Weapon (AHW) are planned.

a Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, D.C.: National Academies Press, 2008), 115, www.nap.edu/catalog.php?record_id=12061.

b Test flights began at Vandenberg Air Force Base in California. The target was the Ronald Reagan Ballistic Missile Defense Test Site on Kwajalein Atoll in the Republic of the Marshall Islands. For a detailed trajectory see Jess Sponable, "Reusable Space Systems: 21st Century Technology Challlenges [Sic]," DARPA, June 17, 2009, 20, www.nianet.org/getattachment/resources/Education/Continuining-Education/Seminars-and-Colloquia/Seminars-2009/Reusable-Space-Systems,-LaRC,-17-Jun-09.pptx.aspx.

c DARPA, "Falcon HTV-2," www.darpa.mil/not__found.aspx?aspxerrorpath=/Our_Work/TTO/Programs/Falcon_HTV-2.aspx (now available from http://web.archive.org/web/20120205015141/http://www.darpa.mil/Our_Work/TTO/Programs/Falcon_HTV-2.aspx); DARPA, "DARPA Concludes Review of Falcon HTV-2 Flight Anomaly," November 16, 2010, www.darpa.mil/WorkArea/DownloadAsset.aspx?id=2147484134.

d DARPA, "Engineering Review Board Concludes Review of HTV-2 Second Test Flight," April 20, 2012, www.darpa.mil/NewsEvents/Releases/2012/04/20.aspx.

e The test flight began at the Pacific Missile Range Facility in Kauai, Hawaii, and the target was Kwajalein Atoll. For an approximate trajectory see U.S. Army Space and Missile Defense Command and Army Forces Strategic Command, *Advanced Hypersonic Weapon Program: Environmental Assessment*, June 2011, 2-8, www.smdcen.us/pubdocs/files/AHW%20Program%20FEA--30Jun11.pdf.

f Office of the Assistant Secretary of Defense (Public Affairs), U.S. Department of Defense, "Department of Defense Announces Successful Test of Army Advanced Hypersonic Weapon Concept," Press Release 958-11, November 17, 2011, www.defense.gov/releases/release.aspx?releaseid=14920.

TABLE 5
Possible Conventional Prompt Global Strike Weapon Systems

	CONVENTIONAL STRIKE MISSILE (DEMONSTRATION FLIGHT CONFIGURATION)	SEA-LAUNCHED INTERMEDIATE-RANGE BALLISTIC MISSILE
Description	Hypersonic boost-glide weapon based in the continental United States	Missile-boosted weapon launched from Virginia-class attack submarines and/or surface ships
Booster	Minotaur IV Lite (Modified Peacekeeper ICBM)[a]	Newly designed intermediate-range ballistic missile
Payload capacity	1,500 kg[a]	*700 kg*[c]
Reentry vehicle	Weaponized HTV-2[a]	Either a steerable reentry vehicle (possibly using the technology developed for the Conventional Trident Modification) or a hypersonic glider (possibly the AHW)
Munition	400 kg particle dispersion weapon.[a] A unitary kinetic energy slug or high explosive warhead could probably be accommodated with straightforward modifications. With more complex modifications, an earth penetrator, dispensed munitions or an unmanned aerial vehicle could be accommodated.	Options probably include a particle dispersion weapon, unitary kinetic energy slug, high explosive warhead or earth penetrator.
Range	>17,000 km[b]	*2,400 km* (four missiles per tube) or *3,700 km* (three missiles per tube) for a steerable reentry vehicle and two-stage missile with a 700 kg payload.[c] Range would be increased with a lighter payload, three-stage missile or a hypersonic gliding warhead.
Comments	This program appears to have been cancelled. However, the Conventional Strike Missile is likely to be representative of a boost-glide weapon based in the continental United States.	The status of this weapon (first announced in January 2012) is unclear.

Properties of the Sea-Launched Intermediate-Range Ballistic Missile marked in italics are based on the assumption that it is similar in design to the earlier Sea-Launched Global Strike Missile concept and are particularly uncertain.

Key: AHW=Advanced Hypersonic Weapon; HTV-2=Hypersonic Technology Vehicle-2; ICBM=Intercontinental Ballistic Missile

a Acquisition Civil/Environmental Engineering, Space and Missile Systems Center, *Environmental Assessment for Conventional Strike Missile Demonstration*, draft, June 2010, 8–9, www.csm-ea.com/CSM%20Demo%20Draft%20EA--Part%201of2%20%2810Jun10%29.pdf.

b Assuming the glide range of the HTV-2 is 17,000 km, the complete system would have a somewhat longer range.

c See appendix C.

Toward an Acquisition Decision

In the not-too-distant future, the Pentagon hopes to move CPGS from a research and development program to an acquisition program. In 2011, then under secretary of defense Ashton Carter is reported to have articulated the goal of making a Materiel Development Decision (the first stage of the formal acquisition process) at the end of FY 2012.[41] This goal was obviously not met and Department of Defense officials now privately indicate that, to enable further research and development of candidate technologies, an acquisition decision is now expected within two or three years.

If and when such a decision is made, the choice of which weapon (or weapons) to procure may not just involve the systems that are currently being developed or considered. Congress, especially the House Armed Services Committee, has repeatedly expressed support for a competitive CPGS acquisition process and, indeed, required it in the FY 2013 National Defense Authorization Act (albeit while granting the secretary of defense waiver authority).[42] In fact, even before this provision was enacted, the Obama administration had indicated its intention to open the process to competition.[43] For example, in a 2011 letter to members of the House Armed Services Committee, Carter expressed his "intent to promote competition in all areas of CPGS acquisition at the system, subsystem, and component levels."[44] To this end, in May 2011, the U.S. Air Force issued a Request for Information, soliciting other potential CPGS concepts.[45]

What other technologies might be under consideration is unknown, but according to media reports, Boeing was expected to respond to the Request for Information with a concept based on the Advanced Maneuvering Reentry Vehicle, which was tested three times in the early 1980s (see table 3).[46] These tests apparently went well enough for the National Research Council (NRC) of the U.S. National Academies to argue in its 2008 report that the first boost-glide system developed should be based on AMaRV.[47] Any such weapon would appear to be a strong candidate in any competition.

Assessing Progress and Prospects

The upcoming acquisition decisions should take into account a range of factors from military effectiveness to geopolitical consequences. At a time of fiscal restraint, however, cost and technical risk are likely to be front and center in the debate. In the past, there has been a clear tendency to underestimate those risks.

In its 2008 report, the NRC supported fielding progressively more ambitious CPGS systems in a step-by-step approach. It proposed starting with the Conventional Trident Modification, continuing with more capable terminally guided ballistic missiles and a boost-glide system based on AMaRV technology, before finally attempting to develop a truly global system using the HTV-2.[48] The National Research Council argued that this "evolutionary" pathway would "balance technological [that is, technical] risk with the rapid fielding of improved capabilities."[49] This approach—the NRC's controversial endorsement of the CTM in particular—would almost certainly minimize *technical* risks.

In practice, the United States has chosen to pursue almost exactly the opposite approach. Rather than follow an evolutionary development pathway, the Pentagon ended up focusing, at least until recently, on the HTV-2—the most sophisticated and challenging technology under consideration. As a result, it is hardly surprising that over the last decade, acquisition timelines have lengthened. There are two reasons for this: Congress's tunnel vision in exercising its oversight role and the Pentagon's excessive technological ambitions.

The decision to focus CPGS efforts on boost-glide technology was essentially made by Congress in 2007 when it denied CTM funding for a second time and restructured the program. What stands out is that lawmakers, focused on the risks of the CTM, have paid little to no attention to the risks—both strategic and technical—posed by the alternative technologies that they chose to fund. For example, asked about these alternatives during hearings by the Senate Armed Services Committee in 2007, General James Cartwright, the commander of U.S. Strategic Command, stated that "we are seeing steady good progress in reducing what we call technical risk,"[50] and he predicted that alternative technologies "could start to appear around the 2012 to 2014 timeframe."[51] He also stated that these alternatives would have "the attributes . . . that we felt were appropriate for [a global strike capability]—speed, range, ambiguity, notice, all of the types of things that you would like to have."[52] These predictions, some of which have already proven overly optimistic, went unexamined; lawmakers were seemingly happy to accept them at face value.[53] In fact, given that Congress's restructuring of the program took place a year *before* the Department of Defense completed an analysis of alternatives for CPGS, it is clear that lawmakers were not really interested in comparing the technical risks of the alternatives.

Lawmakers' tunnel vision—their focus on the risks of the CTM and lack of interest in examining the risks of the alternatives that they decided to fund—has played a role in the program's delays. To be fair, the effect of congressional oversight has not been entirely negative: Congress' insistence that the AHW be funded, over the objections of the Pentagon, has paid dividends in recent years. But the negatives outweigh the positives.

The Department of Defense's management of the HTV-2 program may have exacerbated this problem somewhat. The HTV-2 is a high-performance vehicle that, if successfully developed, could provide the United States with a true global capability as well as an expanded understanding of cutting-edge science and technology.[54] It is also a high-risk project, not least because the HTV-2 is not directly based upon any previously tested design. Because of the high degree of technical risk, the Department of Defense sensibly sought to hedge its bets by exploring lower-risk options, including the CTM. It also sought to manage the FALCON program (of which the HTV-2 was a part) in a way that would mitigate the risk. Specifically, when the program was first conceived in 2003, DARPA sought to place a "major emphasis on incremental flight-testing."[55] In fact, it was rather emphatic on this point, stating that "the government will insist that technologies be developed in the context of a 'building block' flight-test approach and that the FALCON program remain demonstration-focused."[56] To this end, DARPA originally envisaged developing and testing a lower-performance glider, the HTV-1, without global range as a stepping stone to more advanced systems.[57] Even as late as January 2006, DARPA still intended to "develop and flight-test a low-risk, first-generation Hypersonic Technology Vehicle," before moving on to the HTV-2.[58]

This incremental approach did not materialize. Plans to flight-test the HTV-1 were abandoned during 2006.[59] This decision was made, in part, because of challenges associated with manufacturing the vehicle's thermal protection system; reengineering would have been expensive and caused longer delays.[60] Given the outcome of the two HTV-2 tests to date, it is reasonable to ask whether skipping HTV-1 flight tests ultimately proved a false economy.

As officials connected with the program have repeatedly emphasized, even the brief period of controlled aerodynamic flight at about Mach 20 attained during the two HTV-2 tests was an unprecedented achievement. The data collected during these flights are surely of tremendous value. However, the viability of the technology has not been demonstrated. Both HTV-2 tests were terminated while the glider was executing the "pull-up" maneuver after atmospheric reentry (see figure 1 on p. 7) and *before* stable gliding had been attained.[61] For the HTV-2 to become "a highly reliable, highly effective presidential-release weapon" (to use the NRC's criteria),[62] it would, therefore, be necessary to demonstrate not only that the HTV-2 can glide stably over thousands of kilometers but also that, at the end of its flight, it is capable of leaving its glide trajectory and striking a target with sufficient accuracy. In light of these challenges, it is clear why the HTV-2 effort has been downgraded to a risk-mitigation program.

The Advanced Hypersonic Weapon has a shorter range than the HTV-2 and would not allow targets across the globe to be held at risk from the continental United States. But the technical risks associated with the development of the AHW appear to be lower. Because the AHW is shaped like a cone, it can rotate during flight, allowing heat to be spread more evenly across its surface than in the case of the HTV-2. Indeed, excessive heat buildup resulting in damage to the glider's surface caused the failure of the second HTV-2 test flight.[63] Moreover, the AHW is a scaled-up version of SWERVE, a maneuvering vehicle tested three times between 1979 and 1985, and thus benefits from a greater degree of underlying technological maturity.

Against this background, the success of the November 2011 AHW test does not seem that surprising, even if it was still an impressive achievement. When SWERVE was last tested in 1985, it achieved around 70 secs. of stable gliding.[64] The AHW successfully glided for more than ten times as long. And it was quite accurate. The target for the test was an area in the Kwajelein Atoll measuring roughly 290 m by 140 m (950 ft. by 460 ft.).[65] Since the AHW terminated its flight at the "planned impact location," its accuracy must already be no more than about 100 m (330 ft.)—and perhaps significantly better.

Without more information about exactly where the AHW landed relative to the intended aim point, which is not publicly available, it is not possible to identify what else the AHW must demonstrate, beyond the reproducibility of the November 2011 test. Yet, even before the Pentagon restructured the CPGS program in 2012, it was clear that the AHW was not just "a potentially useful research and development tool" that was "still too futuristic for fielding anytime soon," as some media sources claimed, but was actually a viable candidate for CPGS.[66]

Notwithstanding one successful AHW test, the Pentagon's desire to begin exploring the option of the Sea-Launched Intermediate-Range Ballistic Missile reflects, at least in part, the slow overall progress of boost-glide technology. SLIRBM requires the development of both a new missile and a new reentry vehicle. If the reentry vehicle is of the simple steerable type and is based on a previously tested design, then SLIRBM could probably be developed much earlier than any weapon using boost-glide technology (though deployment is a different matter, as explained below).

Estimating Cost and Timelines

It is notoriously difficult to estimate the cost and timelines of procurement programs. However, two government-sponsored reports—the 2008 NRC study and a 2006 study by the Congressional Budget Office—contain potentially informative estimates, which are summarized in table 6.[67] The NRC warns that, because of the nature of complex military procurement programs, "actual costs are more likely to be higher than lower."[68]

The National Research Council and Congressional Budget Office used quite different methodologies to obtain their estimates. The NRC developed "top-down" estimates based on the judgment of the committee members with their considerable experience of military procurement. The Congressional Budget Office developed "bottom-up" estimates by breaking the programs down into their constituent parts and estimating the cost of each part based on past programs. Although the two organizations did not produce fully comparable sets of figures, they do appear broadly consistent where comparison is possible. In particular, there is agreement on the HTV-2 between the NRC's figures for the cost to reach an initial operational capability and the Congressional Budget Office's figures for the costs of research, development, testing, and evaluation. This similarity is reassuring and enhances the credibility of both estimates (especially given their very different methodologies).[69] It is also notable that the estimates of CPGS timelines and costs contained in the NRC and Congressional Budget Office reports were significantly more pessimistic than contemporary contractor briefings to the NRC. These briefings suggested "that almost all of the CPGS options could be fielded within about five years from go-ahead (and at remarkably low costs)."[70] Five years later, the NRC's estimates for the time required to field a capability look increasingly accurate.

TABLE 6

Different Estimates of Timelines and Costs for Potential CPGS Technologies

	NATIONAL RESEARCH COUNCIL			CONGRESSIONAL BUDGET OFFICE	
	EARLIEST INITIAL OPERATIONAL CAPABILITY	COST OF INITIAL OPERATIONAL CAPABILITY (2007 DOLLARS, MILLIONS)	TWENTY-YEAR COST (2007 DOLLARS, MILLIONS)	COST OF RESEARCH, DEVELOPMENT, TESTING, AND EVALUATION (2006 DOLLARS, MILLIONS)	UNIT PROCUREMENT COST (2006 DOLLARS, MILLIONS)
SLIRBM with steerable reentry vehicle[a]	2019–2020[e]	900	2,500–5,000	—	—
Boost-glide missile using HTV-2[b]	2018–2024	900–3,500	5,000–12,500	2,500	36
Boost-glide missile using AMaRV[c]	2021–2025[e]	900–2,600	5,000–10,000	—	—
Boost-glide missile using AHW[d]	—	—	—	2,400	26

The sources for these estimates are Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, the National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 40, www.nap.edu/catalog.php?record_id=12061; and Congressional Budget Office, U.S. Congress, *Alternatives for Long-Range Ground-Attack Systems*, March 2006, xv, www.cbo.gov/sites/default/files/cbofiles/ftpdocs/71xx/doc7112/03-31-strikeforce.pdf. Appendix B gives more detail on how the figures from the National Research Council report are translated into those in this table.

Key: AHW=Advanced Hypersonic Weapon; AMaRV=Advanced Maneuvering Reentry Vehicle; HTV-2=Hypersonic Technology Vehicle-2; SLIRBM=Sea-Launched Intermediate-Range Ballistic Missile

a Assuming that SLIRBM is similar in design to the Sea-Launched Global Strike Missile considered by the National Research Council.

b Referred to as Conventional Strike Missile-2 by the National Research Council and the Long-Range Surface-Based Common Aero Vehicle by the Congressional Budget Office.

c Referred to as Conventional Strike Missile-1 by the National Research Council.

d Assuming that the AHW is similar to the Medium-Range Surface-Based Common Aero Vehicle considered by the Congressional Budget Office.

e The National Research Council estimated the earliest initial operational capability as 2014–2015 for the Sea-Launched Global Strike Missile and 2016–2020 for Conventional Strike Missile-1. However, there has been no work on these systems in the five years since its report so these estimates have been delayed accordingly.

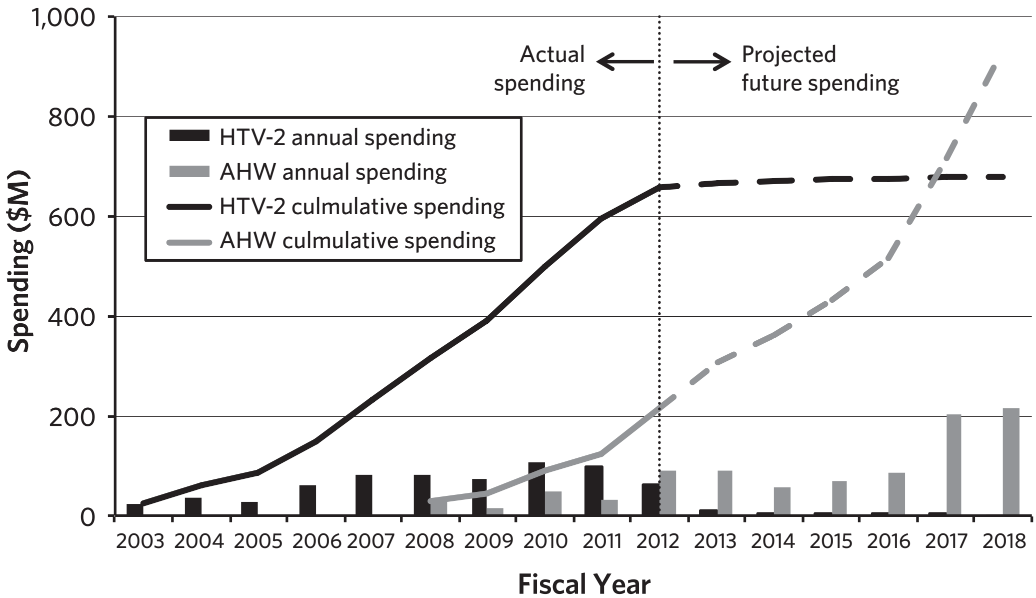
It should go without saying that a successful weapons program involves much more than money. But assuming that over $2 billion is required to reach an initial operational capability for a weaponized version of the AHW, then it would seem that the system is unlikely to become operational until some point in the 2020s. (Figure 2 shows past and planned expenditures for the HTV-2 and AHW programs.) Of course, the uncertainties in this estimate are significant. An initial operational capability might be reached sooner if, as is common, funding is increased during the acquisition phase of a project. Alternatively, it might be reached later if unexpected technical problems are encountered, as is also common.

Although the Sea-Launched Intermediate-Range Ballistic Missile based on steerable reentry vehicle technology could probably be developed substantially sooner than any boost-glide weapon, deploying it may turn out to be a bigger problem. Then secretary of defense Leon Panetta indicated that, if developed, this missile would be deployed in the Virginia Payload Module—an "additional mid-body section" that the U.S. Navy wishes to add to Virginia-class submarines procured in FY 2019 and beyond.[71] These submarines will only see service in the early to middle 2020s. As a result, an initial operational capability for SLIRBM may be attained no earlier than for a boost-glide system.

One possible way of attaining an earlier initial operational capability would be interim basing of SLIRBM in Ohio-class SSGNs. Although this option is almost certainly technically straightforward (for the reasons explained in appendix C), there are at least two major barriers to doing so. The first hurdle is financial. Since the Ohio-class SSGNs are due to be retired in the late 2020s—perhaps a decade after SLIRBM could be first deployed—the U.S. Navy may be reluctant to pay for the necessary conversion work.[72] In addition, Congress has expressed general concern that basing CPGS weapons at sea might increase the probability they could be misidentified as a nuclear weapon.[73] This concern might be exacerbated by the use of a converted ballistic missile submarine. Whatever the merits of this argument, congressional opposition is likely to constitute a second, and potentially larger hurdle.

FIGURE 2

Annual and Cumulative Expenditure for the Hypersonic Technology Vehicle-2 (HTV-2) and Advanced Hypersonic Weapon (AHW) Programs



All data are extracted from budget request documents. Actual spending data are available (or can be inferred) for fiscal year (FY) 2003 to FY 2012. Projected spending for FY 2013 and beyond is obtained from the FY 2014 budget requests. The AHW program is subelement P166 of the Prompt Global Strike Capability Development program (Program Element 0604165D8Z) in defense-wide research, development, test, and evaluation budget requests. Included in the expenditure on the HTV-2 are (i) the Common Aero Vehicle program (PE 0604856F) from Air Force budget requests prior to FY 2009; (ii) subelement P164 of PE 0604165D8Z for FY 2009 and afterward; and (iii) the FALCON subelement of the Space Programs and Technology program (PE 0603287E) from DARPA budget requests prior to FY 2011.

This approach may overestimate or underestimate the true expenditure on the HTV-2. On the one hand, some funds from the FALCON program were spent on the development of a Small Launch Vehicle and not the HTV-2. On the other hand, the new DARPA Integrated Hypersonic program (PE 0603286E), which has not been included, may also contribute to HTV-2 development. Although not exactly comparable, these data appear to be in reasonably good agreement with much less detailed figures provided in White House, *Report on Conventional Prompt Global Strike in Response to Condition 6 of the Resolution of Advice and Consent to Ratification of the New START Treaty*, February 2, 2011, 8. In that document the funds for the HTV-2 technology experiments and the Conventional Strike Missile Weaponized Demonstration are disaggregated. In this graph, they are combined under the HTV-2 expenditure.

HYPERSONIC CRUISE MISSILES

An alternative approach to long-range hypersonic strike is the cruise missile. Although the U.S. Air Force is investing in the development of hypersonic cruise missiles, there is currently relatively little interest in using them for Conventional Prompt Global Strike.[74] Indeed, the development of air-breathing weapons and CPGS technology are bureaucratically distinct. Not only are they are funded separately,[75] but the U.S. Air Force office responsible for developing hypersonic cruise missiles discusses potential requirements not with Air Force Global Strike Command, which is responsible for CPGS, but with Air Combat Command, which is now largely responsible for tactical operations.[76]

Nonetheless, a number of important studies—including the Air Force Analysis of Alternatives and the National Research Council study—have considered the possibility of using hypersonic cruise missiles for prompt conventional strike missions. And, indeed, official descriptions of what hypersonic cruise missiles might be used for are rather similar to descriptions of potential CPGS applications. For example, David Walker, then deputy assistant secretary of the air force for science, technology, and engineering, testified before Congress in April 2013 that

> we've emphasized research in hypersonic technology to provide capability to counter adversary anti-access and area denial, to actively engage time-sensitive targets and to overcome the challenges of distance and time as we shift our focus to the Pacific.[77]

The most obvious objection to using cruise missiles for prompt conventional strike missions is the relatively short-range of fast air-breathing systems. All conceivable hypersonic cruise missiles would have ranges that fall far short of intercontinental, let alone global. In its 2008 study, for instance, the NRC considered a Mach 6 missile with a range of 3,700 km (2,300 mi.).[78] Current U.S. Air Force technology development programs are focused on systems of even shorter range. However, hypersonic cruise missiles could plausibly meet the definition of long-range used here: 1,500 km (930 mi.) or more. Indeed, given the Pentagon's growing interest in conventional prompt *regional* strike, hypersonic cruise missiles deserve more careful consideration than they are currently receiving.

Technological Development

Largely motivated by the goal of developing a "spaceplane" (that is, an airplane capable of reaching space), the United States has, since the 1950s, initiated multiple programs to develop hypersonic airplanes.[79] In contrast to work on rocket-launched MaRVs, which yielded a deployed weapon system among other successes, few of these programs have resulted in flight tests. Even fewer produced significant successes. In 2001, Henry F. Cooper, director of the Strategic Defense Initiative from 1990 to 1993, remarked about spaceplane development that

> I understand that the U.S. has invested about $4 billion in the 70s, 80s and 90s . . . not counting Shuttle development and operations—and the residue of our total investment is four aging Shuttles, one crashed vehicle, a hangar queen, some drop-test articles and static displays.[80]

In the last decade, less emphasis has been placed on the goal of developing a spaceplane, in favor of a new focus on hypersonic cruise missiles and aircraft. In 2005, in fact, the U.S. government was sponsoring at least eight programs aimed at the development of cruise missiles capable of hypersonic flight or, at least, of speeds not too far below.[81] These concepts ranged in ambition from the development of short-range supersonic missiles to a "reusable Hypersonic Cruise Vehicle . . . capable of taking off from a conventional military runway and striking targets [17,000 km or 10,600 mi.] distant in less than two hours."[82] This latter weapon was part of the FALCON program, which also set the development of the HTV-2 boost-glide system in motion. DARPA set a deployment goal of 2025 and even undertook design work into a prototype, called the HTV-3X "Blackswift." This program, like many of the others under way in 2005, has since been cancelled.

In spite of the remarkably high degree of "programmatic volatility," important progress toward the goal of a hypersonic cruise missile has been made. The most promising propulsion system is the rocket-boosted **scramjet** (see the accompanying box for an explanation of how this engine works). This technology was successfully demonstrated for the first time in March 2004 when NASA flew a test vehicle, the X-43A "Hyper-X," at Mach 6.8 for 11 secs.[83] More recently, the U.S. Air Force and DARPA have focused on attaining longer flight times within the X-51A "WaveRider" program. This program saw significant successes in May 2010 and May 2013 when the X-51A flew at Mach 5 for about three and four minutes, respectively. However, there were also setbacks as two other tests in June 2011 and August 2012 ended in failures at an early stage.

As scramjet technology has been developed, various plans to weaponize it have been announced.[84] Most notably, in 2012, the U.S. Air Force announced plans for the High Speed Strike Weapon program to demonstrate a hypersonic cruise missile with the "capability to engage fixed and relocatable targets at extended ranges and survive the most stringent environments presented to us in the next decade."[85] In practice, "extended ranges" would mean distances of between 900 and 1,800 km (560 and 1,100 mi.)—potentially long enough to meet the definition of long range used here.[86] Over the past year, the program's requirements have been further defined and a draft Request for Proposals to industry has been prepared (although submissions have been delayed).[87]

WHAT IS A SCRAMJET?

Scramjet stands for Supersonic Combustion RAMjet. In a normal jet airplane, the engines are equipped with compressors (fans) to force in air, which is then mixed with fuel and ignited. At supersonic speeds, an airplane's forward movement can, by itself, generate enough pressure (known as "ram pressure") to force air into its engines, enabling engines without compressors called ramjets. For vehicles traveling below about Mach 4, the air inside a ramjet engine is slowed down to subsonic speeds. At higher speeds, the air flow can remain supersonic, resulting in an engine known as a scramjet.

Because a scramjet engine must already be moving forward quickly to function effectively, scramjet-powered vehicles need another type of engine to propel the craft to high speeds. This is most simply done with a small rocket booster (a technique successfully employed in the X-43A and X-51A programs). While the U.S. Air Force and DARPA are currently investigating the use of jet engines for this purpose, this technique has not yet been demonstrated and is geared toward reusable hypersonic vehicles such as airplanes. Boosting a cruise missile that would only be used once with an expensive jet engine would be unlikely to be cost effective.

Risks, Timelines, and Costs

The last decade has seen progress toward demonstrating the feasibility of long-range hypersonic cruise missiles (see table 7 for a summary of the test history of the two most important development programs). Most notably, the May 2010 and May 2013 X-51A tests, in which sustained flight at around Mach 5 was achieved for distances of about 210 km (130 mi.) and 370 km (230 mi.) respectively, were important proofs of concept.[88] Nonetheless, much work remains to develop a weapon capable of contributing to possible conventional prompt strike missions. Cruising times, and possibly also cruising speeds, need to be increased. In addition, as the June 2011 and August 2012 test failures demonstrate, reliability is also an issue. Nevertheless, *no* candidate CPGS technology—ballistic, boost-glide, or cruise—has yet proven its reliability in *repeated* testing.

Developing and demonstrating a reliable and effective long-range hypersonic cruise missile will require sustained focus and funding—both of which have been notably absent from past research into air-breathing hypersonic flight. This research has shown considerable programmatic volatility, as programs have appeared and disappeared rapidly. The blame probably rests with technological overreach. Given the limited funding available, there appears to have been a tendency on the part of the U.S. Air Force and DARPA to use the opportunities that did exist to create ambitious, high-risk programs that were prone to failure and funding cuts. In fact, this approach was—to some extent at least—intentional; after all, DARPA was set up precisely for the purpose of funding such projects. However, even strong advocates of air-breathing hypersonic technology acknowledge that, in this area, the high-risk approach has not been successful.[89] Slow and steady wins this race.

Experience to date indicates that the development of hypersonic cruise missiles is more likely to result from a lower risk, evolutionary pathway, building as directly as possible upon actual testing experience, even at the expense of lower performance. The successful X-51A program is a case in point, as it built directly upon technology developed as part of the X-43A program.[90] (The X-43A and X-51A programs also demonstrate the importance of being willing to tolerate some testing failures; something else that has been notably absent in recent U.S. hypersonics research.)

Any estimates of the timetable and costs for developing a long-range hypersonic cruise missile are subject to significant uncertainties. As a point of reference, a senior U.S. official stated that the goal for the High Speed Strike Weapon program is a demonstration flight by 2018.[91] If this milestone is achieved successfully then, based on past experience, an operational weapon might become available by 2025.[92] This timeline is broadly consistent with the estimates produced by the NRC in its 2008 study.[93] It is longer than the probable timelines for any of the boost-glide or ballistic systems—although probably not by much. Current funding levels would have to be increased significantly to develop a long-range hypersonic missile in this timescale. The X-51A program manager, Charlie Brink, has stated that from FY 2004 to FY 2011 about $250 million was spent on the program at an average rate of about $30 million per year.[94] The NRC estimated that attaining an initial operational capability would cost between $900 million and $2.6 billion.[95]

TABLE 7

Testing History of Two Key U.S. Scramjet Development Programs, X-43A "Hyper-X" and X-51A "WaveRider"

DATE OF TEST	APPROXIMATE SCRAMJET BURN TIME (SECS.)	MAXIMUM SPEED (MACH)	NOTES
		X-43A "Hyper-X"	
June 2, 2001[a]	0	Not applicable	Scramjet not initiated after booster failure
March 27, 2004[b]	11	6.8	Mission goals met
November 16, 2004[c]	10	9.6	Mission goals met
		X-51A "WaveRider"	
May 26, 2010[d]	143	4.9[e]	Planned burn time was 240 secs. Flight was terminated early following an anomaly caused by hot gases from the scramjet escaping into the vehicle from a damaged seal.
June 13, 2011[f]	10[g]	5.0	Scramjet ignited using ethylne fuel but failed during transition to JP7 fuel because of a lapse in airflow.
August 14, 2012[e]	Not available	Not available	After separating from the rocket booster, the cruiser lost control due to a faulty control fin.
May 1, 2013[g]	240	5.1	Mission goals met

a NASA, "X-43A Mishap Investigation Board Convenes," Press Release 01-116, June 6, 2001, www.nasa.gov/home/hqnews/2001/01-116.txt.

b NASA, "Guinness World Records Recognizes NASA Speed Record," Press Release 04-279, August 30, 2004, www.nasa.gov/home/hqnews/2004/aug/HQ_04279_guinness_record.html.

c NASA, "Faster Than a Speeding Bullet: Guinness Recognizes NASA Scramjet," Press Release 05-156, June 20, 2005, www.nasa.gov/home/hqnews/2005/jun/HQ_05_156_X43A_Guinness.html.

d Department of Defense, "Upcoming Flight of the X-51A WaveRider Hypersonic Flight Test Demonstrator," transcript of bloggers roundtable, March 15, 2011, www.defense.gov/Blog_files/Blog_assets/0315x51a.pdf, 2–3.

e U.S. Air Force, "X-51A Flight Ends Prematurely," August 15, 2012, www.af.mil/news/story.asp?id=123314235.

f Zach Rosenberg, "Second X-51 Hypersonic Flight Ends Prematurely," *Flightglobal*, June 15, 2011, www.flightglobal.com/news/articles/second-x-51-hypersonic-flight-ends-prematurely-358056.

g Guy Norris, "X-51A's Record-Breaking Hypersonic Milestone," *Aviation Week*, May 3, 2013, www.aviationweek.com/Blogs.aspx?plckPostId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post:af94414b-54c8-4257-817a-2a0696bb63e0.

CONCLUSIONS AND RECOMMENDATIONS

Acceptable cost, acceptable technical risk, and an acceptable development timetable are necessary conditions for deciding to acquire a CPGS weapon system, especially in a time of severe pressure on the defense budget. They are, however, not sufficient because any acquisition decision must also take into account broader considerations, including military utility and strategic risk.

The choice facing the United States is complex. Two boost-glide technologies, the Advanced Hypersonic Weapon and the Hypersonic Technology Vehicle-2, are under development (although the former now attracts almost all CPGS funding). Nascent efforts are being made to develop a hypersonic cruise missile, the High Speed Strike Weapon, which may or may not be suitable for long-range conventional prompt strike. Decisions must be made about the related question of basing mode. The Pentagon has expressed an interest in beginning work on the Sea-Launched Intermediate-Range Ballistic Missile. Key design issues about this weapon—including whether it would be armed with a steerable reentry vehicle or a gliding one such as the AHW—are yet to be decided. Alternatively, if the AHW is weaponized it could also be based on land. Moreover, the desire to create a competitive acquisition process will probably lead to yet more technologies entering the mix.

Without access to classified information, it is not possible to offer a credible recommendation about which system (or systems) the United States should procure. Indeed, even with access to classified information, any such recommendations would still need to await the results of ongoing research. But it is possible to draw a couple of high-level conclusions about how the risks, costs, and development timetables of the four systems compare.

First, the system that could be available with the lowest cost and technical risk is almost certainly SLIRBM, if armed with a steerable reentry vehicle. The costs and risks associated with the development of boost-glide systems or hypersonic cruise missiles are likely to be significantly higher. However, given its successful 2011 test, the AHW probably carries the least risk of any of these alternatives.

Second, the differences in when these weapons might become available are significantly less marked than the differences in their costs and risks. Although SLIRBM could probably be developed before any other system, it could not be deployed (under current plans at least) until Virginia-class attack submarines equipped with the Virginia Payload Module become operational in the early- or mid-2020s. Other systems are likely to reach an initial operational capability no sooner than the mid-2020s—although the uncertainties associated with all these timelines are considerable.

The following three recommendations, which focus on the acquisition *process*, would help ensure that the CPGS program delivers value for money:

1. The Department of Defense should establish whether there is a potential role for long-range hypersonic cruise missiles that is distinct from CPGS. If there is not, these weapons should directly compete for funding with ballistic and boost-glide systems.

Because the office of the assistant secretary of the air force for acquisition (which is responsible for hypersonic cruise missile development) is currently liaising with Air Combat Command—not Air Force Global Strike Command—about warfighter requirements for long-range hypersonic cruise missiles, there is a risk that Air Combat Command is duplicating a mission already assigned to Air Force Global Strike Command. If so, all candidate CPGS technologies—ballistic *and* cruise—should be funded out of the Prompt Global Strike account, enhancing direct competition. (The development of *short-range* hypersonic cruise missiles, if any, should continue to be funded separately.)

2. In scrutinizing the CPGS program, Congress should take a holistic view and compare the benefits and risks of different technologies, rather than focusing almost exclusively—as it has done so far—on the risks of sea-based systems.

A first step in rectifying this problem would be to hold specific hearings on the potential benefits and risks of the CPGS program as a whole.

3. Congress should recognize the reduced technical risks associated with "evolutionary" development pathways.

Over the past few years, the Department of Defense has—in both the development of boost-glide weapons and hypersonic cruise missiles—become increasingly interested in "evolutionary" technologies that directly build upon earlier designs with successful testing histories. Congress should recognize the advantages of this approach for lowering the technical risks, and ultimately the costs, of the CPGS program. With the important exception of its support for the AHW, Congress has generally refused funding for these evolutionary technologies.

WHY IS LONG-RANGE HYPERSONIC STRIKE SO PROBLEMATIC?

The two basic technological approaches to long-range hypersonic conventional strike—rocket-boosted maneuvering reentry vehicles and air-breathing cruise missiles—present quite different problems. According to DARPA, there are three key challenges to developing a MaRV capable of gliding in the atmosphere at perhaps twenty times the speed of sound for a prolonged period: aerodynamics, heat management, and accurate guidance, navigation, and control.[96] Past testing failures can be attributed to each of these challenges.

The first challenge is ensuring stable flight in an aerodynamic regime that is not yet well understood and that is extremely difficult and expensive to simulate in a wind tunnel. Through past experience with conical nuclear reentry vehicles that are designed to fall through the atmosphere as quickly as possible, the United States has considerable understanding that can be applied to terminally guided ballistic missiles. By contrast, the aerodynamics of a glider designed to stay aloft for prolonged distances are much more poorly understood. The 2010 test of the Hypersonic Technology Vehicle-2, for instance, was terminated prematurely when the flight became unstable after the vehicle began to yaw too quickly for it to be corrected.[97]

Second, at the high speeds at which MaRVs travel, friction with the atmosphere generates an extremely large amount of heat. Dissipating this heat so it does not damage the reentry vehicle and thus interfere with its aerodynamic properties is critical. Again, this problem is easier to solve with steerable reentry vehicles that spend only a short amount of time in the atmosphere. It is a much greater challenge for boost-glide systems. Indeed, the 2011 Hypersonic Technology Vehicle-2 test failed when, as a result of heating, "larger than anticipated portions of the vehicle's skin peeled from the aerostructure . . . causing the vehicle to roll abruptly."[98]

The third difficulty is ensuring accurate guidance, navigation, and control so that a weapon impacts sufficiently close to its aim point to cause the damage desired. Excluding short-range weapons, all present and past U.S. ballistic missiles rely exclusively or primarily on inertial navigation.[99] This system does not use external signals (and is hence resistant to interference) but instead computes a missile's position from measurements of acceleration. While generally adequate for the delivery of nuclear weapons, inertial navigation is, by itself, too inaccurate for the delivery of conventional weapons.

The most promising approach to boosting accuracy further is the addition of a Global Position System (GPS) receiver. Maintaining GPS reception, however, presents various technical challenges.[100] Atmospheric heating can generate plasma that can block GPS reception. This problem interfered with a 2002 test of a steerable Trident D5 reentry vehicle that was developed within the E2 program. The interruption of the GPS signal resulted in the reentry vehicle's striking a significant distance from its intended aim point.[101] The high "g-forces" experienced by a gliding reentry vehicle as it "pulls up" out of the ballistic phase of flight and into the gliding phase can also interfere with GPS reception. This problem affected the 2005 test flight of the LETB system (which was capable of very limited gliding and employed an improved version of the E2 system).[102]

The challenges facing the development of long-range hypersonic cruise missiles are quite different, but no less severe. Because cruise missiles travel slower than rocket-launched MaRVs, their aerodynamic regime is better understood. Yet, hypersonic cruise missiles face an additional aerodynamic challenge that MaRVs do not: shaping and controlling the flow of hypersonic air through the scramjet engine to ensure stable combustion. This challenge is frequently compared "to lighting a match in a hurricane and keeping it burning."[103] Much can go wrong. For example, temporary losses of airflow to the engine (known as inlet unstarts) have been a problem during the X-51A program.[104] One caused the premature failure of the June 2011 flight test. Another occurred during the May 2010 flight test, although on that occasion the engine was able to recover.

Another challenge facing hypersonic cruise missiles is the extraordinarily high temperatures of the air passing through the engine.[105] In a Mach 6 cruise missile, the *oncoming* air can reach 1,400ºC (2,500ºF). Following combustion, the exhaust gases expelled from the engine can reach 2,400ºC (4,400ºF). At even higher speeds, the challenge becomes more severe. Problems with managing these hot gases caused the largely successful May 2010 flight to be terminated slightly prematurely.[106]

Other tests of hypersonic cruise missiles have failed for reasons entirely unrelated to the scramjet engine. The June 2002 X-43A test failed even before the engine ignited because of a booster malfunction.[107] The August 2012 test of the X-51A failed because of a problem with a control fin.[108] Indeed, the diversity of reasons for test failures—for both rocket-boosted MaRVs and air-breathing cruise missiles—points to a more fundamental challenge for long-range hypersonic strike: the need to integrate many complicated subsystems where a failure in any one could cause a failure of the whole. The need for each subsystem to be highly reliable and for all the subsystems to work properly with one another probably explains, more than any individual challenge of physics or engineering, the long timescale for the development of long-range hypersonic conventional weapons.

“I SEE [THE ADVANCED HYPERSONIC WEAPON] AS A POTENTIAL LEFT-OF-LAUNCH CAPABILITY IN THE MISSILE DEFENSE BUSINESS.”

— Lieutenant General Richard Formica, Commander of the U.S. Army Space and Missile Defense Command/Army Forces Strategic Command on April 14, 2013, highlighting the possibility of acquiring the Advanced Hypersonic Weapon for potential preemptive strikes on an adversary’s missile force. [1]

DOING THE JOB: CAN CPGS WEAPONS MEET THE MISSION REQUIREMENTS?

KEY INSIGHTS

Different Conventional Prompt Global Strike (CPGS) weapons would have different military strengths and weaknesses; which CPGS system is "best" depends on the scenario.

Which—and indeed whether—CPGS weapons would remain militarily effective over the coming decades depends critically upon the countermeasures adopted by potential adversaries.

- Sophisticated adversaries could gain a useful margin of tactical warning against all CPGS weapons (except perhaps hypersonic cruise missiles) using early-warning satellites and against some CPGS weapons with missile early-warning radars.
- Hypersonic cruise missiles would be the least survivable CPGS weapon against the advanced air and missile defenses that are used to defend high-value targets; terminally guided ballistic missiles would probably be the most survivable.
- All systems might lack survivability if they could not execute evasive terminal maneuvering and could also be potentially vulnerable to advanced GPS denial technologies.

CPGS weapons could plausibly threaten mobile targets only if the surveillance assets used to supply targeting data were deployed in theater. Using such assets, including manned aircraft and unmanned aerial vehicles (UAVs), to attack the targets would be more effective and cheaper.

CPGS weapons armed with the penetrating warheads needed to destroy underground targets would be particularly vulnerable to air and missile defenses.

CPGS weapons would probably allow the United States to hold some additional deeply buried targets at risk without nuclear weapons—but how many is unclear.

The advantages of global CPGS weapons are not compelling, and the U.S. Department of Defense's decision to focus on shorter-range systems is sensible.

Careful analysis is needed to determine whether CPGS weapons or non-prompt alternatives—such as stealth technology, forward-deployed weapons, weapons capable of evasive terminal maneuvering, and weapons that do not rely solely on GPS navigation—would be less likely to fail to meet mission requirements.

Certain enabling capabilities are absolutely critical to CPGS effectiveness, including command and control; intelligence, surveillance, and reconnaissance; and battle damage assessment. They have received insufficient attention to date.

A major question about CPGS weapons is whether they—and their enabling capabilities—can "do the job," that is, whether the various CPGS systems currently under development or consideration can fulfill the particular requirements demanded by each potential mission. Because the United States must decide not only which CPGS system to procure but whether, in fact, to procure any CPGS weapons at all, CPGS must also be compared to potential alternatives if policymakers are to make fully informed decisions. Given how diverse the requirements for different missions are, there is no reason to expect that the same weapon will provide the optimal solution in each case.

Moreover, policymakers must be looking at alternatives across a decades-long time frame. One of the principal arguments for CPGS is that technical innovation by potential adversaries—including enhanced air and missile defenses, the proliferation of mobile missiles, and the emplacement of key assets underground—are rendering existing weapons progressively less effective. Such advancements are likely to continue. For this reason, future U.S. weapon systems must not only be measured against the countermeasures that potential adversaries deploy today, they must also be judged against those that could plausibly be implemented in ten, twenty, or even thirty years. Indeed, given that no CPGS system is likely to be deployed within a decade, the evolution of adversaries' countermeasures is a central issue.

Ultimately, while it is possible, on the basis of open-source information, to identify critical questions that should be asked during the CPGS procurement process, it is not always possible to answer them without access to classified—often highly classified—technical information, especially quantitative data about the performance of U.S. weapon systems and the effectiveness of both adversaries' defenses and U.S. countermeasures to those defenses. As a result, in many places, this chapter is not able to make definitive conclusions about the adequacy of CPGS capabilities. However, there is still significant value in flagging critical questions to augment and encourage other studies that would be needed to reach more concrete conclusions.

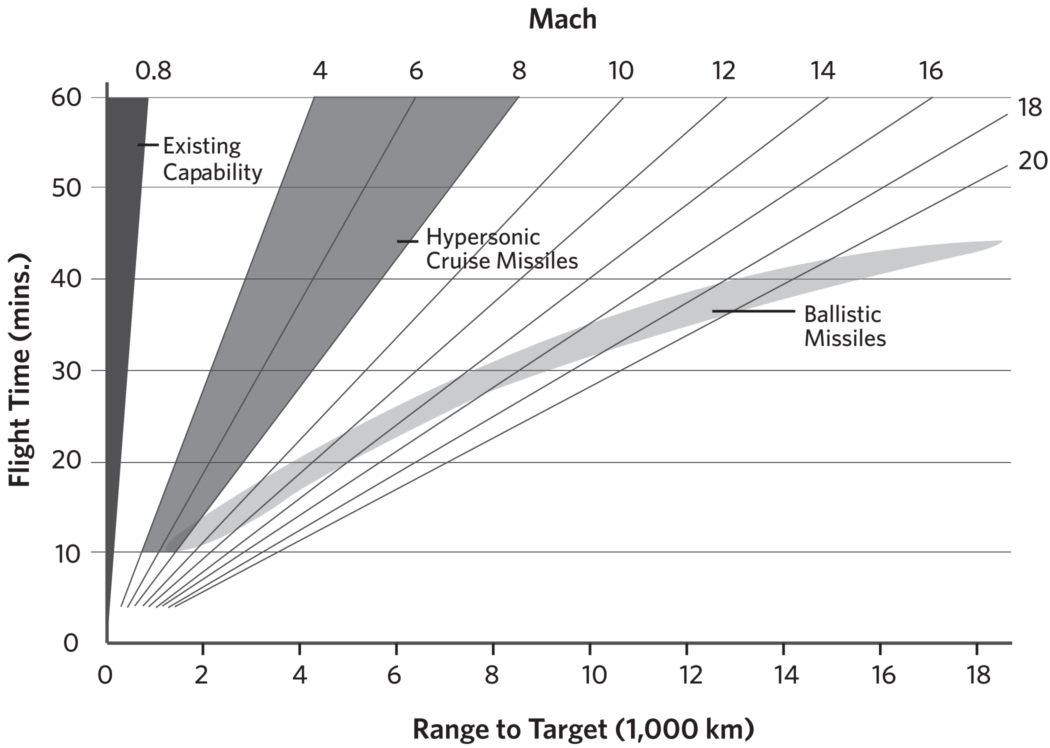
PROMPTNESS AND TACTICAL SURPRISE

Promptness

Promptness—the ability of a weapon to reach a target quickly after an employment decision—is likely to be a requirement for counterterrorism missions as well as responding to a nuclear attack or an attack on an antisatellite weapon. With the exception of nuclear-armed ballistic missiles, there is no kinetic weapon in the current U.S. arsenal that is capable of delivering prompt effects at long distances. (Figure 3 provides a visualization of weapon travel times for existing systems and CPGS weapons, along with an illustration of the variability of promptness among different CPGS systems.)

FIGURE 3

Flight Time Versus Range for Existing Subsonic Systems, Proposed Hypersonic Cruise Missiles, and Ballistic Missiles



Source: Adapted from figure 4-7 from Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 94, www.nap.edu/catalog.php?record_id=12061. Used with permission.

At short distances, it becomes possible to create prompt effects without hypersonic weapons. Missiles, gravity bombs, and other weapons fired from platforms including aircraft, ships, and submarines that are within or close to the theater of operations can often reach their targets more quickly than hypersonic weapons fired from outside.[2] Missiles delivered by UAVs, for example, are now used extensively for counterterrorism operations in Afghanistan, Pakistan, Somalia, and Yemen. The challenge of destroying mobile missiles (discussed below) provides an illustration of the advantages of forward-deployed non-prompt systems compared to CPGS weapons fired from a distance.

Tactical Surprise

Tactical surprise—preventing an adversary from becoming aware that an attack is under way until it is too late to take effective countermeasures—is valued for missions such as defense suppression and preemptive attacks on antisatellite or nuclear capabilities. Whether, in practice, an adversary could use warning of an impending or incoming attack to its advantage would depend, most importantly, on whether it also had strategic warning of the attack. That would be likely because most of the scenarios in which CPGS weapons might be employed would probably be preceded by a crisis. With enough strategic warning, the adversary could enable its forces to make more effective use of tactical warning by, for example, preparing mobile missiles to move or starting to disperse them, deploying mobile GPS jammers, or warning its troops that a strike might be imminent.

U.S. plans from the Cold War to respond to tactical warning of an incoming Soviet nuclear attack provide a point of reference for assessing how much warning time an adversary would need either to use its weapons before they were destroyed or to implement last-minute countermeasures. In the Cold War, such warning might have been as long as about thirty minutes, but could have been less than ten minutes (depending on nature of the attack).[3] If thirty minutes of warning were available, a significant fraction of the warning period would have been consumed by a series of discussions among increasingly senior decisionmakers.[4] Given this, it seems plausible that a sophisticated and well-prepared contemporary adversary could capitalize on ten minutes of tactical warning of a CPGS attack—and perhaps even less—if it were willing to forgo discussions among senior leaders by deciding on a response plan in advance or by pre-delegating the authority to decide on a response to field commanders.

There appear to be at least two main opportunities for an adversary to learn that a CPGS attack was under way: by detecting the launch of a missile or by detecting the incoming missile with radar.[5]

One opportunity would be detection of the rocket booster that all potential CPGS weapons (including hypersonic cruise missiles) use. The hot exhaust gases produced by long-range rockets during their boost phase can be detected by the overhead persistent infrared satellites used for missile warning (such as the older U.S. Defense Support Program satellites, the newer Space-Based Infrared System satellites, and their Russian equivalents).[6] Such satellites are optimized to detect exactly the kind of rocket that would be used to boost hypersonic glide weapons or terminally guided ballistic missiles. Whether they are also capable of detecting the smaller rockets that would be used to accelerate hypersonic cruise missiles is unclear (such boosters have cooler exhaust gases that produce a weaker infrared signal).

Today, only the United States and Russia have space-based missile early-warning systems.[7] Moreover, given the technological sophistication and cost of the required satellites, it is highly unlikely that any other potential U.S. adversary will develop them over the next two or three decades.[8] The one conceivable exception is China, which commissioned land-based radars for missile early warning in the 1970s.[9] In the last few years, the U.S. Department of Defense has hinted that China has recently enhanced its capabilities,[10] and it may be considering further improvements,[11] but no details of any specific modernization efforts are publicly available. Nonetheless, given these developments as well as China's ongoing strategic modernization (which includes significant investments in early warning against aircraft), it seems sensible to consider the possibility that Beijing could decide to follow the United States and Russia, and build a space-based missile early-warning system.[12] Indeed, a U.S. decision to develop CPGS could stimulate Beijing to move in this direction, if it has not already decided to do so.

An early-warning satellite would detect a CPGS weapon shortly after launch. In the case of a long-range boost-glide weapon launched from the continental United States at China, the warning time would be in the vicinity of 30 minutes. By contrast, shorter-range weapons, such as forward-deployed boost-glide systems and hypersonic cruise missiles, have shorter travel times and would provide correspondingly narrower margins of warning. For instance, a 1,500 km (930 mi.) strike with a hypersonic cruise missile or a 3,500 km (2,200 mi.) strike with a boost-glide weapon or ballistic missile would both result in about fifteen to twenty minutes of warning, assuming that early-warning satellites can detect the rocket boosters used for hypersonic cruise missiles.[13] (See table 8 for a summary of these figures.) Beijing could take steps to increase this warning time by moving its own key assets further inland, away from the coast, as U.S. missiles would generally approach China from the east. It could also continue to invest in defenses that might force some U.S. platforms, most likely aircraft and surface ships, to operate further from their targets. If successful, these steps could potentially earn China a few extra minutes of warning.

The final—and most probable—means by which a state could gain warning of an incoming CPGS attack would be radar. Unlike early-warning satellites, early-warning radars are very widespread; their technology is much simpler and cheaper. However, most current radars are optimized for aircraft early warning and would need to be modified to detect CPGS weapons, which generally cruise at higher altitudes than aircraft. The much more powerful (and expensive) radars designed to detect ballistic missiles early in flight could also be employed to provide warning of a CPGS attack. Table 8 shows the warning time of a CPGS strike that would be provided by a modified air-defense radar, based on technology roughly equivalent to the radars associated with Russia's S-300 air defense system, and an advanced missile early-warning radar (assuming that the radar is 500 km or 310 mi. in front of the target).

The radars associated with Russia's S-300 air defense system are a useful reference point, not because Russia is a potential target of CPGS, but because the S-300 has been widely exported, including to China, which has now indigenized it.[14] At the time of this writing, Russia is also insisting that it will export the system to Syria.[15] (A sale to Iran was also agreed but never completed.[16]) Moreover, the S-300 is now fairly old (the first variants were initially deployed in the 1980s) and so represents a level of technology that may be within reach of many states in the next few decades.

TABLE 8

Approximate Warning Times for CPGS Strikes Against Different Adversary Detection Systems

		HTV-2 (GLOBAL BOOST-GLIDE SYSTEM)	AHW (NON-GLOBAL BOOST-GLIDE SYSTEM)	INTERMEDIATE-RANGE BALLISTIC MISSILE	MACH 5 HYPERSONIC CRUISE MISSILE
Strike range (km)		11,000	3,500	3,500	1,500
Tactical warning time (min.)	Early-warning satellites	33	16	19	16[a]
	Missile early-warning radar[b]	4	4	14	11
	Modified air-defense radar[c]	3	3	0	8

It is assumed that the target is located 500 km behind the radar. The values in the table can be bigger or smaller by a few minutes depending on the locations of radars and targets, and the density of the radar network. The calculations for boost-glide systems are presented in James M. Acton, "Hypersonic Boost-Glide Weapons," (forthcoming). The intermediate-range ballistic missile is discussed further in appendix C.

Key: AHW=Advanced Hypersonic Weapon; HTV-2=Hypersonic Technology Vehicle-2

a Assuming that early-warning satellites could detect the booster used to accelerate hypersonic cruise missiles. Otherwise this figure would be zero.

b The missile early-warning radar is assumed to be horizon limited and, like the U.S. Pave Paws radar, can be angled to no lower than between 2 and 3 degrees to the horizontal. Missile Defense Agency, *National Missile Defense Deployment: Final Environmental Impact Statement*, July 1, 2000, vol. 4, appendix H, 1-6, www.mda.mil/global/documents/pdf/env_gmd_eis_append_h.pdf. It would be capable of detecting an incoming hypersonic cruise missile or hypersonic glider (at an altitude of between 30 km and 40 km) at a distance of between 400 km and 600 km (the calculations to produce the table assume a distance of 500 km).

c A modified air-defense radar could detect an incoming hypersonic cruise missile, which would probably have a radar cross section of between 0.01 m^2 and 1 m^2 (depending on design), at a distance of about 100 km to 300 km (the calculations to produce the table assume a distance of 200 km). Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, Air Force Science and Technology Board, and Commission on Engineering and Technical Systems, National Research Council, *Review and Evaluation of the Air Force Hypersonic Technology Program* (Washington, DC: National Academy Press, 1998), 54–55, www.nap.edu/catalog.php?record_id=6195. (Note the graph on p. 55 relates to the distance at which a missile can be engaged not the range at which it can be detected.) The same radar could detect a hypersonic glider at similar distances, albeit probably closer to 100 km. Acton, "Hypersonic Boost-Glide Weapons."

At a high level, two simple conclusions can be drawn. First, in some scenarios, an adversary could gain a potentially useful margin of warning of a CPGS attack if equipped with early-warning satellites or missile early-warning radars. Modified air-defense radars could not provide a useful degree of tactical warning except, perhaps, against hypersonic cruise missiles. Second, there is no single CPGS weapon system that minimizes the margin of warning in all circumstances. The optimal weapon depends upon the approach (or approaches) the adversary adopts to gain early warning. This finding is best illustrated in the case of the intermediate-range ballistic missile, which provides the least warning time against modified air-defense radars and the most against missile early-warning radars (see appendix C for more).

A final issue for consideration is whether slower weapons that are hard to detect could give an adversary less warning time than CPGS systems. Weapon systems that could potentially fall into the hard-to-detect category include not only stealth aircraft (such as the B-2 bomber) but also very low altitude "ground-hugging" cruise missiles. (Hypersonic cruise missiles must travel at high altitudes where the atmosphere is thinner and so cannot "hide" close to the ground.) It is beyond the scope of this report to analyze the efficacy of these alternative approaches and whether they might be compromised over time (indeed, such an analysis is probably impossible at the unclassified level). A full assessment of the relative merits of stealth and speed in minimizing adversary warning should be undertaken as part of the CPGS procurement process.

VULNERABILITY TO DEFENSES

Another central argument for CPGS weapons is that the development and diffusion of increasingly sophisticated defensive systems might render existing U.S. weapons impotent. Whether CPGS systems can penetrate these same defenses is, therefore, an important issue. Defenses include not only **air and missile defenses** that can physically destroy an incoming weapon but also those that are capable of degrading a weapon's performance without actually destroying it. The most widespread type of defense capable of this kind of "functional kill" is **GPS denial technology** designed to disable a weapon's guidance system.

GPS Denial

GPS denial is very relevant to the CPGS discussion for three reasons. First, prototype CPGS weapons appear to rely primarily on GPS navigation; any system that enters into production is likely to do so too.[17] Second, for CPGS weapons to be militarily effective, they must be extremely accurate; reducing their accuracy could significantly undermine their utility. Third, GPS denial is potentially easier and cheaper—and thus represents a more likely challenge—than air and missile defenses.

The simplest and most likely approach to GPS denial is **jamming**, that is, interfering with GPS signals by broadcasting a much stronger signal at the same frequency.[18]

Over the last two decades, potential adversaries have worked hard to exploit this vulnerability while the United States has worked hard to foil them. There are reports that the Soviet Union started research into GPS jamming and has since sold jammers to "anyone with the funds to purchase them."[19] In 2010, then South Korean defense minister, Kim Tae-young, stated that North Korea had imported truck-based GPS jammers from Russia.[20] Seoul subsequently accused Pyongyang of actually using GPS jamming technology, including in a 2012 incident that affected over 500 airplanes around Seoul's two airports.[21] China is also believed to have been very active in this area. In 2007, for instance, it was widely reported that the U.S. intelligence community was concerned that China had produced large numbers of truck-based GPS jammers.[22]

Since 2000, the United States has responded with multiple ongoing efforts, including by increasing the power of GPS satellites and developing harder-to-jam signals.[23] Pentagon plans announced in 2011 would shrink the range at which a low-powered jammer could successfully disable a handheld GPS receiver from 90 km (56 mi.) to 4 km (2.5 mi.) by 2030.[24] Moreover, the kind of GPS receiver carried by a CPGS weapon may well be significantly harder to jam than handheld ones. Nonetheless, potential adversaries might try to protect critical assets—those which CPGS weapons might be used to threaten—with exactly the kind of expensive but much more powerful jammers that both North Korea and China are reported to have procured. Such truck-based jammers could have larger ranges by a factor of 100, compared with low-powered jammers.[25]

How much effect jamming would have on CPGS accuracy is impossible to say at present. The critical issue appears to be how well a GPS navigation system can be integrated with an inertial navigation system (a technology that does not rely on external data). Inertial navigation is not sufficiently accurate by itself over the whole flight but could take over, in the event of GPS denial, for the final portion. The 2008 NRC report seemed relatively optimistic about the possibility of using inertial navigation in this way.[26] A report by the Defense Science Board published a year later was rather less sanguine.[27]

To complicate matters further, competition in this area is very dynamic. There are almost certainly steps that the United States could take to further enhance the integrity of the GPS system and steps potential adversaries could take to undermine it.[28] Moreover, there is also the possibility that an adversary could attempt to disable or destroy the satellites that broadcast GPS signals (discussed further in chapter 5). Attacking GPS satellites would be difficult, and to significantly degrade the accuracy of GPS navigation systems for even a short period of time, multiple satellites would have to be destroyed. But, over the course of the next two or three decades, such attacks might become more foreseeable.

The implications of GPS jamming may ultimately depend on the specific mission. Over the long run, for example, China's potential to deny the United States use of GPS is likely to be much greater than North Korea's or Iran's.[29] The threat of GPS denial is pertinent to all weapons that use GPS—that is, virtually all high-precision U.S. weapons—but given the cost per weapon of CPGS systems, they become a significantly less attractive investment as the risk of effective GPS denial increases. Indeed, if this risk is high, then weapons that are capable of robust performance in the face of widespread GPS denial (such as cruise missiles capable of navigating by terrain detection) might be a more sensible investment.[30]

Air and Missile Defenses

Air and missile defenses pose a second threat to CPGS weapons. In broad terms, defenses can be divided into **area defenses**, capable of protecting broad swathes of territory, and **point defenses**, capable of protecting particular targets or clusters of targets. The Ground-Based Mid-Course Defense system deployed in California and Alaska to protect the United States against a North Korean intercontinental ballistic missile (ICBM) is an example of the former. Patriot missiles, which are designed to intercept short-range missiles in their terminal phase, are examples of the latter.

Area defenses against boost-glide vehicles would be extraordinarily difficult—significantly harder than against ICBMs—because the land- and sea-based radars designed to detect and track ICBMs would be less effective against hypersonic gliders.[31] Such defenses against other forms of CPGS weapons would still be a daunting technical challenge and probably out of the reach of any potential U.S. adversary for the foreseeable future.

Point defenses against CPGS weapons are more realistic. They are expensive and therefore could not be used to defend large numbers of potential targets. But an adversary could well deem it worthwhile to try to use them to protect exactly those very high-value targets that CPGS might threaten.

The survivability of CPGS weapons against robust defenses depends in part on the type of munition they are delivering. Underground facilities are often identified as potential targets for CPGS weapons. However, a penetrating warhead designed to destroy a buried facility must be delivered no faster than about Mach 3.5.[32] At higher speeds, it deforms to such a degree on contact with the ground that its effectiveness is reduced. Consequently, a CPGS weapon would have to slow quite significantly from its cruising speed to deliver a penetrating warhead, thus becoming potentially vulnerable to robust air defenses.

There has been some discussion of using CPGS weapons to dispense submunitions (that is, a number of smaller weapons). Delivery of these weapons may also require a CPGS system to slow down significantly. Estimates of the speed at which they could be deployed range from Mach 1 to Mach 5.[33] Even Mach 5, according to the NRC, "seems . . . questionably low for surviving strong area air defenses."[34]

Other types of munitions could be delivered at the cruising speed of the weapon with implications for survivability. Hypersonic missiles would have the slowest cruising speed of any candidate CPGS system and would be the least survivable. In a 1998 report, the NRC concluded that an air defense system modeled on Russia's S-300 would have a lethal range of about 55 km (34 mi.) against a Mach 5 hypersonic cruise missile.[35] The exact figure does depend somewhat on how efficiently the missile reflects radar signals, but even in the most optimistic case considered by the NRC, the range is still more than enough for a respectable point defense system. Given the potential for the further proliferation of the S-300 or comparable systems—and of even more advanced technology—it is not surprising that, ten years later, in its 2008 report on CPGS, the NRC was still "wonder[ing] . . . about the hypersonic cruise missile's survivability against strong regional and local air defenses."[36]

The challenges of defending against conventionally armed ballistic missiles or boost-glide weapons are significantly greater. Area defenses are particularly challenging because they require an incoming missile to be intercepted early in flight while it can still reach a large number of potential targets—and thus overcoming the challenges of early detection and exo-atmospheric countermeasures. This principle is understood by defensive players in American football, who try to knock down a pass as soon as it leaves the quarterback's hands to protect the whole of the downfield area but face imposing defensive linemen blocking their paths. By contrast, the challenges to point defenses are much less severe. In this case, much like a cornerback marking a wide receiver, it becomes possible to wait until an incoming missile reenters the atmosphere before intercepting it. Although only a small area can be protected in this way, the challenges of detecting missiles shortly after launch and defeating countermeasures are avoided. Indeed, while there has been controversy about the efficacy of U.S. defenses designed to intercept ballistic missiles in midcourse (that is, after their motors have stopped firing but before they reenter the atmosphere), U.S. terminal defenses have an impressive test record.[37]

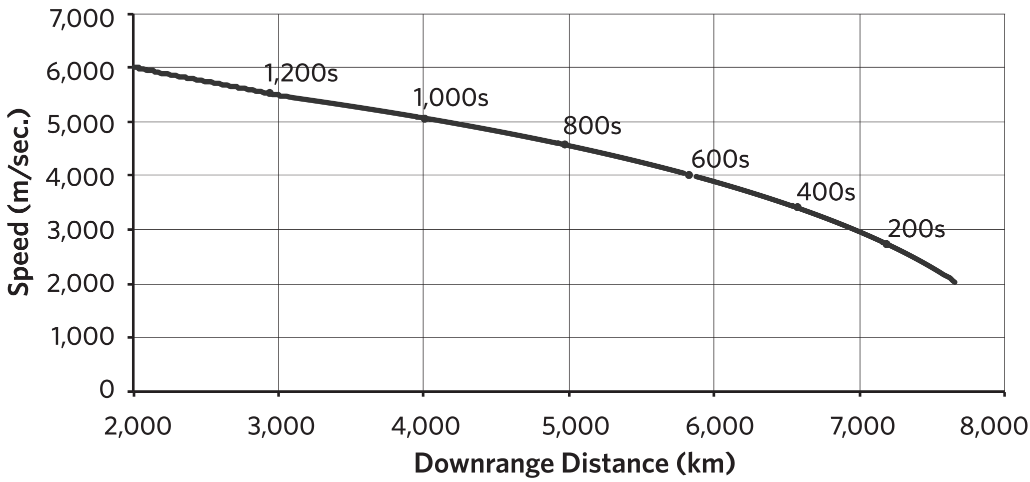
While the level of technology represented by the S-300 may have some capability against short-range ballistic missiles, it is not likely to be effective against potential CPGS weapons other than hypersonic cruise missiles. More sophisticated defenses—like Russia's S-300V or S-400—would be required to deal with terminally guided ballistic missiles or boost-glide weapons. The most sophisticated variants of the S-300V are reported to have been successfully tested against missiles with ranges of up to 2,500 km (1,600 mi.), while the S-400 is more capable still.[38] These systems—as well as more advanced successors such as the long-anticipated S-500—represent the kind of technology that might become more widely available over the next few decades, whether through purchase, technology transfer, copying, or indigenous development. Russia has sold the S-300V system, and sales of the S-400 have reportedly been agreed.[39] Most significantly for this analysis, Russia and China have a long and complex history of cooperation in air and missile defense, which they have recently decided to intensify.[40] In 2012 and 2013, there were multiple media reports that Russia had agreed to sell China the S-400 system (although according to the U.S. Department of Defense, Russia has stated that no contract has yet been signed and delivery is not expected until 2017 or later).[41] The S-300V and S-400 thus plausibly represent the kind of defenses that CPGS weapons might have to penetrate to destroy high-value targets in China or elsewhere.[42]

How effective such defenses might prove under wartime conditions against either ballistic missiles or boost-glide systems is a critical question that is extremely difficult to assess. Nevertheless, putting questions of absolute effectiveness aside, three general considerations suggest that ballistic missiles may be rather more survivable than boost-glide systems against robust terminal defenses.

First, although hypersonic gliders can reenter the atmosphere at the extremely high speeds characteristic of an ICBM, they slow significantly over the course of their trajectory because of air resistance. Take the planned speed of the two Hypersonic Technology Vehicle-2 (HTV-2) test flights that have been held to date (see figure 4). If the glider had reached the end of its flight rather than malfunctioning, it would have been travelling at around 2,000 m/sec. (4,500 mph). To put this figure in perspective, it is roughly equal to the speed that a ballistic missile with a range of 500 km (310 mi.) has on reentering the atmosphere. Such short-range missiles, including certain Scud variants, are relatively vulnerable to missile defenses. Hypersonic gliders could be made somewhat less vulnerable by starting them at higher speeds.[43] That said, under most plausible scenarios, hypersonic gliders would be likely to reach their targets at speeds characteristic of intermediate-range—and more likely medium-range—ballistic missiles, thus making them potentially vulnerable to missile defense systems comparable to the S-300V and S-400.[44]

FIGURE 4

Graph of Speed Against Downrange Distance During the Atmospheric Portion of the Hypersonic Technology Vehicle-2 Test Flights



Note that the graph starts 2,000 km downrange when the glider reenters the atmosphere. The time markings show the number of seconds until the end of the flight. During both test flights, the gliders failed to travel more than about 1,000 km after reentry. The planned trajectory of both flights was the "A" trajectory, as shown in Jess Sponable, "Reusable Space Systems: 21st Century Technology Challlenges [Sic]," Defense Advanced Research Projects Agency, June 17, 2009, 20, www.nianet.org/getattachment/resources/Education/Continuining-Education/Seminars-and-Colloquia/Seminars-2009/Reusable-Space-Systems,-LaRC,-17-Jun-09.pptx.aspx. For details of the calculations used to generate this graph see James M. Acton, "Hypersonic Boost-Glide Weapons," (forthcoming).

A second vulnerability of gliders is that they cannot be "hidden" from missile defense radars by countermeasures such as decoys because they spend the majority of their trajectory in the atmosphere.[45] Consequently, radars might be able to lock onto an incoming glider sooner than they would able to lock onto an incoming ballistic missile, which can generally be protected by countermeasures until a later point in its trajectory.

Third, hypersonic gliders appear to be at least as large—and probably significantly larger—than typical missile reentry vehicles and have broadly similar shapes.[46] As a result, radars capable of detecting and/or tracking missile reentry vehicles would probably also be capable of doing the same against boost-glide vehicles.[47] Given that the shape of a hypersonic glider is largely dictated by aerodynamic considerations, it seems unlikely it could be changed to complicate radar detection significantly. Yet, even if a "stealthy" hypersonic glider were somehow possible, the prodigious quantities of heat generated by friction with the atmosphere could provide an alternative opportunity for detection and tracking using infrared sensors. Indeed, the HTV-2 produces so much heat that it is actually visible to the naked eye, as a video of one of its tests shows.[48]

One critical area of uncertainty is whether any of the CPGS systems under consideration—hypersonic cruise missiles, terminally guided ballistic missiles, or boost-glide weapons—are capable of sufficient maneuvering to defeat air and missile defenses systems by "dodging" the interceptors. Of course, all these weapons are capable of some degree of terminal maneuvering; the question is whether any of them can be made sufficiently fast and unpredictable to defeat defenses while preserving the required degree of accuracy. Once again, it is not possible to reach a firm conclusion in the absence of detailed design information, but more maneuvering capability would lead to additional physical stresses that might lower reliability. The issue could be critical in determining whether these weapons are survivable in the face of robust defenses.

The Bottom Line

The conclusions to be drawn from these considerations are complex. There seems little doubt that, for the foreseeable future, any CPGS weapons would be designed to penetrate most defenses. But the most robust defenses are likely to be found around exactly the kind of targets that CPGS would be intended to hold at risk.

While it is hard to say much about the survivability of CPGS weapons in absolute terms, more can be said about their relative survivability. If GPS denial is a problem, it would likely be a problem for all the candidate technologies (although the effects might be more or less pronounced depending on the system's design and its operational profile). By contrast, there would appear to be significant differences in survivability against sophisticated air and missile defense systems. CPGS systems armed with penetrators or submunitions would almost certainly be the most vulnerable. Among weapons armed with other types of warheads, hypersonic cruise missiles would almost certainly be the most vulnerable. More tentatively, there are reasons to believe that boost-glide systems would be less survivable than terminally guided ballistic missiles.

Ultimately, the survivability of CPGS systems in the face of sophisticated defenses would appear to depend on two issues that are difficult to assess without classified data: the feasibility of outfitting them with accurate backup navigation systems in the event of GPS denial and their ability to execute evasive terminal maneuvering without unacceptable loss of accuracy.

For defeating advanced air and missile defenses, the main alternative to speed is stealth, including intrinsically stealthy weapons and terrain-hugging cruise missiles. These classes of weapon can more easily be equipped with backup navigation systems in the event of GPS denial. Ultimately, it is far from obvious whether speed or stealth is likely to be the most effective technique for overcoming sophisticated defenses over the next few decades. It would be a mistake, however, to assume that the speed offered by the CPGS concept is necessarily the best approach.

RANGE

There is considerable variation in the ranges of the CPGS weapons currently under development.

At one extreme is the HTV-2 with its global reach. The Advanced Hypersonic Weapon (AHW), a boost-glide system with a planned range of 8,000 km (5,000 mi.), would also have a range well beyond the 5,500 km (3,400 mi.) threshold that traditionally defines an intercontinental weapon. Hypersonic cruise missiles, which might not have enough range to qualify as long range for the purposes of this report, lie at the other extreme. Conventionally armed ballistic missiles fall in between.

The United States already has non-prompt conventional platforms with global reach. Bombers, in particular, have essentially unlimited range if mid-air refueling is available. B-2s, for instance, have flown non-stop from their base in Missouri to conduct missions over Afghanistan, Iraq, and Kosovo, and exercises over South Korea.[49] Flying at speeds of slightly less than Mach 1, these aircraft can reach a target anywhere in the world in less than a day and probable target regions significantly faster. If forward basing or more time is available then a wider range of systems, enabling a much greater volume of fire, can come into play (although some targets deep within continental land masses can currently be held at risk only with aircraft-delivered weapons or nuclear weapons).

The main reason given for developing global CPGS weapons is their ability to hold at risk some important potential targets across the globe. Yet, this is not a compelling rationale, as all the missions for which CPGS might be employed—with the potential exception of counterterrorism—are likely to be preceded by a crisis. To some extent, strategic warning and range are fungible; the United States could use the warning time afforded by a crisis to relocate non-global systems, if needed. Certainly, there are risks with this approach. The warning time could be insufficient, especially to enable the repositioning of sea-based platforms. The United States could also underestimate the significance of an unfolding crisis and simply fail to prepare. But in the end, these risks need to be weighed against the greater costs of global weapons.

Counterterrorism is a somewhat singular mission because the possibility of eliminating a high-ranking terrorist could, plausibly, arise without enough warning time to use existing systems (though the killing of Osama bin Laden clearly indicates that this is certainly not guaranteed to be the case). Yet, even here, the case for global CPGS systems is not as strong as it may first appear. In theory, a terrorist target could "pop up" anywhere on the globe. In reality, such a target is significantly more likely to appear in long-recognized conflict zones than anywhere else. If they had a sufficiently long range, sea-based non-global CPGS systems could provide continuous coverage of regions of interest—especially if they were deployed on ships or submarines that the United States already deploys routinely.

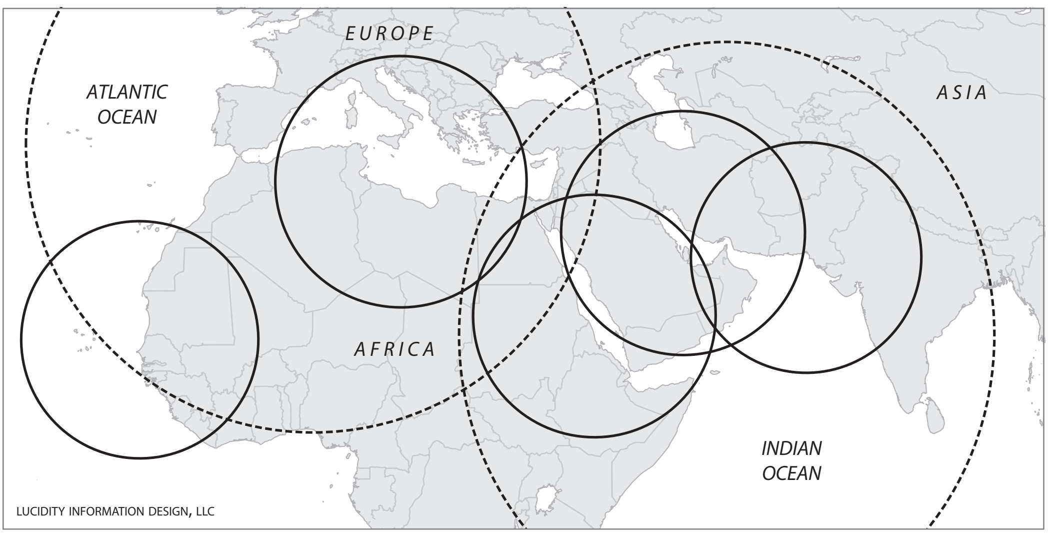
Another argument for global CPGS weapons is that they could be based in the United States, thus avoiding the need for forward bases on foreign soil. But the particular non-global CPGS weapons that the United States is researching appear to obviate this need (or at least significantly ameliorate it). Naval systems (whether ship- or submarine-based) could bypass the need for forward bases. If hypersonic cruise missiles were delivered by long-range bombers, they could do so too. The only non-global system that might be land-based is the AHW, but this system would have such a long range that, if based in Guam and Diego Garcia, it could reach almost any place of interest. The weapon could thus be placed on U.S. soil or the soil of the closest U.S. ally, the United Kingdom.

The **strategic depth** of the target state impacts range requirements as well. Geography and the effect of defenses can both potentially force the United States to employ standoff weapons capable of being launched from outside the adversary's "threat ring." These implications are case specific. Strikes on China would appear to require weapons with the longest ranges—given the antisatellite facility in western China near Xinjiang that is over 2,500 km (1,600 mi.) from the nearest coastline, for instance.[50] Moreover, Chinese defenses could potentially interfere with U.S. operations, especially those involving U.S. aircraft and surface ships. At the other extreme, strikes on North Korea would only require weapons with relatively short ranges since no part of North Korea is further than about 200 km (120 mi.) from the nearest coast and its defenses are minimal. Iran would be an intermediate case. Sea-based weapons with a range of around 1,000 km (620 mi.) would be needed to provide complete coverage of Iran (depending on whether U.S. assets could safely reach the Persian Gulf through the Strait of Hormuz).

Another advantage of increased range is that it would allow greater coverage from fewer platforms—a particular consideration for North Africa, the Middle East, Afghanistan, and Pakistan, where a number of possible targets are spread across a wide area. (Figure 5 shows the coverage provided by candidate CPGS systems in this region.) Two missions for CPGS are potentially relevant to this region: counternuclear strikes against a nuclear-armed Iran and counterterrorism operations in various states including Pakistan, Afghanistan, Yemen, Somalia, Sudan, and—depending on their future political evolution—Mali and Libya. Complete coverage of this entire region could be provided by a single AHW system (although overflight issues could arise).[51] Alternatively, such coverage could be provided by two naval vessels carrying ballistic missiles with a range of 3,500 km (2,200 mi.). Meanwhile, five ships or submarines carrying hypersonic cruise missiles with a relatively ambitious range of 1,500 km (930 mi.) would be required to provide near-complete coverage of areas of interest. In practice, however, hypersonic cruise missiles would probably be air-launched, allowing fewer platforms to provide complete coverage (assuming they could penetrate air defenses), but at the expense of promptness.

FIGURE 5

Coverage of North Africa, the Middle East, Afghanistan, and Pakistan Provided by Possible CPGS Weapon Systems



The solid and dashed lines show the coverage of, respectively, five ships or submarines carrying hypersonic cruise missiles with a range of 1,500 km, and two vessels carrying ballistic missiles with a range of 3,500 km (firing positions about 100 km from the nearest coast are assumed). Alternatively, a single deployment of boost-glide weapons based on the Advanced Hypersonic Weapon could provide complete coverage of the region.

Long-range, land-based weapons, such as boost-glide systems based on the HTV-2 and possibly also the AHW, have the disadvantage that they cannot easily be used to signal U.S. resolve in a crisis. Shorter-range systems that can be deployed forward can potentially be used more effectively for this purpose. The ideal system for signaling would be capable of covert deployment so the president could choose whether to signal (in some scenarios, a covert deployment might be preferable to avoid exacerbating a crisis). In this regard, submarines and perhaps aircraft (especially stealthy ones) may have some advantages over surface ships. (The deployment of any of these systems could be made overt by announcing it publicly or communicating it privately, and perhaps also by deliberately creating evidence of a deployment that foreign intelligence services could detect.)

For all these reasons, the Department of Defense's decision to refocus on non-global CPGS weapons appears to be sensible. While global weapons would enjoy some advantages, the trade-offs associated with increased range are complex and the optimal solution depends sensitively on both the mission and the potential adversary. Ultimately, there may well a trade-off (as there often is) between research and development costs, and operations and maintenance costs; longer-range systems are likely to have higher research and development costs and higher unit production costs, but fewer systems would probably be required.

DESTROYING THE TARGET

In the broadest of terms, there are three different classes of target in the missions for which CPGS might be employed: (i) **fixed soft targets** (such as large radars); (ii) **mobile soft targets** (such as terrorists or mobile missiles); and (iii) **hard and deeply buried targets** (such as bunkers used for warhead storage or command and control). Although there can be important variations between targets within each category, these three basic classes provide a useful framework for further discussion.[52]

Before diving into the details of each category, there is one overarching consideration that bears emphasizing: the very high unit cost of CPGS weapons compared to virtually all other non-nuclear weapons. Even if one CPGS weapon were to have a higher kill probability against some particular target than one weapon of another type, the non-prompt weapon could still turn out to be more effective if multiple units could be used for the same cost as one CPGS weapon. In theory, this trade-off is susceptible to quantitative analysis using detailed information about the design of the weapon, its cost and the nature of the target. Because CPGS is still a research and development program, the required information for this type of analysis is not yet available. Once the information is available, the Department of Defense should conduct the kind of quantitative analysis suggested here and use the results to inform any acquisition decision.

Fixed Soft Targets

CPGS weapons would likely be effective against fixed soft targets.[53] Although the weapons could be loaded with explosive warheads, a more effective means of destroying such targets would probably be through the use of a **particle dispersion warhead**, such as that planned for the (now cancelled) Conventional Strike Missile demonstration flight.[54] This warhead would consist of several thousand metal rods, known as **flechettes**. Shortly before impact, a small quantity of explosive would be used to disperse these rods, creating a circular "cloud," tens of meters in diameter, made up of flechettes travelling very rapidly toward the target. The flechettes would damage the target simply by punching holes through it (the explosive has no role in this; its only role is to disperse the flechettes).

That said, for two reasons, the effectiveness of CPGS weapons against fixed soft targets is not a particularly important consideration. First, the majority of likely mission-critical targets for CPGS would be either mobile or buried (see table 1 on p. 26). Second, existing weapons, including air-dropped bombs and cruise missiles, are also likely to be effective against fixed soft targets.[55]

Mobile Targets

A much more significant and notoriously difficult challenge is destroying mobile targets, including terrorists, anti-ship ballistic missiles, some antisatellite weapons and most nuclear-armed ballistic missiles. Indeed, all states with ballistic missiles that the United States might plausibly attack with CPGS—North Korea, Iran, and China—use mobility as the primary means of protecting their missile forces.[56] For this reason, if CPGS is to be used to eliminate missiles preemptively—or, as one U.S. military officer put it, to become "a potential left-of-launch capability in the missile defense business"—its ability to eliminate mobile missiles is critical.[57]

The challenges of attacking mobile missiles were famously highlighted by the "great Scud hunt" during the 1991 Gulf War when the United States failed to achieve a single confirmed kill of a missile-related target despite 1,460 sorties directed against them.[58] U.S. capabilities to attack mobile targets have improved significantly since then.[59] However, the following considerations suggest that the circumstances in which CPGS would be most effective against mobile targets—when airborne assets were operating from within the theater to provide targeting data—are also circumstances in which CPGS would not be needed (because the airborne assets used for surveillance could also carry weapons).

The easiest way to destroy a mobile target is to wait until it stops moving before striking it. For example, some North Korean road-mobile missiles, such as the Nodong, must be fueled before use, creating a window of maybe thirty to ninety minutes—and perhaps even longer—in which they would be stationary before launch.[60] In other cases, it is preferable to try to attack a missile while it is moving. For example, mobile missiles with storable propellants, including all Chinese ballistic missiles, could be launched much more quickly than Nodong missiles. If such a missile were detected while moving, it would be highly desirable to try to attack it immediately. Waiting for it to stop would carry the risk of "losing" it and then failing to reacquire it before it was used. Of course, this risk might be more tolerable if the weapon were armed with a conventional rather than a nuclear warhead. Nonetheless, in many circumstances, the strategy of waiting for a mobile target to stop before attacking would probably be a poor second to attacking while it was on the move.

While striking mobile targets once they have stopped is clearly aided by having fast weapons, such as CPGS, with short travel times, weapon speed does not obviate the need for outstanding intelligence, surveillance, and reconnaissance (ISR). Attacking a moving target is an even harder problem. Under a rather optimistic set of assumptions, a CPGS system armed with a particle dispersion warhead might have to land within 100 m (300 ft.) of a mobile missile to destroy it.[61] Meanwhile, a transporter-erector launcher carrying a missile and moving at 40 km/h (25 mph) could cover this distance in less than ten seconds. Destroying such a weapon while it is moving therefore requires virtually continuous surveillance, as well as the ability to update the incoming weapon, while it is in flight, on the target's expected location on impact.

Given the challenges associated with ensuring the reception of GPS signals, providing in-flight updates to CPGS weapons may be a greater technical challenge than it first appears, especially for boost-glide weapons and terminally guided ballistic missiles. Intriguingly, the fiscal year 2014 budget request lists the provision of in-flight target updates as one of the goals for the HTV-2 program but not for the AHW.[62] This would appear to suggest that the latter program, which is now the frontrunner, is not currently intended to have this capability.

Of course, the issue of in-flight target updates would only arise if real-time data on a target's location were available. Because U.S. ISR systems are so highly classified, any discussion of their capabilities is necessarily subject to significant uncertainties. That said, there are good reasons to question whether American ISR systems able to operate from outside the theater are capable of tracking moving missiles with enough reliability to enable attacks with a reasonable chance of success. In theory, two assets based in space could be used for this purpose: visual reconnaissance satellites and satellite-based radar.[63] In practice, the former suffers from two insurmountable weaknesses.[64] They are unable to obtain imagery through cloud cover, and they are incapable of providing anything like continuous-enough coverage to track mobile missiles.[65]

Satellite-based radar is somewhat more promising.[66] It offers an all-weather capability. Moreover, although the United States does not currently possess enough satellites to enable the reliable tracking of mobile targets, the number that would be required is not so large as to be entirely unfeasible.[67] Indeed, over the last fifteen years, the United States has initiated various plans to develop a constellation of satellite-based radars capable of providing near continuous coverage of most of the globe.[68] The National Research Council singled out the most recent of these programs, the Space Radar, as enhancing the U.S. capability to find mobile targets from "episodic" to "relatively reliable,"[69] but this program was cancelled in 2008—apparently between the completion of the NRC's report and its publication.[70] There does not appear to be any successor program in place and, given current financial realities, neither is there likely to be.[71]

For the foreseeable future, it is airborne assets—including both manned aircraft and UAVs—that present the best available means for tracking mobile missiles, as demonstrated during the 2006 Lebanon war when Israel had considerable success hunting and destroying Hezbollah's medium- and long-range rocket launchers.[72] It is beyond the scope of this report to analyze how effective this approach would prove against a state as opposed to a terrorist group (though clearly the challenges would be less daunting in North Korea, a small state with weak air defenses, than China, a vast state with sophisticated air defenses).[73] Instead, it suffices to say simply that if the battlespace were sufficiently permissive to allow the widespread use of airborne assets for ISR, then employing those assets—rather than CPGS—to attack mobile targets would almost certainly be cheaper and more effective. A subsonic cruise missile or guided bomb launched from within a theater would be likely to reach its target significantly more quickly than a CPGS weapon launched from a distance. As a result, the slower weapon would probably have a higher kill probability.[74]

One additional challenge, though this list in many ways just scratches the surface, would be distinguishing between hostile and non-hostile targets. Discriminating between Chinese transporter-erector launchers and other heavy trucks on busy roads in Eastern China could be tricky.[75] Discriminating between a jeep carrying a terrorist and a jeep carrying a civilian could be harder still.[76] Potential U.S. adversaries could add yet more difficulty, especially in the case of mobile missiles, by countermeasures that might be as simple as camouflage or the use of decoys. To be fair, these complications could arise with the use of any weapon system, not just CPGS. However, the problems would be particularly acute when only space-based ISR assets were available.[77] There are, therefore, legitimate questions as to how much CPGS would enhance the U.S. capability to successfully prosecute attacks against mobile targets.

Hard and Deeply Buried Targets

Many targets relevant to potential CPGS missions, including command and control nodes and warhead storage facilities, are buried.

In a 2005 report, the National Research Council relayed a Defense Intelligence Agency estimate that potential U.S. adversaries possessed about 2,000 hard and deeply buried facilities with a "major strategic function."[78] The NRC also stated that this number was increasing at a rate of about 10 percent per year (largely, but not exclusively, because of new discoveries by the United States). If this rate of growth had been sustained, the number of buried facilities known to the United States would have doubled since 2005. "Hundreds" of these facilities are located at a depth equivalent to between 20 m (70 ft.) and 100 m (300 ft.) of reinforced concrete.[79] "Many" are buried at 100 m to 250 m (800 ft.), with some deeper still.[80] To put these figures in perspective, the most effective non-nuclear "bunker buster" that the United States currently possesses—the GBU-57, a newly developed air-dropped bomb more commonly known as the "Massive Ordnance Penetrator"—is reportedly able to penetrate to a depth of 20 m in concrete.[81]

Penetrators delivered by CPGS weapons would have one major advantage and one major disadvantage compared to air-dropped bombs, such as the Massive Ordnance Penetrator. Their advantage would be their much greater speed, which would allow them to penetrate more deeply.[82] Simple calculations suggest that CPGS-delivered weapons could plausibly penetrate to a depth of 30 m (100 ft.) or 40 m (130 ft.) in concrete—50 to 100 percent greater than the Massive Ordnance Penetrator.[83] (The result depends on what assumptions are made about what length and mass of penetrator a CPGS weapon could accommodate.)

The disadvantage of a CPGS-delivered penetrator would be the relatively small amount of conventional explosive it could carry. The Massive Ordnance Penetrator, which really does live up to its name, weighing in at 13,600 kg (30,000 lb.), is reported to carry 2,400 kg (5,000 lb.) of high explosives.[84] This would be detonated when the weapon reached the target facility, after penetrating through the soil and rock that protects it, in order to destroy its contents. By contrast, a CPGS-delivered penetrator would probably be able to carry no more than 225 kg (500 lb.) of high explosive and would, therefore, have a significantly smaller destructive ability.[85] Thus, CPGS-delivered penetrators would likely only be effective if the layout of an underground facility is well characterized (so critical components within it can be targeted) or if the facility is small (so that the whole of it can be destroyed).

Unfortunately, without access to classified information, it is not possible to estimate the number of *additional* hard and buried targets that CPGS weapons could hold at risk. However, what can be said is that the figure depends on both the number of targets that are within the reach of CPGS weapons but beyond the reach of existing weapons *and*, of these, how many are either well characterized or small.

That said, there is one type of target that merits a more in-depth discussion because of its political and strategic significance: missile silos. Chinese and Russian analysts have expressed concerns about the vulnerability of their nuclear missile silos to precision-guided conventional weapons, including (but not limited to) CPGS weapons. These concerns are complex and multifaceted and encompass a variety of weapon effects.[86] Analyzing them all, many of which do not apply to CPGS, is beyond the scope of this report. The following discussion is, therefore, restricted to the question most obviously raised by the development of CPGS: Would penetrating munitions delivered by CPGS pose more of a threat to silos than the most powerful existing penetrators?

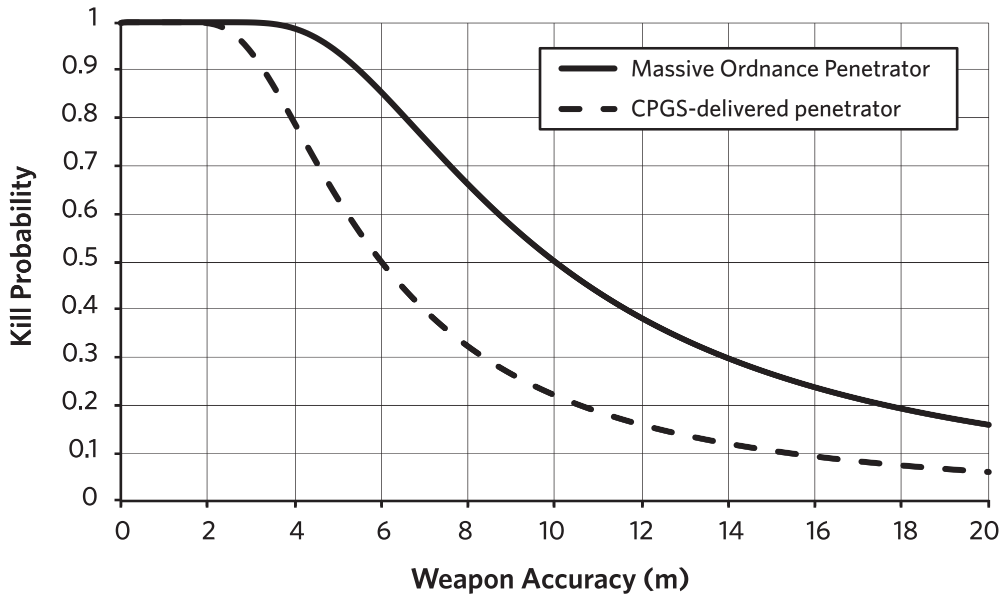
A penetrating munition could destroy a silo-based missile by penetrating through the silo door to reach the silo tube and its contents. The doors to Russian SS-18 silos are about 1 m (3 ft.) thick and made largely from reinforced concrete.[87] It seems highly unlikely, therefore, that one could stop a penetrator (whether CPGS delivered or air dropped).

That said, a silo is also a small target and would be hard to hit directly. The SS-18 silo tube, for example, is just 5.9 m (19 ft.) in diameter.[88] Of course, if the weapon missed the silo tube it could still cause serious damage by penetrating into the surrounding concrete and rock and detonating its conventional explosive. If detonated in hard rock, the Massive Ordnance Penetrator might produce a crater of up to about 8 m (26 ft.) in radius, whereas a CPGS-delivered penetrator might produce a crater less than half that size.[89] This difference suggests that, if the weapons had equal accuracy, the Massive Ordnance Penetrator would probably be *more* effective at attacking silos than a CPGS-delivered weapon (as illustrated in figure 6). Moreover, because GPS jamming efforts might impair the accuracy of CPGS weapons more than the Massive Ordnance Penetrator (which is equipped with a proven backup guidance system), they might further reduce the effectiveness of CPGS-delivered penetrators compared to the Massive Ordnance Penetrator.

The absolute degree of threat that either weapon poses to silos is harder to judge and could only be assessed definitively on the basis of more detailed modeling. However, these approximate cratering calculations suggest that any penetrating weapon requires an accuracy of a few meters if it is to pose a realistic threat to silos. While such accuracy is achievable with GPS navigation under ideal conditions, it would only be achievable in wartime if the United States were successful at thwarting Russian or Chinese GPS-jamming efforts.

FIGURE 6

Graph of the Kill Probability of the Massive Ordnance Penetrator and a CPGS-Delivered Penetrator Used Against an SS-18 Silo as a Function of Weapon Accuracy



Technically, weapon accuracy is given by circular error probable, that is, the radius of a circle in which the weapon has a 50 percent chance of landing. The performance of the GBU-28, an existing penetrator that is smaller than the Massive Ordnance Penetrator, would be broadly similar to the CPGS-delivered penetrator. For the details of the calculation see James M. Acton, "Hypersonic Boost-Glide Weapons," (forthcoming).

The Bottom Line

The main advantage of CPGS weapons compared to existing conventional weapons, in terms of holding additional targets at risk, is extending the depth at which buried targets can be reached, perhaps by as much as a factor of two. However, without access to classified information, it is not known how many such targets there are and whether they are sufficiently well characterized to enable successful CPGS attacks. CPGS weapons can also hold fixed soft targets at risk, but existing conventional weapons can do so too. By contrast, some existing capabilities, specifically aircraft and UAVs operating from within the theater, are probably more effective than CPGS weapons at attacking mobile targets.

ENABLING CAPABILITIES

In the missions for which CPGS might be employed, enabling capabilities—intelligence, surveillance, and reconnaissance; command, control, and communications; and battle damage assessment—are every bit as central to success as the weapons themselves. In general, missions that require promptness place higher demands on enabling capabilities than those that require tactical surprise because there is much less time to plan and execute an attack. In a short time, it can be extremely challenging to specify a target's location with sufficient accuracy to enable a successful strike.[90] A useful example, given by the NRC in its 2008 report, is the challenge of acting upon a report by a human source indicating that a ship carrying a "weapon of mass destruction . . . is moored at Pier 9."[91] Before the ship can be struck, this message would have to be interpreted to determine where "Pier 9" is. Most likely, the site would then have to be imaged, both to help confirm the report's veracity but also to determine the exact location of the ship. This location would then have to be translated into coordinates very accurately. In parallel, the president would also need to consider the pros and cons of a strike before authorizing it. To facilitate such consideration, it might be necessary to prepare an assessment of the strike's probable effectiveness and the expected collateral damage. All this would have to be completed before the ship started to sail.

In theory, all of these processes could be sped up by investments in enabling capabilities (including the development of general guidelines for acceptable collateral damage if they do not already exist). Other aspects of intelligence collection might, however, be less susceptible to acceleration. The counterterrorism scenarios invoked for CPGS often rely, implicitly or explicitly, on a single "silver bullet" of intelligence (such as, in the NRC scenario, the message from a human source about the location of the ship)—a rather unusual scenario. It seems unlikely that a president would authorize the use of a CPGS weapon on the basis of a single source; in practice, confirming intelligence could take a considerable length of time (for example, going back to the NRC scenario again, satellite imagery could rapidly verify that a ship is indeed moored at Pier 9, but it not could confirm the ship's cargo). Even more importantly, publicly available information suggests that successful U.S. operations to capture or kill terrorists of the caliber that would potentially merit the use of CPGS, including Osama bin Laden, Abu Zubaydah, and Abu Musab al-Zarqawi, have required the fusion of data from multiple sources, requiring weeks, if not months, of painstaking detective work.[92] If, in practice, weeks—or even months—are required to track down an important terrorist then it would almost certainly be possible to kill him with non-prompt weapons, including special forces, manned aircraft, or UAVs (indeed, special forces create the advantage of being able to capture rather than kill a terrorist).[93]

That said, as advocates of the use of CPGS for counterterrorism purposes point out, while counterterrorism scenarios in which the United States would need a prompt long-range strike capability to capitalize upon intelligence may be unlikely, it is also impossible to rule them out entirely.[94] Inevitably, the decision about whether to procure CPGS for low-probability, high-consequence counterterrorism missions comes down to a judgment call on the part of U.S. decisionmakers. To assist with this decision, the U.S. agencies involved in counterterrorism should attempt to identify historical examples of occasions when the United States has failed to capitalize on intelligence that would have enabled it to kill or capture an important terrorist, because it lacked a CPGS capability. While the past is not a perfect guide to the future, such data would nonetheless clearly be helpful to decisionmakers.

The type of target can also significantly affect the demands placed on ISR. Beyond mobile assets, another example is underground targets. Finding and characterizing an underground target can be extremely difficult.[95] As the 2009 Defense Science Board study notes, even if the general location of an underground facility is known, its exact structure may not be.[96] Without such knowledge it might not be possible to destroy the facility, even if a warhead is capable of penetrating far enough underground to reach it. Other options for "functional defeat" might still exist (such as sealing entrances or air vents). But, if they do, then other munitions, like cruise missiles or gravity bombs, could likely inflict the required level of damage.[97]

Command and control and battle damage assessment often attract less attention. Some of the potential missions for CPGS weapons would allow for very little delay before a weapon is launched, creating particular challenges for reliable command and control (even if little can be said about the details of overcoming such challenges). The importance of battle damage assessment should also not be overlooked. There are some missions where this capability would be nice to have rather than need to have. For example, if American satellites were being attacked, a U.S. president might authorize a strike on the adversary's remaining antisatellite weapons even if a reliable means to assess the strike's effectiveness were not available (an indirect indication would, in any case, be provided by whether attacks on U.S. satellites continued). In other cases, the president may not be willing to authorize a strike unless convincing evidence of its effects was available. The killing of Osama bin Laden is a case in point. President Barack Obama was reportedly advised to use an aircraft to attempt to kill bin Laden by key advisers, including Defense Secretary Robert Gates (who later changed his mind) and Vice Chairman of the Joint Chiefs of Staff James Cartwright.[98] Obama, however, sent in a U.S. Navy SEAL team, presumably in large part to prove—to himself, to the American public, to Pakistan, and to wider international community—that bin Laden had actually been present.[99] This example is illustrative of how difficult remote battle damage assessment could be; positively identifying a terrorist's remains after a remote kinetic strike—whether conducted with an aircraft or a CPGS weapon—might well prove impossible.[100] It is also illustrative of the more general point that, without the required enabling capabilities, CPGS weapons could prove unusable.

Assessing the status of U.S. enabling capabilities is difficult because they are so highly classified. Indeed, in 2008, the Government Accountability Office (GAO) reported that the Prompt Global Strike Analysis of Alternatives (conducted by the U.S. Air Force) had not taken enabling capabilities into account because, among other reasons, "the study staff lacks the special access clearances required to obtain information on all [Department of Defense] efforts for improving enabling capabilities."[101] Nonetheless, taken as a whole, the evidence suggests that U.S. enabling capabilities currently lag behind CPGS weapons development.

Serious weaknesses in enabling capabilities were also highlighted by three government-sponsored studies conducted during the administration of President George W. Bush: the 2004 and 2009 Defense Science Board reports and the 2008 National Research Council report.[102] It bears remembering that the Space Radar program, which the NRC identified as being particularly important in tacking mobile targets, was cancelled even before the report was published. The NRC also called for the implementation of plans to reduce the time between earth observation satellites visiting the same part of the globe and enhancing the Digital Point Positional Data Base, a tool that allows mission planners to rapidly and accurately identify the coordinates of a target.[103] It is not possible to assess whether these recommendations have been acted upon.

One area of ISR that has progressed rapidly since 2008 is unmanned aerial vehicles. This is something of a double-edged sword for CPGS since UAVs could—and, in many cases, do—carry weapons that are capable of destroying soft targets much more cheaply and promptly than CPGS.[104]

Probably more worrying than specific gaps in enabling capabilities are possible organizational deficiencies within the Department of the Defense that may cause this issue to receive insufficient attention. The 2008 GAO report expressed concern that major Department of Defense studies (including the CPGS Analysis of Alternatives) did not analyze what enabling capabilities would be required but instead simply "assumed that certain needed improvements . . . would be available when any future [weapon] system is fielded."[105] To correct this and other related deficiencies, the GAO recommended that the Pentagon "conduct a comprehensive assessment of enabling capabilities to identify any specific global strike operational requirements and priorities and when these capabilities are needed to support future offensive strike systems."[106] Nominally, the Department of Defense "concurred" with this recommendation. However, in its detailed answer, it indicated the issue would be addressed within other ongoing studies, thus actually appearing to reject the dedicated and comprehensive study advocated by the GAO.[107] Moreover, none of the senior Pentagon officials interviewed for this report knew of any comprehensive study into enabling capabilities. Without such a study it is hard to have confidence that specific gaps in enabling capabilities will be filled.

CONCLUSIONS AND RECOMMENDATIONS

The complexity of discussing whether CPGS weapons can meet the mission requirements is a reflection of the complexity of the contemporary technological competition between offense and defense. This interplay is summarized in table 9, which illustrates that there is no single "best" CPGS weapon. Weapon effectiveness depends on the scenario; the weapon that would be most effective in one scenario could be least effective in another.

This underscores the central theme of this report: procurement decisions about CPGS should be taken in regard to specific scenarios and adversaries. A more abstract capabilities-based strategy is unlikely to yield the optimum approach—not least because this approach is unlikely to give sufficient attention to the question of enabling capabilities, which appears to have been neglected so far.

One of the central issues in CPGS procurement is whether non-prompt alternatives would be more likely to be able to defeat potential countermeasures. In scenarios where tactical surprise, rather than promptness, is required, stealth technology is the principal competitor to CPGS (the leading technological competitors are also shown in table 9). The relative effectiveness of speed and stealth is a critical issue for the CPGS procurement process—especially at a time of severe downward pressure on the defense budget when prioritization is becoming increasingly important.

TABLE 9

Summary of U.S. Requirements for Potential CPGS Missions, Potential Adversary Countermeasures, and Their Implications for U.S. Technological Choices

U.S. REQUIREMENT	ADVERSARY COUNTERMEASURE	RELATIVE EFFECTIVENESS OF CPGS TECHNOLOGIES (IN DESCENDING ORDER)	LEADING COMPETITOR TO CPGS
Tactical surprise	Launch detection	1. Weapons with short travel times 2. Weapons with long travel times	Stealth
	In-flight detection (missile early-warning radar)	1. Boost-glide missiles 2. Hypersonic cruise missiles 3. Terminally guided ballistic missiles	
	In-flight detection (modified air-defense radar)	1. Terminally guided ballistic missiles 2. Boost-glide missiles 3. Hypersonic cruise missiles	
Promptness	Strategic depth[a]	1. Weapons with short travel times 2. Weapons with long travel times	Non-prompt weapons delivered from within the theater
Defense penetration	GPS denial	Unclear	Guidance systems capable of functioning without GPS
	Air and missile defenses	1. Terminally guided ballistic missiles[b] 2. Boost-glide missiles[b] 3. Hypersonic cruise missiles[b] 4. Any missile carrying a penetrating warhead, submunitions, or UAVs	Stealth and/or terminal maneuverability
Sufficient range to reach the target	Strategic depth[a]	1. Longer-range weapons 2. Shorter-range weapons	Stealth[c]
Ability to destroy the target	Mobility	1. Shorter-range weapons with the ability to accept in-flight target updates 2. Longer-range weapons without the ability to accept in-flight target updates	Non-prompt weapons delivered by aircraft and/or UAVs deployed from within the theater
	Hardness and burial	1. Weapons capable of carrying a heavier and longer payload 2. Weapons capable of carrying a lighter and shorter payload	Air-dropped penetrating munitions

Key: CPGS=Conventional Prompt Global Strike; GPS=Global Positioning System; UAV=Unmanned Aerial Vehicle

a Includes not only geography but also the effect of defenses in so far as they force U.S. platforms to operate at a greater distance from the target.

b Assuming the missile does not carry a penetrating warhead, submunitions, or a UAV.

c In the sense that stealth allows delivery platforms to penetrate defenses and approach their targets more closely before releasing a weapon.

Against this background, the following recommendations can be made:

1. Before deciding which, if any, CPGS technology to procure, the Department of Defense should conduct classified studies into possible adversary countermeasures over the next two or three decades, including a comparison of the effect of such countermeasures on non-prompt alternatives.

Particularly valuable would be studies into

- The relative ability of CPGS weapons and stealth technology, over the next two or three decades, to ensure tactical surprise and penetrate advanced air and missile defenses

- The implications of advanced GPS denial technologies for CPGS weapons and non-prompt alternatives

2. Before funding the acquisition of any CPGS technology, the U.S. Congress should require that the Department of Defense conduct the studies listed in point 1, if it has not already done so.

Congress should require that the Department of Defense brief lawmakers on the results of these studies and, to the extent possible, publish unclassified summaries.

3. Before funding the acquisition of any CPGS technology, Congress should require an unclassified statement from the Department of Defense comparing CPGS weapons and non-prompt alternatives in terms of their ability to hold mobile targets, and hard and deeply buried targets at risk; their relative unit cost; and their capability to successfully prosecute each of the missions for which the Department of Defense is considering acquiring CPGS weapons.

The analysis underlying the statement about the capability of each alternative to carry out the necessary missions must consider how the cost of CPGS weapons compared to the alternatives affects the volume of fire that could be brought to bear against a given target.

4. Before funding the acquisition of any CPGS technology, Congress should require that the Department of Defense conduct a comprehensive and dedicated examination of gaps in enabling capabilities; and develop plans, with cost estimates, to fill these gaps.

As the Government Accountability Office has suggested, this report should not be subsumed into other broader CPGS studies, but should be a stand-alone effort.

5. The U.S. agencies involved in counterterrorism should attempt to identify historical examples of occasions when the United States has failed to capitalize on intelligence that would have enabled it to kill or capture an important terrorist because it lacked a CPGS capability.

Former senior officials could be brought in to judge whether the available intelligence would actually have been persuasive enough to prompt a president to use a CPGS weapon, had one been available.

“A TREASONABLE ACT TO OUR NATIONAL INTERESTS.”

— Russian Deputy Prime Minister Dmitry Rogozin on the decision to curtail research into hypersonic technology at the end of the Soviet era.[1]

ANYTHING YOU CAN DO…: WHAT CPGS-LIKE WEAPONS ARE OTHER STATES DEVELOPING?

KEY INSIGHTS

China has deployed medium-range terminally guided ballistic missiles that are similar to Conventional Prompt Global Strike (CPGS) weapons and are capable of contributing to anti-access/area-denial operations. One potential role of U.S. CPGS weapons would be combatting these capabilities.

It does not appear that China has yet conducted a test against a moving target at sea of the most sophisticated of its CPGS-like weapons, the anti-ship DF-21D missile, probably making it difficult for Beijing to accurately assess the weapon's effectiveness.

It is very likely that China is engaged in the development of conventional intermediate-range ballistic missiles. The evidence that Beijing has already committed to the development of prompt intercontinental or global conventional weapons is weaker.

Russian officials have repeatedly emphasized the importance of developing prompt long-range conventional weapons—hypersonic cruise missiles, in particular—and there are signs of research and development activities in this area, building upon significant Russian experience with both scramjet and maneuvering reentry vehicle technology. These programs are, however, at a very early stage and it seems unlikely that even with concerted research and development efforts, Russia could deploy a long-range hypersonic conventional weapon in the next decade.

Chinese, Russian, and U.S. thinking about the potential utility and significance of long-range hypersonic conventional weapons show clear commonalities. In particular, important doctrinal texts from all three states argue that because these weapons can hold at risk targets that only nuclear weapons used to be able to threaten, they can contribute decisively to strategic strike operations and strategic deterrence.

In late 2012, the U.S. National Intelligence Council highlighted the likelihood that, over the next two decades, long-range high-precision conventional capabilities will become more widespread:

> almost universal access to precision navigation GPS data is accelerating the diffusion of precision-strike capabilities to state and nonstate actors, which we expect will be widespread by 2030. The proliferation of precision-guided weapons would allow critical infrastructures to be put at risk by many more potential adversaries . . . The proliferation of long-range precision weapons and antiship missile systems would pose significant challenges to US or NATO to forward deploy forces, limiting in-theater options for military action.[2]

While subsonic cruise missiles are likely to be the focus of most foreign efforts in this domain, programs to develop long-range hypersonic strike capabilities can also be expected, as the National Intelligence Council hints with its reference to "anti-ship" missiles. Indeed, a number of potential U.S. adversaries have already initiated programs that are similar to, if somewhat less ambitious than, Conventional Prompt Global Strike.

A discussion of these programs serves various purposes. First, it corrects the impression—one that is particularly prevalent within the international arms control community—that efforts to develop prompt long-range conventional strike capabilities are exclusively American. In fact, the two states who complain most about the CPGS program—Russia and China—are also the two other states that are most active in this area. Second, comparing the different routes taken by these states sheds some light on the range of possible technological approaches to long-range hypersonic strike and their challenges. Third, and most important, foreign programs have both direct and indirect implications for U.S. procurement decisions.

Foreign long-range hypersonic strike programs can constitute a direct argument within the United States for the CPGS program. This dynamic is most obviously seen with China's terminally guided ballistic missiles, a series of CPGS-like systems including the DF-21D anti-ship missile, which the Pentagon assesses has a range in excess of 1,500 km (930 mi.), and a number of land-attack systems of varying ranges.[3] These missiles are designed to contribute to anti-access/area-denial operations by holding American ships, especially aircraft carriers, and U.S. bases in the western Pacific at risk. The challenge of defeating such capabilities is an important argument within the United States for CPGS weapons that could penetrate Chinese defenses, disable anti-access/area-denial capabilities, and hence pave the way for follow-on attacks by less survivable forces. More generally, foreign programs constitute an argument for U.S. research and development efforts so American policymakers can be better informed about the potential capabilities of foreign weapons and hence their implications for U.S. security. An analysis of foreign CPGS-like programs—Chinese efforts in particular—can, therefore, contribute to decisionmaking about U.S. programs.

More indirectly, the suggestion that the United States should not acquire CPGS weapons is countered by the argument that other states are developing similar capabilities and that the United States must not be "left behind." A 2012 report by the National Institute of Public Policy, for example, chides U.S. leaders for "debating the issues" surrounding CPGS while "other countries are developing and deploying conventionally-armed ballistic missiles with greater range and accuracy."[4] Indeed, this line of reasoning is a relatively potent domestic justification for various U.S. military procurement projects. For example, proponents of "modernizing" the U.S. nuclear arsenal and weapons complex regularly make unfavorable comparisons between U.S. nuclear weapon programs and those in Russia and China.[5] Even though the officials and analysts who make this argument rarely explain *why* Russian and Chinese modernization efforts would undermine American security absent a countervailing program,[6] such comparisons resonate politically within the United States. (To be clear, this is not to imply that greater U.S. efforts to extend the life of warheads or update the weapons complex are unneeded; but, it is to argue that such programs should be motivated by—and scaled to—ensuring the continued reliability and effectiveness of U.S. nuclear weapons rather than by the existence of foreign programs.)

Without doubt the program of most relevance to the United States is China's, with Russia's the runner-up. An assessment of Chinese programs is particularly important because of a number of alarming recent accounts about how quickly China's capabilities are developing.[7]

CHINA

China first began to field short-range conventional ballistic missiles (with ranges less than 1,000 km or 620 mi.) in the early 1990s. However, its interest in longer-range systems probably dates back to the 1995–1996 Taiwan Straits crisis when the United States was able to deploy, with impunity, two carrier strike groups (or carrier battle groups as they were then known) into the region.[8] Since then China appears to have followed an evolutionary pathway to developing longer-range and more sophisticated conventional ballistic missiles, with the development of an anti-ship ballistic missile apparently being a key goal. An important marker on this journey was DF-21C, a terminally guided medium-range ballistic missile that was reportedly first tested in 2002 and could be used to attack U.S bases in Japan.[9]

The U.S. Department of Defense first stated that China was developing a new variant of DF-21 with an anti-ship capability in 2008 (although a more general Chinese interest in anti-ship ballistic missiles had been reported by the U.S. intelligence community earlier).[10] In December 2010, Admiral Robert Willard, the commander of U.S. Pacific Command, stated that this variant, by then named DF-21D, had reached what the United States would term an "initial operational capability."[11] However, Willard went on to add that "they continue to develop it. It will continue to undergo testing, I would imagine, for several more years." He also stated that "[w]e have not seen an over-water test of the entire system."

For its part, the Chinese government has sent mixed messages about DF-21D's state of readiness. In a February 2011 *Global Times* article, a Chinese military source was quoted as stating that DF-21D "is already deployed in the army."[12] Five months later the chief of staff of the People's Liberation Army, General Chen Bingde, was quoted as saying that the missile was "still undergoing experimental testing and will be used as a defensive weapon when it is successfully developed."[13] These two statements are not literally contradictory—China is known to deploy weapons under development—but they do send out quite different messages about China's confidence in the readiness of DF-21D.

Enabling capabilities—intelligence, surveillance, and reconnaissance to locate and track a ship as well as command and control to process this information and quickly authorize a strike—are absolutely essential to DF-21D's overall effectiveness (another point that critics of the U.S. response to this weapon tend to underplay). Indeed, in early 2013, it was widely reported that China had successfully demonstrated DF-21D against a stationary target in the Gobi Desert.[14] However, while this test may have demonstrated the accuracy of the missile, it provides no information about China's ability to locate or track a moving target that is hundreds if not thousands of kilometers from China's coast.[15]

To be sure, China has been developing and deploying a range of assets that could be used for surveillance, including earth observation satellites, high altitude airships, over-the-horizon radar, and unmanned aerial vehicles.[16] However, it is impossible from unclassified sources to reach an overall determination of the efficacy of these enabling capabilities and hence of the weapon system as a whole. Indeed, such an assessment may be impossible even with access to classified information. In January 2011, Vice Admiral David Dorsett, then deputy chief of naval operations for information dominance, stated in reference to China that because DF-21D has not been tested against a moving target at sea, "I'm assessing that they don't know" how effective it would be.[17] In short, there is a high degree of uncertainty around the effectiveness of DF-21D against U.S. aircraft carriers. While more alarmist accounts may be correct, the available information does not support any kind of definitive conclusion one way or the other.

While China may originally have been motivated to move beyond short-range ballistic missiles and develop longer-range weapons to hold U.S. naval assets at risk, Beijing now appears to believe that these weapons could potentially be useful for a broader set of missions.[18] DF-21C, which could only plausibly be used to attack stationary land-based targets, is a case in point.[19] Moreover, there is growing evidence that China is in the process of developing—and may even be close to deploying—conventional ballistic missiles with longer ranges.

The same February 2011 *Global Times* article that announced the deployment of DF-21D also announced the development of a successor with a range of 4,000 km (2,500 mi.).[20] Although the credibility of *Global Times'* stories is sometimes questionable (and the People's Liberation Army chief of staff appeared to distance himself from this particular article), this development appears to have recently been confirmed by the U.S. Department of Defense, which assessed unambiguously for the first time in 2013 that China "is developing conventional intermediate-range ballistic missiles" (defined as having ranges between 3,000 km and 5,000 km or 1,900 mi. and 3,100 mi.).[21] For many years, there have been reports that such missiles (variously called DF-25, DF-26, or DF-27) were in development, but none of these reports could be considered authoritative.[22]

One obvious purpose for these weapons would be to hold American ships at risk at greater distances from China's coast.[23] There may, however, be a number of other potential targets. *The Science of Second Artillery Campaigns*, a leaked secret textbook for personnel from the Second Artillery Corps, which is responsible for China's land-based ballistic missile force, states that possible targets for conventional missiles include:

> the enemy's strategic [and] campaign command centers['] communication hubs, radar stations, and other information targets, missile positions, air force bases, naval bases and targets like campaign landing

> fields, airborne fields, railway organization stations and bridges, important army groups, logistical bases, energy facilities, electrical power centers, etc.[24]

Based on this list, specific targets for Chinese conventional intermediate-range missiles could include U.S. military bases on Guam and in Australia, and military targets in Alaska, including the fixed Cobra Dane missile defense radar in Shemya and the sea-based X-band missile defense radar, which is nominally based out of Adak.

The potential deterrent value of conventional long-range ballistic missiles is also stressed in some Chinese sources. For example, *The Science of Military Strategy*, an important, official Chinese textbook published in 2001, argues that conventional deterrence is assuming greater importance because of concerns about the credibility of nuclear deterrence and because conventional deterrence is "more controllable and less risky."[25] It goes on to argue, in terms very similar to a number of U.S. publications (especially a 2004 Defense Science Board report, *Future Strategic Strike Skills*), that

> the gap of operational efficiency between non-nuclear weapons and nuclear weapons has been narrowed. The application of advanced guidance technology has also made the long-range precision strike possible.[26]

Taken together, Chinese doctrine and the technological trajectory of the state's conventional ballistic missile programs raise the question of whether Beijing is interested in eventually developing intercontinental weapons that could reach targets in Hawaii and the continental United States and eventually even global weapons. In a detailed study based on the Chinese technical literature, U.S. analyst Mark Stokes has identified a significant number of exploratory studies into the practicalities of boost-glide weapons (as well as long-range hypersonic cruise missiles).[27] How to interpret these studies is, however, a matter for legitimate debate.

Stokes has inferred from them the existence of an overarching "phased approach for the development of a conventional global precision strike capability."[28] The four phases of this putative program (which are coincident with the 11th to 14th Five Year Plans) would see China develop progressively longer capabilities, starting with DF-21D in phase 1 (which was supposed to be completed by 2010) and concluding with the development of a global capability by 2025. While Stokes's evidence is certainly *consistent* with such a plan, it is far from conclusive.[29] An equally plausible interpretation is that the studies are geared toward understanding the capability of potential U.S. CPGS weapons in order to guard against strategic surprise. A third interpretation is that such programs are simply ad hoc pieces of speculative research initiated by scientists interested in technology that is being publicly touted by the United States rather than being centrally directed according to some overarching plan.

In the final analysis, the current status and future direction of Chinese efforts in this area remain murky. Until DF-21D has been tested against moving targets at sea, the People's Liberation Army as well as the Pentagon is likely to be uncertain about its effectiveness. There is also significant uncertainty about the future of Chinese programs in this area. There is now clear evidence that China is developing conventional intermediate-range ballistic missiles. It remains unclear whether Beijing is yet committed to developing intercontinental or global prompt conventional weapons.

The technical challenges that China would face in developing such weapons, especially boost-glide systems, should not be underestimated. Without question, the technology and expertise generated by the DF-21C and DF-21D programs would be an excellent starting point. However, various U.S. sources argue that the maneuvering reentry vehicle technology underlying DF-21D is similar to—if not directly based on—the U.S. Pershing II missile.[30] This missile was first deployed in 1983 and had a range of about 1,800 km (1,100 mi.). Thirty years later the United States is still at least a decade away from deploying a Conventional Prompt Global Strike system. Granted, there was a significant hiatus in U.S. efforts. But the difficulties faced by the United States in building upon its considerable experience (which included flight testing much more sophisticated maneuvering reentry vehicles—MaRVs—than Pershing II's) demonstrate the real challenges associated with developing accurate hypersonic weapons capable of travelling intercontinental distances.

The problem of navigation is illustrative of the *qualitatively* new challenges facing China if it seeks to progress from DF-21D to a boost-glide weapon with a significantly longer range. Like Pershing II, DF-21D reportedly relies on one or more types of radar, during the final stages of flight, for homing in on the target.[31] In a long-range boost-glide weapon, however, terminal homing would be both technically challenging and probably insufficient to compensate for the navigation errors accrued during flight; continual midcourse navigation updates would be needed.[32] The United States has chosen GPS for this purpose. China has started to deploy is own similar system, Beidou, which is eventually intended to provide global coverage. Still, ensuring the reception of navigation data during all stages of the boost-glide flight path presents its own set of technical challenges (as do all of the other potential solutions).[33]

Given sufficient time and resources China would surely be able to overcome this challenge (as the United States appears to have done) as well as the many others it would face. However, it is unlikely the process would be quick or painless; it would certainly not be a case of just putting the reentry vehicle developed for DF-21D on a more powerful booster.

RUSSIA

In China, there are signs of technological progress toward the development of prompt long-range conventional weapons, but official statements on the subject have been few and far between. In Russia, the opposite is true: there have been repeated high-level pronouncements about the significance of these weapons and the importance of Russia's acquiring them, but there is little evidence, in recent years at least, of significant progress in this direction.

Russian officials have recently emphasized the promise and the threat of technological developments in conventional weaponry. For example, in a February 2012 article, Vladimir Putin, who was Russia's prime minister at that point, argued that, while nuclear deterrence should prevent large-scale aggression against Russia,

> we should take into account that technological progress in various areas, from new models of weapons and military hardware to information and communications technology, has fundamentally changed the nature of armed conflict. For instance, as high-precision long-range weapons with conventional charges become more common, they will become the means of achieving a decisive victory in conflicts, including a global conflict.[34]

In the same article, Putin called for an ambitious program to modernize all aspects of Russia's armed forces. Within this context, he argued that Russia should

> design and adopt next-generation weapons and combat units, including high-precision weapons, whose capabilities . . . are close to those of nuclear deterrent forces.[35]

Underlying this statement appears to be the idea—echoed in elements of both American and Chinese strategic thinking—that conventional weapons can now be employed for missions that have hitherto been the exclusive domain of nuclear weapons. Russia's 2010 Military Doctrine also appears to support this idea, albeit in more oblique terms, when it states that "in the context of the implementation by the Russian Federation of strategic deterrence measures of a forceful nature, provision is made for the utilization of precision weapons."[36]

In contrast to the United States and China, which have focused on ballistic and boost-glide technology, Russia's primary interest appears to lie in long-range hypersonic cruise missiles. A few months after Putin's article, Dmitry Rogozin, Russia's deputy prime minister with responsibility for the defense industry, expressed concern about U.S. hypersonic cruise missile programs and argued that Russia needed its own efforts in this direction, emphasizing long-range systems.[37]

Since these remarks, Rogozin has led efforts to reorganize parts of the Russian defense industry, apparently in part to support the development of hypersonic cruise missiles. In July 2012, he announced his intention to combine two companies with extensive experience in the development of precision-guided munitions into a “super holding company” with responsibility for the development of hypersonic cruise missiles.[38] Then, in October 2012, Putin signed a new law creating the Russian Foundation for Advanced Research Projects in the Defense Industry, which is modeled on the U.S. Defense Advanced Research Projects Agency (DARPA), to sponsor high-risk projects.[39] Rogozin, who was the driving force behind the creation of this new agency, has identified hypersonic technology research as one of its priorities.[40]

In spite of all this activity, there is, however, little sign yet of a coherent research agenda to develop a long-range hypersonic cruise missile. Only one concrete hypersonic missile program has been publicly discussed to date: an Indo-Russian joint venture to develop a missile, dubbed BrahMos 2, capable of travelling at between Mach 5 and 7.[41] Since 1998, the two states have been working together to develop BrahMos 1, a short-range supersonic cruise missile (with multiple variants that are in different stages of development, testing, and deployment).[42] In March 2012, the Indian head of this program stated that the new missile “would not differ much from the existing BrahMos missile in weight and dimensions, so that it could be used in existing launchers . . . In this case it would not take too much work to convert such systems to hypersonic.”[43]

These remarks are puzzling. BrahMos 1 is powered by a ramjet engine. To enable hypersonic flight, BrahMos 2 would presumably be powered by a quite different—and much more technically challenging—scramjet, making it an essentially different missile from BrahMos 1. Consequently, the stated goal of testing this new weapon by 2017 seems rather ambitious.[44] Moreover, if the new missile’s range were similar to BrahMos 1’s (300 km to 500 km—190 mi. to 310 mi.—depending on the variant), it would certainly not be the long-range missile that Rogozin has urged Russia to develop.

Apart from BrahMos 2, Rogozin has also stated that Russia’s new long-range bomber (PAK-DA) should be hypersonic.[45] However, this is an entirely unrealistic goal (not least because a new bomber is supposed to be ready by 2020) and there seems little prospect that it will be pursued.

Should Russia initiate a serious program to develop a long-range hypersonic missile, it would certainly have some relevant experience on which to build. Most useful would be a series of flight tests during the 1990s.[46] Like NASA’s X-43A, Russia’s Kholod was a “flying laboratory” intended to advance scientific understanding of the practicalities of hypersonic flight.[47] The first flight, conducted in November 1991, marked the first-ever successful test of a scramjet. A successful second test and an unsuccessful third test were conducted in cooperation with France in 1992 and 1995. During a fourth and final test, conducted jointly with NASA in 1998, the missile reached speeds of over Mach 6.4 during a burn lasting 77 secs.

While the results of this impressive test series would certainly be very useful to the designers of a long-range missile, many challenges remain. The most obvious of these is the need for much longer burn times. In addition, Kholod (like the X-43A) used liquid hydrogen, which is extremely flammable, as a fuel. Development of a militarily useful weapon would probably require a scramjet that used easier-to-handle hydrocarbon fuel.

A second program from the 1990s, Kh-90 GELA, is also potentially relevant.[48] GELA appears to have been powered either by a scramjet or a high-performance ramjet. However, as the uncertainty about even this basic design feature suggests, almost no reliable information about this program is available. More generally, Russia has extensive experience with ramjet engines, which it has successfully used in a number of deployed weapons with ranges up to a few hundred kilometers. Ramjets are, however, sufficiently different from scramjets that Russia's experience with the former is unlikely to enable it to develop the latter in anything less than a decade or so of intensive research.[49]

An alternative—and in some ways more obvious—approach for Russia would be to adopt ballistic or boost-glide systems to deliver conventional warheads. Indeed, on December 14, 2012, Colonel General Sergei Karakayev, the commander of Russia's Strategic Rocket Forces, stated that the new "heavy" liquid-fueled intercontinental ballistic missile that is currently under development would allow Russia "the capability of creating a strategic high-accuracy weapon system with a conventional payload with practically global range, if the U.S. does not pull back from its program for creating such missile systems."[50] This statement appears to be the first time that a senior Russian official has, in recent years at least, publicly expressed an interest in conventional long-range ballistic missiles.

Russian research into MaRV technology (known in Russian as *ptishka* or "birdie") is, in fact, probably at a more advanced stage than its scramjet program. The Soviet Union is reported to have begun developing MaRV technology in the 1980s to deliver nuclear weapons out of concern that existing reentry vehicles might not be able to penetrate the highly effective defenses foreseen by President Ronald Reagan's "Star Wars" program.[51] As such, the program was driven by fears virtually identical to those that catalyzed similar U.S. efforts some two decades earlier. Russian efforts were revitalized at some point in the 1990s, apparently again for the purpose of ensuring that nuclear-armed delivery systems could defeat possible future U.S. ballistic missile defenses.[52] Two tests of a maneuvering reentry vehicle—in February 2004 and November 2005—were widely reported.[53] Informed observers have, however, speculated that Russia has conducted other tests of this or a similar technology more recently.[54] Overall, as with Russia's development of scramjet-powered cruise missiles, uncertainty abounds about the status of the program.[55]

Converting this technology into a delivery system for conventional warheads might not be straightforward. In particular, it is unlikely that a maneuvering reentry vehicle designed for a nuclear warhead would have the necessary accuracy for the delivery of a conventional weapon. While Russian research into MaRVs that can defeat ballistic missile defenses would, therefore, be helpful in developing a conventional boost-glide weapon, extensive further research and development would probably be needed. Whether serious work in this direction has yet begun is unclear.

There is some circumstantial evidence that Russian interest in conventional boost-glide systems pre-dates Karakayev's statement. During New Strategic Arms Reduction Treaty (New START) negotiations in 2009, Russia sought an outright ban on the emplacement of conventional warheads on intercontinental ballistic missiles or sea-launched ballistic missiles (the United States and Russia eventually agreed to count such systems as nuclear armed). Surprisingly, however, Russia did not ask for the same provision to be applied to conventional boost-glide systems.[56] One possible interpretation is that, by 2009, Russia intended to create—or already had in place—a program to develop conventional boost-glide weapons and did not want them to be treaty accountable. Of course, this argument is speculative and such a program's existence is far from proven. In any case, if such a program exists, an operational capability is probably at least a decade away (and quite possibly further in the future).

OTHER STATES

While Chinese and Russian programs to develop CPGS-like weapons are the most relevant to U.S. policy, similar research is being conducted in a number of other states.[57] A variety of European Union members along with Japan have long-standing research programs into both hypersonic air-breathing systems and gliders. Although most of these programs are motivated by civilian ends—in particular, the development of hypersonic passenger transport and the long-sought-after spaceplane—they could, in principle, be applied for military purposes.[58] Australia, as part of its collaboration with the U.S. Air Force Research Laboratory, has also been active in this area but for explicitly military purposes. None of these programs is of much security significance for the United States.

Programs in India and Pakistan are, perhaps, of more interest because of their potential—over the long term—to impact military dynamics between these two states as well as those between India and China.[59] In addition to India's stated interest in hypersonic cruise missiles and its pursuit of their development collaboratively with Russia, New Delhi also has an active ballistic missile program. Its longest-range missile with a conventional variant is believed to be the Agni I, with a range of about 1,000 km (620 mi.).[60] However, even with a terminal guidance system that uses radar homing, this missile's accuracy is reported to be only 25 m (80 ft.), implying its military effectiveness (when armed with a non-nuclear warhead) is marginal. Improvements in terminal guidance technology, which does appear to be an area of active research within India, would enable New Delhi to field accurate terminally guided conventional ballistic missiles of progressively longer ranges (although it is unclear whether it is interested in doing so).[61]

Pakistan also appears to have some interest in conventional ballistic missiles. In fact, it is believed to have developed a conventional variant of its furthest-reaching missile, the Shaheen II with a range of 2,500 km (1,600 mi.).[62] However, whether a conventionally armed Shaheen II has anything like the accuracy required to make it militarily effective is much more of an open question. While there are some claims that this missile is equipped with a terminal guidance system giving it "surgical precision," most sources state that its guidance system is purely inertial and that its accuracy is around 350 m (1,100 ft.).[63] As a result, there is some reason to suspect that Pakistan's ballistic missiles are either intended as weapons of terror or to ensure nothing more than bragging rights.

CONCLUSIONS

Given the potential for CPGS-like weapon programs in China—and, to a lesser extent, Russia—to affect U.S. procurement decisions, a good understanding of the status of these programs would be very useful. Unfortunately, such an understanding is impossible to develop based on publicly available information.

In the case of China, it is certainly possible by examining the available data selectively to paint a picture of very rapidly developing Chinese capabilities, typified by the deployment of the DF-21D anti-ship ballistic missile. Taken holistically, however, the available evidence does not allow for any kind of categorical statement about the probable military effectiveness of this weapon. This is not to say that the more alarmist accounts are necessarily wrong, but it is to argue that there is significant degree of uncertainty. This uncertainty derives from a number of causes, including a lack of knowledge about the status of relevant enabling capabilities, contradictory Chinese signals, and questions about the likely effectiveness of U.S. countermeasures. Moreover, the uncertainty is not purely epistemic; given the absence of overwater testing of the entire system, even Beijing is unlikely to be able to accurately assess DF-21D's effectiveness.

China is now developing conventional ballistic missiles with ranges longer than DF-21D. There is some weaker evidence that Beijing has a "grand plan" to develop prompt conventional weapons with intercontinental or even global ranges. However, the challenges of doing so would be significant. Indeed, the evidence strongly suggests that the United States has a significant lead in the relevant technologies.

In spite of the increasingly loud rhetoric coming from Moscow, there is little evidence that it has yet made much progress toward the development of CPGS-like weapons (although once again there is much uncertainty). That said, Russia has considerable relevant experience, including from the Soviet era on which to build. In fact, it is probable that, all other things being equal, Russia could deploy a conventional long-range boost-glide weapon or hypersonic cruise missile more rapidly than China. Unfortunately, from a Russian perspective, all other things are not equal and China's much greater economic resources may turn out to be more than sufficient to compensate for Russia's technological lead.

These programs could have various security implications for the United States. For example, if China (or less likely Russia) develops accurate long-range conventional weapons capable of reaching targets on U.S. soil, the United States might have to start hardening or burying more key facilities (just as China, Russia, and other potential U.S. adversaries have done).

Whether these programs—China's in particular—constitute an argument for a *symmetric* U.S. response hinges on the utility of CPGS for defense suppression. Chinese efforts are focused on hindering or preventing the United States from "interfering" in a conflict involving Taiwan or another U.S. ally. These efforts are, therefore, an argument in favor of the United States' acquiring CPGS weapons to the extent that CPGS can effectively counter Chinese anti-access/area-denial capabilities.

No recommendations flow immediately from the analysis presented in this chapter. Whether CPGS weapons would be an effective military response to similar Chinese programs ultimately boils down to the question of whether they could reliably penetrate robust defenses and hold mobile targets at risk. Some of the recommendations that have already been made are geared toward helping the United States find the answer. A second policy question facing U.S. decisionmakers is whether the acquisition of CPGS might prompt China and Russia to accelerate their efforts at long-range hypersonic strike. This issue is most usefully discussed within the broader context of the potential international implications of CPGS.

“CONGRESS DID NOT TRUST THE BUSH ADMINISTRATION WITH SHARP OBJECTS.”

— A senior official in the administration of President George W. Bush
on why the U.S. Congress refused funding for the Conventional Trident Modification.[1]

COMPLEX INTERACTIONS: WHAT ARE THE INTERNATIONAL IMPLICATIONS OF CPGS?

KEY INSIGHTS

Conventional Prompt Global Strike (CPGS) weapons would probably simultaneously enhance deterrence and undermine efforts to manage conflict escalation.

Potential escalation risks that could be created or exacerbated by CPGS include

- Warhead ambiguity
- Destination ambiguity—an observing state's uncertainty about whether it was the target of a CPGS attack
- Target ambiguity—an observing state's uncertainty about whether the United States intended to attack a conventional or nuclear target with a CPGS weapon
- Crisis instability—pressures felt by an adversary to use or threaten to use weapons out of concern that they lacked survivability

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Warhead ambiguity has been the focus and could be an issue in the event of CPGS strikes against China (should it develop advanced early-warning capabilities) or Russia, but other risks of escalation—including to the nuclear level—would probably be more serious.

A number of characteristics are desirable from the perspective of reducing risk, including

- Separate deployment areas and different trajectories for CPGS and nuclear weapons
- Boosters with no nuclear association for CPGS
- Predictable trajectories for CPGS weapons
- Observable midcourse trajectories for CPGS weapons
- Limited CPGS deployments

All potential CPGS systems have some undesirable characteristics. The destabilizing aspects of boost-glide systems—their trajectories are unpredictable and cannot be observed after the boost phase—have not been adequately recognized.

Cooperative approaches would generally be more effective than unilateral measures in mitigating the strategic risks.

Relevant non-treaty-based confidence-building measures that the United States could implement to ease Russian and Chinese concerns about CPGS and other U.S. high-precision conventional weapons include: inspections, launch notifications, data exchanges, basing restrictions and movement notifications, observation of exercises, and joint studies.

Making all CPGS systems accountable in any future arms control treaty would be a powerful means of risk reduction. However, it would be difficult to subject certain sea-based CPGS weapons to an arms control regime.

Public and congressional debate about Conventional Prompt Global Strike has focused on one issue above all others: **warhead ambiguity**—that is, the possibility of China or Russia misidentifying a CPGS weapon as armed with a nuclear warhead and ordering a nuclear response. The importance this issue has assumed is not surprising. The goal of preventing accidental nuclear war is undeniably important, as virtually all participants in the debate acknowledge (even if proponents and opponents of CPGS tend to disagree over how likely it is that the use of a CPGS weapon might start one). In addition, given how complex and nuanced many issues surrounding CPGS are, an issue as stark and deceptively simple as warhead ambiguity provides a focal point for debate.

In the political domain, the concern expressed by Congress about this problem has led both sides of the debate to stress the issue in discussions about CPGS. Proponents have felt obliged to argue that alternatives to the Conventional Trident Modification (CTM) remove any possibility for ambiguity. Opponents, meanwhile, have naturally tended to emphasize an argument that has been shown to have traction with lawmakers.

The ambiguity tail is now wagging the dog of the larger CPGS debate. This almost exclusive focus has tended to obscure other ways that other states might respond to the development, deployment, and possible use of CPGS. On the positive side of the ledger, CPGS might make potential adversaries more wary about transgressing key interests of the United States and its allies, thus enhancing deterrence and potentially also the assurance of those allies. Other responses might be more negative. For example, if CPGS increases Russian concerns about the survivability of its nuclear forces, then Moscow might build up those forces after the 2021 expiration of the New Strategic Arms Reduction Treaty (New START). Similar fears in China could prompt Beijing to become even more resistant than it currently is to greater transparency. Either outcome would be of significant concern to both the United States and its allies.

Meanwhile, in the heat of a crisis, the use of CPGS weapons could generate incentives—apart from warhead ambiguity—for an adversary to escalate the conflict, including to the nuclear level. For instance, China is reported to use the same command-and-control system for its nuclear and conventional missiles. If, in a crisis, the United States were to attack this command-and-control system with CPGS in order to deny China the use of its conventional anti-ship ballistic missiles, Beijing could believe that the United States was actually seeking to deny it the use of its nuclear forces. In this scenario, Beijing could plausibly respond with the use of nuclear weapons. This alternative ambiguity problem—referred to here as **target ambiguity**—and certain other risks would probably be more serious than the "traditional" warhead ambiguity problem. In analyzing these risks, one issue that is particularly germane to procurement decisions is whether some CPGS systems would pose less of a risk than others.

WARHEAD AND DESTINATION AMBIGUITY

If and when Congress is asked to appropriate funds to acquire a CPGS system, there is a significant chance that **warhead ambiguity** will become a—if not the—central issue once again. This risk was the stated reason for Congress's refusal to fund the CTM.[2] Even if, for some lawmakers, warhead ambiguity was indicative of a more general distrust of that administration's security policies, there are good reasons to suppose that this issue will remain highly contentious. Indeed, an indicator of the issue's importance is that it is usually referred to as *the* ambiguity problem, even though warhead ambiguity is not the only form of ambiguity.

There is general agreement that a state misinterpreting a CPGS weapon as a nuclear weapon and launching a nuclear response would be a low-probability, high-consequence scenario. But it is extremely difficult to estimate just how small this probability would be and to judge how small it would need to be for the benefits of CPGS to outweigh the risks. These conceptual problems are exacerbated by the relative absence of historical precedents and the consequent need to focus on hypothetical situations.[3] As a result, intense disagreement is virtually inevitable.

Given how much has already been written on the subject, there is little more this report can add to the question of how much of a problem warhead ambiguity would be.[4] Therefore, after briefly reviewing the basic lines of argument, attention is focused on a different question: However big or small of a problem warhead ambiguity is judged to be, how much would it be ameliorated by the U.S. choice of CPGS technology? This question is salient because supporters of CPGS—including the administration of President Barack Obama—have argued that warhead ambiguity could be mitigated by choosing CPGS "concepts with characteristics that are intended to be observable and distinguishable from that [sic] of an [intercontinental ballistic missile (ICBM)] or [sea-launched ballistic missile (SLBM)] armed with a nuclear weapon."[5]

Warhead ambiguity could only arise in connection with a state capable of detecting a CPGS weapon and authorizing a nuclear response before the incoming weapon reached its target (at which point it could unambiguously be identified as non-nuclear). Today, only Russia fits that description since it is currently the only state, besides the United States, to have early-warning satellites (and, for that matter, the only potential U.S. adversary to have an extensive radar-based early-warning system for missiles).

China has no early-warning satellites, so it would probably gain too little warning of attack for warhead ambiguity to arise. But because China might develop an advanced early-warning system in the future, it is important to analyze the risks of warhead ambiguity in relation to China, as the 2008 study by the National Research Council (NRC) of the U.S. National Academies notes.[6]

Even if China does develop advanced early-warning capabilities, it would still, in general, not be able to authorize an immediate nuclear response to warning of an attack because it reportedly stores its nuclear warheads and missile separately.[7] Of course, in the event of increased U.S.-China tensions, Beijing might alert its nuclear forces, potentially enabling a rapid nuclear response to a CPGS strike.[8] After all, it would make little strategic sense for China to develop an advanced missile early-warning system if it only planned to alert its nuclear forces after an adversary's nuclear strike. There is also the possibility that, in the future, China may change its nuclear posture and keep some or all of its nuclear forces on permanent alert.[9]

A useful starting point for analyzing warhead ambiguity is the NRC's observation that there are "two, logically and practically distinct, aspects of the ambiguity issue:"[10]

> 1) the possibility that Russia—or, in the future, China—might interpret a CPGS launch against a third state as an incoming nuclear attack against itself;
>
> 2) the possibility that Russia—or, in the future, China—might interpret a CPGS launch against itself as a nuclear attack.

There seems little doubt that the first of these scenarios would be more likely if, by chance or otherwise, the crisis with the third state coincided with a period of heightened Russian-U.S. or Sino-U.S. tensions. There seems equally little doubt that warhead ambiguity would be more likely to be a problem in the case of a CPGS attack against Russia or China than against a third state. In practice, this really means a CPGS attack against China since none of the missions for which CPGS might be used would involve attacks against Russia.

Arguing that the relative risk of warhead ambiguity would be greater in the event of attacks on Russia or China than on third parties does not, of course, speak to the absolute risk of either scenario. It is here that the debate really starts. The National Research Council reached the conclusion that, in any scenario, "the risk of the observing nation's launching a nuclear retaliatory attack is very low."[11] The NRC, as well as analysts who agree with its conclusion, advances two basic arguments. First, because of missiles tests and space launches, Russia already has procedures in place for "detecting and monitoring missiles and rockets after launch to establish their trajectories."[12] Such launches include SLBM tests from operational submarines that the United States and Russia have conducted for more than fifty years without incident (assisted by a bilateral ballistic missile launch notification agreement since 1988). The procedures developed to monitor these launches would probably ensure that Russia does not mistake a CPGS launch against a third state as a launch against Russia. Second, even if Russia—or China in the future—reached the incorrect conclusion that a nuclear attack on them was under way, the fear of nuclear escalation would create strong incentives to act extremely cautiously.[13] In particular, the NRC points out that since any CPGS attack would be relatively small, Moscow "would have every reason not to order an immediate counterattack because the few missiles in flight could not significantly degrade the country's ability to respond after the situation was clarified."[14] It concedes that because China's nuclear forces are less survivable, Beijing's "erroneous perception that a small nuclear attack was underway would perhaps be somewhat more likely to be regarded as a serious threat than would be the case for Russia." However, it goes on to argue that China "would have many mechanisms by which to improve the survivability of its forces."[15] (Indeed, the U.S. Department of Defense regularly assesses that China is already engaged in such activities.[16])

Analysts who reach the opposite conclusion from the NRC argue that, given the stakes involved, even a small probability of warhead ambiguity leading to nuclear use should be unacceptable.[17] They also make various arguments as to why, in the heat of the moment, mistakes and miscalculation—rather than rational judgment—could lead to a nuclear response. For instance, Pavel Podvig, a noted observer of Russian strategic forces, points to the complex and tightly coupled nature of early-warning systems and argues that a CPGS launch could lead to "a series of inadvertent actions in the strategic forces command-and-control system, leading to a decision to launch missiles."[18] Other analysts point to the effect of factors such as short decision times, poor communication, and inadequate training for the personnel who staff early-warning systems.[19] U.S. scientist Theodore Postol has gone further and posits that Russia could even have a rational reason to worry about the effect of a small nuclear salvo on the survivability of its forces. He argues that because one or more nuclear weapons detonated at high altitude could blind Russian early-warning radars, they might, in fact, be the prelude to a large-scale strike.[20]

Unquestionably, these arguments are strongest in the case of CPGS attacks against Russia or China, if and when the latter develops more advanced early-warning capabilities. Perhaps the most trenchant criticism of the NRC's logic comes from U.S. analyst Joshua Pollack. He notes that the NRC rejects land-based conventional ICBMs because they would need to pass over Russian airspace on the way to many potential targets in the Eastern hemisphere. He then points out that "if a ballistic missile *overflight* of Russia en route to third-party targets would be unacceptable, it is difficult to understand how actual attacks on Russian or Chinese targets with the same weapons could be acceptable."[21] Indeed, on this point, some proponents of CPGS appear to fall short by focusing their analysis of the risks of warhead ambiguity on the least problematic case—the Russian response to attacks on third parties—rather than the most problematic case—direct attacks against China.[22] If Beijing acquires advanced early-warning capabilities, such strikes could realistically create warhead ambiguity. That said, even in this case, warhead ambiguity would be probably rather less serious than other potential risks.

Whether or not this conclusion is accepted, it seems likely that Congress will only fund the acquisition of a CPGS system if it can be persuaded that the risks of warhead ambiguity can be mitigated. In this regard, two conceptually different sets of mitigation techniques have been proposed: cooperative and unilateral. The former, which were emphasized by the NRC and would require U.S.-Russian (or Sino-U.S.) cooperation to implement, include inspections, monitoring, and data exchanges.[23] By contrast, the

Obama administration and most other CPGS supporters have generally emphasized American unilateral steps that, they argue, could enable Russia or China to distinguish between a nuclear missile and a CPGS weapon. These measures include

- locating land-based CPGS systems away from ICBM fields
- not using the boosters from existing ICBMs and SLBMs for CPGS weapons
- adopting hypersonic gliders that fly in a non-ballistic trajectory
- employing a terminal guidance system for CPGS weapons that could enable them to maneuver, unlike current ICBMs and SLBMs[24]

For three reasons these steps by themselves—that is, without associated cooperative measures—would be unlikely to do much to mitigate warhead ambiguity and might actually make it worse and create new risks.

First, without cooperative measures, a potential U.S. adversary might believe that the United States had actually placed nuclear warheads on a CPGS system. This fear may appear fanciful to U.S. analysts who understand that, because of the need to obtain funding from Congress and satisfy U.S. safety and reliability requirements for nuclear weapons, such a step could never be taken secretly. However, this concern has been raised, particularly by Chinese experts.[25]

Moreover, the NRC recognized that "other countries could never be confident that there is not a nuclear warhead on a new U.S. system simply because the United States says so."[26] In fact, in 2009, the then secretary of defense, Robert Gates, said in describing Russian objections to the Bush administration's missile defense plans that "the Russians believed, despite our best efforts to dissuade them, that the ground-based interceptors in Poland could be fitted with nuclear weapons and become an offensive weapon."[27]

Fears that CPGS weapons could actually be armed with nuclear warheads might be compounded because a number of the boosters being used for CPGS flight tests are retired nuclear weapon delivery vehicles—a point not lost on some Russian experts.[28] While the United States might develop a new booster for any deployed CPGS weapons, it might also decide, on the grounds of cost, to continue using these boosters.[29]

Second, in practice, a number of the features that could potentially distinguish CPGS weapons from nuclear weapons would only be of limited utility. If the United States adopts a sea-based CPGS system, for instance, it would presumably not be possible to separate its deployment areas from the deployment areas for SSBNs (ballistic missile submarines).[30] Features that distinguish CPGS weapons from nuclear weapons during the terminal phase of flight would seem to be irrelevant to reducing warhead ambiguity because the terminal phase occurs too late and lasts for too short a time to provide useful information to decisionmakers. Most importantly, because hypersonic gliders and hypersonic cruise missiles would fly at much lower altitudes than ballistic missiles, they would be invisible to missile early-warning radars for most of their trajectory.[31] Consequently, they would be detectable during their boost phase using an early-warning satellite, but they would then disappear from view. They would only become observable if they happened to pass within a few hundred kilometers of an early-warning radar. A ballistic missile, by contrast, could be tracked for much more of its trajectory. The extent to which warhead ambiguity would be mitigated by an *unobservable* characteristic is, to say the least, an open question.

Third, the problem of tracking hypersonic gliders and cruise missiles is exacerbated by their maneuverability. This maneuverability could result in a different type of ambiguity, **destination ambiguity**, which U.S. analysts M. Elaine Bunn (now a U.S. deputy assistant secretary of defense) and Vincent A. Manzo have defined as "when a state observes a U.S. CPGS strike against a third party and incorrectly concludes that it is under nuclear or conventional attack."[32]

Destination ambiguity, coupled with the difficulty of tracking hypersonic gliders and cruise missiles, appears liable to increase the probability that Russia or China could wrongly conclude that a CPGS weapon were heading for their territory. In this scenario, if Moscow or Beijing misidentified the CPGS weapon as a nuclear weapon (because of warhead ambiguity) they might launch a nuclear response. However, even if they correctly identified the CPGS weapon as conventional, the mistaken belief they were under non-nuclear attack could still spark a crisis.

Two broad conclusions can be drawn. First, in general, the warhead ambiguity problem has been overstated. But it might become an issue if the United States launched a CPGS strike on China (should it develop advanced early-warning capabilities) or, much less likely, on Russia. It could also become an issue if the United States adopted a CPGS technology with a high degree of midcourse maneuverability (such as a boost-glide weapon or hypersonic cruise missile). Because these systems would have unpredictable trajectories that were unobservable after the boost phase, they would create destination ambiguity. In turn, an observing state might mistakenly believe that a CPGS weapon was heading for its territory, not only exacerbating the risk of warhead ambiguity but also creating new risks of escalation.

ARE SEA-BASED SYSTEMS INTRINSICALLY MORE DESTABILIZING THAN LAND-BASED SYSTEMS?

Congress has expressed particular concern about the possibility of warhead ambiguity resulting from basing CPGS systems at sea.[33] These concerns originated with the planned Conventional Trident Modification, which would have seen conventional warheads placed on a delivery system that is exclusively associated with nuclear weapons. Similarly, there is concern about the use of SSGNs for CPGS because these submarines used to carry nuclear-armed ballistic missiles.

One problem with this argument is that it ignores the nuclear ancestry of other potential basing modes. In particular, land-based concepts might use former ICBMs and SLBMs as launch vehicles. By contrast, some sea-based concepts, such as a newly designed intermediate-range ballistic missile launched from Virginia-class attack submarines, could be entirely free from nuclear ancestry.

But to complicate matters further, having an association with nuclear weapons can actually be positive from the perspective of mitigating warhead ambiguity.

Precisely because SSBNs carry nuclear weapons and SSGNs used to, they are covered by an arms control inspection regime, which could be helpful in demonstrating to Russia, and perhaps China, that CPGS weapons were indeed conventionally armed.

CPGS weapons that are sea-based could also be launched from areas where nuclear weapons are deployed. This is a real disadvantage, but it must be weighed against the other factors that might exacerbate or mitigate warhead *and* destination ambiguity. For example, it is far from obvious that the ambiguity risks associated with observable and predictable sea-launched ballistic missiles would be less than the risks associated with unobservable and unpredictable land-based boost-glide systems, even though the latter were deployed in areas separate from nuclear weapons. In short, there is no persuasive case to be made that sea-based systems would be inherently more risky than all other basing modes; specific concepts need to be assessed on their merits.

Second, to the extent that warhead ambiguity is a problem, there is no purely technical solution—a point made, for example, by the current chief of naval operations, Admiral Jonathan Greenert.[34] A cooperative approach is required. The National Research Council reached a similar—if frequently forgotten—conclusion:

> One thing, and perhaps only one, is absolutely clear about the ambiguity problem: Simply using something other than Trident missiles (or another legacy ballistic system) as the delivery platform does not avoid the problem entirely. . . . There simply is no "bright line" between nuclear and conventional systems when relatively long-range platforms are being considered.[35]

FORCE SURVIVABILITY

While Russian and Chinese experts and officials have occasionally mentioned the warhead ambiguity problem, their biggest concern appears to be that CPGS might undermine their nuclear deterrents.[36] In other words, their primary fear is not that they might mistake a CPGS weapon for a nuclear weapon but that an unambiguously conventional attack might be able to degrade—or perhaps even eliminate—their nuclear forces.

In fact, Russian and Chinese concerns about the impact of U.S. conventional weapons on the survivability of their nuclear forces are not purely—or perhaps even primarily—focused on CPGS. Russian analysts, in particular, have been very explicit in identifying a perceived threat from multiple forms of "precision-guided weapons," including "long-range sea-launched and air-launched cruise missiles . . . and powerful air bombs and guided missiles, which can be delivered by U.S. heavy bombers and tactical aviation."[37] According to Vladimir Dvorkin, a retired Russian major general who served as head of a military institute devoted to modeling nuclear exchanges, such weapons "pose a threat to all branches of the strategic nuclear triad, including the silo and mobile launchers of the Strategic Rocket Forces . . . strategic submarines in bases, and strategic bombers."[38]

As evidence of the depth of Moscow's concerns, Russian analysts point to its significant and ongoing investment in air and missile defenses.[39] This investment is highlighted in Russia's 2010 Military Doctrine, which identifies one of the main tasks of Russia's military as ensuring "the air defense of the Russian Federation's most important military facilities and readiness to rebuff strikes by means of air and space attack."[40] To interpret this provision, Alexei Arbatov, a Russian analyst and former Duma member, Dvorkin, and academic Sergei Oznobishchev note that because

> there are currently no orbital weapons, and there is no prospect that they will appear in the foreseeable future, the notion "means of air and space attack" apparently relates to conventionally armed cruise missiles and ballistic missiles, with high precision guidance provided by space information systems.[41]

Evgeny Miasnikov, a Russian analyst who has written extensively on these issues, argues that Russian concerns are now so acute that

> a number of [Russian] experts believe that [precision-guided weapons] pose a greater threat to the survivability of Russian [strategic nuclear forces] over the medium term than do ballistic missile defenses, since over this timeframe no technological breakthroughs are anticipated that could significantly improve the effectiveness of [ballistic missile defenses] against ICBMs, while at the same time the United States has already amassed a considerable counterforce capability for its [precision-guided weapons], which in the future will only grow.[42]

For the time being at least, Russian analysts who argue that precision-guided conventional weapons pose a greater threat than ballistic missile defense to Russian nuclear forces appear to be in the minority. However, if U.S. missile defenses continue to be developed more slowly than planned (as the cancellation of phase four of the European Phased Adaptive Approach typifies) and Washington moves ahead with a CPGS acquisition program, it seems possible that high-precision conventional weapons could move to the forefront of Russia's concerns.

China's nuclear forces are much smaller, and hence less survivable, than Russia's—a problem compounded by its lack of an advanced missile early-warning capability. (China's development of such a capability, while probably stabilizing on balance, would not be without risk because it would also create the possibility for warhead and destination ambiguity.) In broad terms, Beijing appears to share Moscow's concerns about U.S. high-precision conventional weapons. While Chinese analysts and officials have generally been less explicit about exactly which U.S. conventional weapons they consider problematic—tending to talk generally about "conventional strategic strike capabilities"[43] or simply "conventional weapons"[44]—the evidence suggests that their concerns are, if anything, even broader than those of their Russian counterparts.[45] A clear and important statement of concern comes from the leaked *The Science of Second Artillery Campaigns*, which identifies China's "nuclear missile troops and their launch sites" as "the core targets" of an adversary's preemptive attacks.[46] It then calls upon Second Artillery forces to prepare defenses

> against the precision guided weapon attacks launched from the enemy's land (sea) platforms, against weapon attacks delivered from the enemy's aerial platforms, and against the attacks mounted by the enemy's airborne troops, and attacks and harassments carried out by the enemy's special operation forces.[47]

It is clear from the subsequent text that "precision guided weapons" refers to cruise missiles (indeed, Iraq's success in shooting down several Tomahawk cruise missiles during the 1991 Gulf War is highlighted).[48] Most noticeable, however, is the reference to airborne and special operations forces as a threat to the survivability of China's nuclear weapons. While Russian analysts have occasionally raised such fears, they appear to be at the margins of the Russian debate. To see such concerns highlighted in (what is believed to be) an authoritative Chinese document is, therefore, striking. Further evidence for the depth of Chinese concerns comes from an extensive series of interviews about the U.S. Nuclear Posture Review conducted during 2010 by Lora Saalman, an expert on Chinese nuclear policy. She reports that Chinese experts raised developments in conventional weaponry more often than any other subject.[49]

One particular concern identified by both Russian and Chinese analysts is the possibility that the combination of ballistic missile defense and high-precision conventional weapons could allow the United States to attempt a disarming first strike without crossing the nuclear threshold. In 2007, Anatoly Antonov, who served as chief Russian negotiator for New START and is now a deputy defense minister, stated in characteristically flamboyant terms that

> we see a direct link between US plans for global missile defence and the prompt global strike concept which means the ability to strike any point on the globe within an hour of the relevant decision. This concept, when combined with global missile defence, becomes a means of seeking to dominate the world politically and strategically. This is a rather serious factor which undermines the principles of mutual deterrence and mutual security and erodes the architecture of strategic stability.[50]

In a similar—if less dramatic—vein, Major General Yao Yunzhu, from China's Academy of Military Sciences, has written of calls within China to reform its no-first-use commitment (that is, its pledge not to use nuclear weapons first). Such calls, she states, result from two concerns:

> 1) The Ballistic Missile Defense systems that the United States and its allies have deployed, or are planning to deploy, are capable of intercepting residue [that is, surviving] Chinese nuclear weapons launched for retaliation after it has already been attacked….
>
> 2) The United States is developing a series of conventional strategic strike capabilities. Once deployed, they could have the capability to strike China's nuclear arsenal.[51]

Underlying the concerns of officials and analysts in both China and Russia is the twin fear that the United States would be less inhibited using conventional weapons than nuclear weapons and that a nuclear response to a conventional first strike would lack credibility. Various Chinese experts argue that conventional counterforce is a way to circumvent the "taboo" associated with the use of nuclear weapons.[52] Meanwhile, Arbatov writes of an "unspoken assumption" among Russian analysts that "traditional nuclear deterrence may not be effective against conventional counterforce threats, since nuclear retaliation [by Russia]. . . would invite suicide by follow-on nuclear strikes [by the United States] and thus lacks credibility."[53] Arbatov, it should be noted, roundly rejects this analysis himself—elsewhere he emphasizes his belief that a Russian nuclear response would be sufficiently credible to deter a U.S. conventional first strike[54]—but he argues that fear of conventional counterforce is nonetheless widely held within the Russian expert community.

Chinese and Russian concerns about conventional counterforce may elicit little sympathy from most U.S. analysts and officials, but they result from the kind of worst-case analysis undertaken by all defense establishments. Not only is there pessimism about the effectiveness of nuclear weapons, in extremis, for deterring a conventional counterforce strike but Beijing and Moscow also appear to worry that, even if CPGS started off as a small-scale capability, it could, in time, be expanded significantly and rapidly. This concern is exacerbated by the belief that it is just too sophisticated a capability not to be ultimately directed toward Russia and China. Arbatov, for example, argues that

> Russians just cannot believe that such complicated and expensive systems are only meant to target terrorists, who can be dealt with by much cheaper and simpler weapons. The idea that America needs weapons with short flight times to destroy reckless state leaders and terrorists looks ridiculous to most Russian experts.[55]

Russian and Chinese fears are also fueled by a handful of official statements. Taken as a whole, official U.S. documents and statements indicate very little interest in using U.S.

conventional forces to hold Chinese or Russian nuclear forces at risk. But there are exceptions. Yao, for example, has pointed to the 2013 National Defense Authorization Act, which mandates a report into the ability of the United States to "use *conventional* and nuclear forces to neutralize" Chinese underground tunnels.[56] She could equally well have pointed to statements by General James Cartwright, who while serving as the commander of U.S. Strategic Command, clearly stated an interest on various occasions in substituting nuclear weapons with conventional ones.[57] Fuel is also added to the fire by official-sounding advisory bodies, such as the Defense Science Board, which in 2004 stated that "over time, the United States may develop full protection capabilities against all conceivable [weapons of mass destruction–armed] adversaries."[58] Given that it is hardly unknown for U.S. analysts to seize upon isolated statements by Chinese and Russian officials and argue that they prove the existence of some hitherto undisclosed policy, it should not be all that surprising when Chinese and Russian experts do the same.

Regardless of whether Chinese and Russian concerns are reasonable, the United States has, as a matter of policy, pledged to try to ease them. The 2010 Nuclear Posture Review states that Conventional Prompt Global Strike will "not negatively [affect] the stability of our nuclear relationships with Russia or China."[59] To try to persuade Moscow and Beijing of this, the United States offered to commence strategic dialogues with both states (an invitation Beijing has not yet accepted).[60] These promises were not made for altruistic reasons, rather they reflect an understanding that managing Russian and Chinese concerns is very much in the U.S. interest.

If China or Russia perceives that its nuclear deterrent is being seriously compromised, it may decide to augment its nuclear forces (although any calculation in this regard is likely to be based on the totality of U.S. strategic forces, including nuclear forces, non-prompt conventional forces, and ballistic missile defense, not just CPGS). In Russia's case, the multiple-warhead "heavy" ICBM it is currently developing could allow it to expand its nuclear forces rapidly after New START expires at relatively low cost (however foolhardy such a step would be as a response to CPGS).[61] Meanwhile, China's current—rather slow—expansion of its nuclear forces could potentially be dialed up or continued for longer than would otherwise have been the case.[62]

Developments in U.S. precision conventional weapons could also have implications for China's no-first-use pledge. While there is considerable debate over the credibility of this pledge in the United States, there is also bipartisan agreement that a decision by China to renounce this commitment would be viewed as a provocative step, especially by U.S. allies.[63] In recent years, there has been a debate within China about whether to retain no first use, sparked, in part, by concerns about advances in U.S. conventional weaponry.[64] Yao, for example, states that "speculations on a possible change to the [no-first-use] policy have not been conjured up without reason" and goes on to call for efforts to "alleviate

China's concerns," including those related to U.S. "conventional strategic strike capabilities."[65] It is very much in the U.S. interest to try to do so to persuade Beijing not to repudiate no first use.

Russian and Chinese concerns about U.S. conventional weapons may also affect U.S. arms control goals. The United States currently seeks to negotiate a successor agreement to New START that would include Russia's large stockpile of tactical nuclear weapons, which are a source of significant concern for a number of NATO allies.[66] Moscow has emphasized on numerous occasions that any such agreement will be contingent on its concerns, including those that relate to CPGS, being addressed.[67] Most significantly, on June 19, 2013—just hours before Obama's speech in Berlin calling for further nuclear reductions—Putin personally emphasized concerns about "high-precision conventional weapon systems that in their strike capabilities come close to strategic nuclear weapons" in a "pre-buttal" of Obama's proposals.[68]

The United States and its Asian allies are also concerned by China's strategic modernization and gradual nuclear build-up and seek to engage China in a strategic dialogue to build mutual confidence.[69] To the extent that China's opacity is a way of enhancing the survivability of its nuclear forces, Chinese fears about CPGS are likely to make this process harder.[70]

In a deep crisis, Chinese and Russian concerns that the United States might be able—with some combination of nuclear forces, conventional forces, and ballistic missile defense—to eliminate their nuclear forces could have even more serious ramifications. If either state became genuinely worried—most likely during an ongoing conventional conflict—that the United States could launch a first strike, it might use or threaten to use nuclear weapons first, generating what is known as **crisis instability**. One extremely remote possibility is that Russia might try to preemptively disarm the United States. A more likely possibility would be for Moscow or Beijing to authorize the limited use of nuclear weapons or the threat of such use in an attempt to terrify the United States into backing down.[71] *The Science of Second Artillery Campaigns*, for example, advocates threatening preemptive nuclear use "when a militarily powerful country armed with nuclear missiles . . . carries out medium or high strength continuous air raids against our major strategic targets, and when our side lacks a brilliant plan for resisting the enemy."[72] The bottom line is that whether or not the United States believes that Chinese and Russian concerns about U.S. strategic conventional capabilities are justified, it has clear reasons to try to manage them.

One particularly important U.S. unilateral decision, in terms of influencing Chinese and Russian threat perceptions, would be the size of any CPGS deployment. Although both Moscow and Beijing worry that a small CPGS deployment might be expanded significantly and rapidly, the feasibility of such an expansion would depend on whether the United States repurposed existing missile delivery systems (that is, retired nuclear missiles) or if it built an entirely new delivery system for CPGS. Specifically, if the United States used existing launch vehicles, which are limited in number, and subsequently decided to expand any CPGS deployment, it would have to develop, test, and procure a new missile, thus providing Moscow and Beijing with years of warning. There is a trade-off here. While the use of a former nuclear delivery vehicle for CPGS risks worsening the warhead ambiguity problem, since crisis instability is a more likely cause of escalation, easing instability at the expense of exacerbating ambiguity might well have net benefit.

Whether in practice it would be possible for the United States to use existing delivery systems for CPGS is unclear (it would depend on the size of any deployment and the chosen basing mode). Nonetheless, this possibility should be seriously explored by the Pentagon (and not least because it would be significantly cheaper than developing a new delivery system).

ESCALATION, ENTANGLEMENT, AND TARGET AMBIGUITY

CPGS could have other potential implications for escalation that, like destination ambiguity and crisis instability, would probably be rather more serious than warhead ambiguity.

There appears to be an ongoing debate within Russia about whether to threaten to retaliate against CPGS use with tactical nuclear weapons. This debate is driven by a widely held fear in the Russian defense establishment that, in the words of Russian President Vladimir Putin, "as high-precision long-range weapons with conventional charges become more common, they will become the means of achieving a decisive victory in conflicts, including a global conflict."[73] Sergei Rogov (Director of the Institute for American and Canadian Studies) and three retired generals, Viktor Esin, Pavel Zolotarev, and Valeriy Yarynich, argue that fear is "one of the reasons for lowering the 'nuclear threshold' in the official Russian Military Doctrine."[74] In a similar vein, Arbatov, Dvorkin, and Oznobishchev write that

> Moscow would consider [tactical nuclear weapons] as a counterbalance to the U.S. high-precision weapons (as a means of striking against forward bases of the U.S. air force and groups of navy) and an asymmetrical deterrent of the "threat of aerospace attack." There is an opinion that the use of [tactical nuclear weapons] at early stages in response to aggression with the use of high-precision weapons is more likely than mounting a retaliatory strike with strategic nuclear forces (which would provoke the other party to mount [a] strategic nuclear strike).[75]

As undesirable as Moscow's identifying tactical nuclear weapons as a counterweight to CPGS may be, the issue is also somewhat academic since the United States would be extremely unlikely to use CPGS against Russia. By contrast, some potential missions for CPGS—particularly defense suppression and countering antisatellite (ASAT) capabilities—could involve strikes on China.

Clearly, the risk of escalation following attacks on China is a much bigger question than any one weapon system. These risks have been discussed recently in the context of the Pentagon's evolving Air-Sea Battle concept, which, according to the 2010 Quadrennial Defense Review, is focused on "defeating adversaries across the range of military operations, including adversaries equipped with sophisticated anti-access and area denial capabilities."[76] Analyzing the implications of Air-Sea Battle for escalation management is a complex task. Few would dispute the assertion that attacks on mainland China could be highly escalatory; there is debate about whether the benefits of such attacks would outweigh the risks and whether they are alternative, less escalatory ways of achieving similar ends.[77] To the extent that CPGS is able to hold at risk targets that other weapon systems cannot, it could create certain additional risks of escalation. In this regard, attacks on command and control (which might be hard or buried), mobile non-nuclear missiles, and ASAT weapons—which are all potential targets for CPGS—could carry particular risks of escalation.

Chinese command and control would be one potentially important target in any defense suppression campaign, particularly for the purpose of denying Beijing the ability to use its conventional anti-ship ballistic missiles.[78] These missiles are operated by the Second Artillery Force, which is also responsible for China's land-based nuclear weapons, reportedly using a shared command and control system.[79] As a result of this "entanglement" between nuclear and conventional forces, Joshua Pollack argues that

> [American] attempts to "decapitate" Chinese command-and-control capabilities for conventional missiles could implicate China's nuclear deterrent force . . . This places U.S. planners in a bind. Targeting central command-and-control nodes could threaten China's nuclear deterrent and might be interpreted as a prelude to—or equivalent to—a nuclear first strike . . . Yet it is difficult to imagine that, in the event of an armed conflict, a U.S. commander would be content to absorb a barrage of precision strikes.[80]

This form of ambiguity—in which Beijing is uncertain whether the target of the attacks is nuclear or conventional—might be termed **target ambiguity**. It is quite different from warhead ambiguity, in which the uncertainty is about the nature of the weapon being used to conduct the attack. The risks of escalation in this case appear to be serious because, if Beijing believed that the United States was in the process of attempting to execute a first strike, it could have plausible incentives to resort to the use nuclear weapons.

The United States could also use CPGS weapons to attack mobile assets, including conventional missiles and ASAT weapons. Such attacks would probably be less likely than attacks on command and control because there would be no “good time” in a conflict to initiate them. One possibility would be to attack mobile weapons early in a crisis, before they had been dispersed. However, precisely because such a step would almost certainly lead to escalation that might otherwise be avoidable, a U.S. president might be very reluctant to authorize it. Alternatively, attempting to destroy these weapons after dispersal would be much harder and the probability of failure would be higher.

In the event the United States were to attempt an attack on mobile weapons—whether before or after dispersal—another form of entanglement could create risks of escalation to the nuclear level. China’s conventional anti-ship ballistic missile and the ASAT weapon it tested in 2007 are both variants of the nuclear-capable DF-21. In a major conventional conflict, thick with the fog of war, distinguishing between conventional and nuclear weapons might be very difficult, if not effectively impossible. As a result, there is the possibility that the United States might *accidentally* attack a Chinese nuclear weapon, also creating target ambiguity. If Beijing incorrectly (but understandably) concluded that Washington had intended to attack its nuclear forces, a Chinese nuclear response in this scenario would be possible. Even if Beijing correctly identified that its nuclear forces were not the intended target, it would probably still view the attacks as extremely provocative and escalatory (though a nuclear response would be very unlikely).

If Beijing improves its missile early-warning capabilities in the future, the risks of target ambiguity could be exacerbated by the use of boost-glide systems or hypersonic cruise missiles compared to terminally guided ballistic missiles. Specifically, because the former are maneuverable, Beijing could worry that its nuclear forces were under attack, even if Washington had correctly identified—and was aiming for—strictly non-nuclear assets. By contrast, because Beijing could observe and reliably predict the trajectory of ballistic missiles (at least until very late in flight), their use could be somewhat less escalatory.

Another escalation pathway could occur if CPGS weapons were used to hold Chinese ASAT weapons at risk (or if Beijing wrongly perceived that CPGS was being used in this way). In a conflict, Beijing might well attempt to interfere with the effectiveness of U.S. weapons by GPS denial, likely through jamming in the first instance. If U.S. counter-jamming efforts were successful, Beijing might consider launching attacks on GPS satellites, either with kinetic ASAT weapons or perhaps lasers.[81] To be sure, such attacks would be both difficult and unattractive. Because GPS satellites orbit at an altitude of about 20,000 km (12,400 mi.), destroying or disabling them would be much more difficult than attacking a weather satellite at 850 km (530 mi.), as China did in 2007. Moreover, its distributed architecture gives the GPS system a high degree of redundancy.[82] Simulations indicate that to significantly degrade U.S. GPS capability with direct ascent ASAT weapons, China would typically have to destroy at least four satellites and, even then, the effect would only last for a maximum of two hours (unless additional satellites were attacked).[83]

These problems notwithstanding, there could still be strong incentives for Beijing to attack U.S. GPS satellites in the critical opening phase of a conflict, mostly obviously over Taiwan. In particular, such attacks could be politically—and perhaps militarily—decisive, if they allowed China to protect its anti-access/area-denial capabilities for even just a few hours and, in that time, disable or sink a U.S. aircraft carrier. Fearing this, the United States could have a correspondingly strong incentive to attack Chinese ASAT weapons, or their enabling capabilities, early in a crisis using CPGS. This possibility would, in turn, give China an incentive to preempt the United States and destroy GPS satellites, thus defending against the possibility of CPGS attacks.

In other words, at the start of a major conflict, both the China and the United States could have a clear incentive to "go first" and attempt to destroy the other's critical assets—U.S. GPS satellites and Chinese ASAT capabilities—in order to protect their own.[84] In this scenario, the "reciprocal fear of surprise attack" could precipitate a conflict or significantly escalate the level of violence.[85] The underlying logic is, of course, very familiar from the concept of instability discussed extensively in the nuclear deterrence literature. Instability is not, however, an exclusively nuclear concept, as this demonstrates.[86]

DETERRENCE, DISPLACEMENT, AND DUPLICATION

In addition to affecting an adversary's behavior in a crisis or a conflict, CPGS could also have effects on potential adversaries during peacetime. One desirable possibility is that it might contribute to deterrence.[87] Not only would this be a good in itself, but enhanced conventional deterrence could allow the United States to further reduce the role of nuclear weapons in its defense doctrine (which would probably be applauded by many non-nuclear-weapon states and regarded with quiet concern by nuclear-armed potential adversaries worried about conventional counterforce).

Conventional deterrence is generally argued to rely upon making an adversary believe that it would be unable to achieve its objectives quickly and at relatively low cost.[88] As such, it stems from the total capability of U.S. forces that are deployed locally or could be available quickly. For this reason, it is usually hard to disaggregate the contribution made by any one particular weapon system. However, given that proponents argue CPGS could be uniquely able to hold certain high value targets at risk in scenarios where nuclear use would be politically unacceptable, there is certainly a plausible argument that it could make a significant contribution to deterrence. In fact, in assessing this contribution, what matters is not so much the actual capability and usability of CPGS, as potential adversaries' perception of these characteristics.

Accurately assessing potential adversaries' perception of any U.S. weapon system, especially one like CPGS that is still a research and development project, is difficult. But Russian and Chinese fears about the possible impact of CPGS weapons on the survivability of their nuclear forces do suggest that they view CPGS as both highly capable and significantly more usable than nuclear weapons. Interpreting this one data point requires a good deal of caution. Being more usable than nuclear weapons is an extremely low bar (in most conflicts, being no less usable than other conventional weapons would be the relevant criterion). Because Beijing and Moscow are concerned about U.S. precision-guided weapons in general, it is hard to disaggregate their particular thoughts about CPGS (which may change anyway as candidate technologies are further developed and tested). Finally, Russian and Chinese views may not be representative of other states.

These caveats notwithstanding, the evidence does tentatively suggest that CPGS is likely to enhance deterrence. Additionally, the risks of escalation resulting from the use of CPGS may also be a deterrent in themselves.[89] Specifically, these risks might persuade a potential adversary contemplating aggression against the United States or an ally that it would be unlikely to achieve its objectives quickly or painlessly and thus help tip the adversary's calculation in favor of restraint.

The potential deterrent value of CPGS therefore creates a dilemma for the United States that is thrown into sharpest relief by the case of China. On the one hand, CPGS could help deter Beijing from initiating actions that could spark a conventional conflict. On the other hand, it could make escalation, including to the nuclear level, more likely once such a conflict started.

Balancing deterrence with the risks of escalation may also have implications for assuring U.S. allies. While a serious discussion of CPGS is yet to start in any U.S. friend or ally, the Japanese attitude toward Air-Sea Battle is potentially instructive. Given Tokyo's concerns about Beijing, Japanese experts and officials are certainly receptive to the concept of Air-Sea Battle. However, they also express concerns about escalation and, very specifically, the possibility that if the United States conducted strikes against mainland China, Beijing would retaliate with strikes against U.S. bases on Japan.[90] CPGS might, therefore, be a mixed blessing for assurance.

A second potential peacetime effect of CPGS could be to prompt potential adversaries to focus their military investments on weapons and infrastructure that would be less vulnerable to American conventional strike capabilities—a process that might be termed **displacement**. This phenomenon is, of course, nothing new. As U.S. conventional strike capabilities have improved over the last few decades, potential adversaries have focused on protecting key assets by burial or mobility, but the deployment of CPGS could speed up this trend.

From a U.S. perspective, displacement has both positive and negative implications. While forcing adversaries to redirect limited resources to countermeasures contributes to limiting their overall capabilities, displacement also results in any advantage being temporary. This should certainly not be taken as an automatic argument against CPGS; if it were, it would be an automatic argument against ever deploying any new military technology for fear of eventual obsolescence. Yet, it is an argument for carefully assessing how much of an advantage CPGS would provide to the United States and how long this advantage would last, and comparing these to the costs of the system.

In assessing the long-term cost effectiveness of CPGS, the Defense Science Board concluded, in 2009, that

> the deployment of global range conventional ballistic missiles capable of striking fixed coordinates will neither be a watershed capability for the U.S., nor is it likely to provide any lasting asymmetric capability for us.[91]

While the Defense Science Board did not elaborate upon its reasoning in any detail, the apparent logic here is straightforward and compelling. The number of additional fixed underground targets that CPGS might allow the United States to hold at risk would probably be relatively small. Meanwhile, since many surface targets that are currently fixed could be made mobile (leveraging large investments that potential U.S. adversaries have already made), the advantages gained by the ability to destroy time-critical, fixed, surface targets would probably not be long lasting. By contrast, if CPGS weapons could hold mobile targets at risk, they would create a much more durable long-term advantage.

CPGS might also prompt potential adversaries to duplicate the United States, that is, develop similar systems of their own.[92] The National Research Council expressed little sympathy for concerns about **duplication**, arguing that

> On balance, the committee judges that the deployment or use of CTM or other CPGS systems is by itself unlikely to have a substantial effect . . . on the development of similar systems by other countries. In general, countries will do what is in their own national interest and within their technological capability and financial capacity, regardless of what the United States does—or does not do—about CPGS.[93]

The problem with this argument is that it ignores the question of how states define their national interest. There is, in fact, clear evidence that, where military doctrine and technology are concerned, other states pay extremely close attention to American developments, analyze their effectiveness, and attempt to replicate concepts or technologies they judge to be effective (this process may be speeded up by espionage but is not dependent on it). As such, the innovative and well-funded U.S. research and development sector acts as something of a testing ground for advanced militaries worldwide. U.S. programs may have other influences: they can confer prestige on a technology and hand proponents a powerful example to use in bureaucratic battles over procurement. But, it is important to emphasize that, whatever "non-rational" factors may contribute to other states' copying the United States, the strategy of investing limited resources in technologies and doctrines that the United States has shown to be effective has an entirely rational basis.[94]

One very clear example of duplication is the proliferation of unmanned aerial vehicles over the last decade. Some of this proliferation has been fueled by sales—predominantly from Israel and the United States, which pioneered the technology—but many states have also initiated indigenous development programs. In reference to these programs, the Government Accountability Office stated in 2012 that

> the number of countries developing UAVs has increased dramatically from 2005 to the present . . . This growth is attributed to countries seeing the success of the United States with UAVs in Iraq and Afghanistan and deciding to invest resources into UAV development to compete economically and militarily in this emerging area.[95]

Chinese development of conventional long-range hypersonic weapons is another excellent example of duplication. U.S. scholars Andrew Erickson and David Yang argue that the American Pershing II ballistic missile "inspired" Chinese research into maneuvering warheads, ultimately resulting in the DF-21D anti-ship missile.[96] As evidence they point to more than 50 Chinese-language studies on Pershing II published from the late 1970s onward. Chinese sources also acknowledge foreign influences. *The Science of Second Artillery Campaigns*, for example, is absolutely explicit in identifying foreign examples as important drivers for the development of Chinese conventional missiles. After a detailed summary of historical "missile force campaigns," starting with the German V-1 and V-2 attacks during World War II and culminating with the 1991 Gulf War, it adds that

> especially after the Gulf War, our military under the correct leadership of Chairman Jiang Zemin had formulated the military strategic principles for the new era. In order to adjust to the requirements of future high

> tech localized warfare, the Central Military Commission had assigned the new mission of "Double [that is, conventional and nuclear] Deterrence and Double Operations" to Second Artillery.[97]

Conventional missiles are by no means the only area in which China has used the United States as a source of military innovation. China has also learned extensively from U.S. developments in, for example, joint operations and so-called C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance).[98]

The influence that the United States has recently had on Russian military developments is less well documented. However, it is unlikely to be a coincidence that Russian interest in long-range hypersonic conventional weapons reemerged shortly after the United States initiated significant programs in this area. Indeed, the commander of Russia's Strategic Rocket Forces has publicly connected Russian interest in conventional boost-glide weapons with the U.S. CPGS program.[99]

There is, therefore, a plausible argument that the development of CPGS by the United States would make the development of similar systems by foreign states—Russia and China, in particular—more likely (especially if testing or employment demonstrates the system's efficacy). The most obvious counterargument is that China and Russia are already committed to developing such systems and will continue regardless of U.S. actions.[100] But the future of Chinese and Russian programs is unclear and quite possibly undecided. While China is investing in conventional intermediate-range ballistic missiles, its commitment to the development of longer-range systems is unproven. Meanwhile, Russian conventional long-range hypersonic weapons programs are at an early stage and, while Moscow may talk a good game, its commitment to these programs also remains to be seen. Given the extent to which U.S. programs have acted as a model for Beijing, and possibly for Moscow too, there is some reason to suppose that the United States will continue to influence China and Russia.

To be very clear: to argue that the U.S. development of CPGS may *influence* decisions by other states is not to imply any inevitability. If the United States pursues CPGS, duplication will not be certain. Conversely, there is no guarantee that if the United States refrains from developing CPGS, other states will show similar restraint. Rather, the point is that it would be a mistake to assume, as the NRC does, that Chinese and Russian efforts will be completely decoupled from U.S. efforts.

COOPERATIVE CONFIDENCE BUILDING

Some potential risks of CPGS could be mitigated with cooperative confidence-building measures. In particular, there are steps that could be taken to alleviate the warhead ambiguity problem and to ease Russian and Chinese fears about the survivability of their nuclear forces. Other problems would be less amenable to cooperative risk reduction. For example, if the United States takes a doctrinal decision to acquire CPGS for missions that might involve attacks on China, there is probably little that could be done cooperatively to reduce the risks of escalation following such strikes. While improved crisis communication might make some difference, cooperative measures agreed in peacetime would be unlikely to prove effective if, during a war, the United States used CPGS weapons to attack targets on mainland China. If Washington decides against using CPGS on targets in China, it should attempt to communicate this decision to Beijing to reduce the risk of Chinese leaders' concluding mistakenly that they were under attack should the United States use a boost-glide weapon or hypersonic cruise missile against North Korea (or, for that matter, any other state near China).

As described in the 2008 NRC report, cooperative measures could enable any state capable of observing a CPGS launch to gain confidence that a nuclear weapon had not been used. While the details are rather complex, three conceptually different measures can be envisaged:[101]

(i) Inspections of CPGS weapons to verify that their warheads are non-nuclear; [102]

(ii) Authenticated surveillance of each CPGS weapon to demonstrate that, following an inspection, a verified conventional warhead is not swapped out for another; and that, in the event of a launch, it is a non-nuclear weapon that has been used; and

(iii) Notifications by the United States of any CPGS launch.

Some or all of these measures could be implemented in virtually any combination (with the one exception that surveillance would have very little value unless coupled with inspections). The United States could usefully explore with Russia, and hopefully China, which combinations would be useful.

One obvious factor that might affect the calculation is basing mode. For example, for land-based systems that were deployed away from existing ICBM fields, inspections by themselves might suffice. By contrast, more robust measures might be desirable in the case of sea-based systems that could be fired from the launch areas for nuclear missiles. Unfortunately, sea-basing is the case in which the implementation of confidence-building measures would probably be hardest (as discussed further below).

There might be some resistance to notifying other states of CPGS launches. Most obviously, the United States would not be willing to notify Beijing of a launch if China were also the target. There could also be concern in the United States that, if Moscow or Beijing disagreed with the United States over the use of force, it might pass the notification on to the intended target. That said, this problem might not be insoluble. For instance, one hour of advance notification might be sufficient for Russia (or China in the future) to alert its early-warning system to an impending CPGS launch but might not be long enough for Moscow (or Beijing) to pass on this notification. Moreover, the United States could withhold the location of the target. Once again, the United States could usefully explore this issue with Russia and China (in separate bilateral tracks).

Other measures could help reassure Moscow and Beijing about the survivability of their nuclear forces. Informal confidence-building measures could be helpful in this context regardless of whether CPGS is included in any future arms control treaty. Perhaps the biggest advantage of such measures is that they could be applied to those conventional capabilities, long-range cruise missiles in particular, that the United States would not agree to subject to binding limits. By easing Russian concerns about cruise missiles, confidence building might lead Moscow to agree that they should be excluded from the scope of any future arms control negotiation.

Confidence building need not—and, indeed, should not—be a one-way street. As U.S. officials have emphasized, Russia and China are both investing heavily in conventional cruise missiles and other precision-guided weapons.[103] All parties, including the United States, could therefore benefit from reciprocal confidence-building measures, such as data exchanges.

In recent years, numerous confidence-building proposals have been put forward, including by Russian experts, creating an excellent basis for official discussions.[104] The following summarizes some of the more promising ideas.

- **Data exchanges**

  U.S.-Russian reciprocal data exchanges covering high-precision conventional weapons could enhance each side's confidence in its estimates of the other side's forces and increase predictability, which, in Russia's case, would hopefully translate into enhanced confidence in the survivability of its nuclear forces. Data exchanges covering some other weapon types have long been facilitated within the Organization for Security and Cooperation in Europe (OSCE), of which both Russia and the United States are members, as well as its predecessors.[105] Indeed, given Russian concerns about NATO, it is worth considering the possibility of a multilateral data exchange involving OSCE states instead of, or in addition to, a bilateral arrangement.

Data exchanges about precision-guided weapons, including cruise missiles, could cover acquisition and/or deployment. On the former, the parties could agree to exchange information about plans, over the next five years say, for the procurement of agreed types of high-precision conventional weapons.[106] They could also agree to give, perhaps, one year's notice of changes in such plans. Russian experts have called for data exchanges on "the practice of deploying high precision weapons on ships, submarines and aircraft."[107] This could be accomplished by, for example, exchanging data about the number of agreed types of high-precision conventional weapons deployed in certain theaters.

Clearly, considerable joint work would be needed to develop the exact terms of and definitions for any data exchange. However, such work could be useful in itself by facilitating a conversation about each state's doctrine for the employment of precision-guided weapons.

A U.S.-China data exchange would be significantly harder to orchestrate but could be a useful longer-term goal. For example, the United States could provide China with data on its procurement plans for CPGS in return for China providing data on similar Chinese weapons, such as DF-21D.[108] Once again, the dialogue needed to develop the details of such a data exchange could prove every bit as valuable as the exchange itself.

- **Basing restrictions and movement notifications**

Basing restrictions and movement notifications could serve purposes similar to data exchanges and, again, there are clear precedents. New START forbids the basing of heavy bombers outside of national territory and requires notifications about their movements. (These basing restrictions, it is important to emphasize, do not prevent bombers from being "temporarily located" abroad while on operations.[109]) Russia and the United States could agree to apply these measures, on a voluntary basis, to bombers not covered by New START.[110] A prime candidate in this regard would be the U.S. B-1B bomber, which was originally accountable under New START but ceased to be following an exhibition to demonstrate that the B-1B is no longer equipped for nuclear missions.

In a similar vein, Arbatov et al. have proposed a ban on the basing of U.S. strike aircraft on the territory of new NATO members in return for Russia's assuming similar obligations with respect to its allies.[111] A legally binding agreement may be a step too far for NATO initially, but mirroring the language used in its promise not to base tactical nuclear weapons on the territory of new NATO members, the United States could declare publicly that it has "no need, no plan, and no intention" of deploying its strike aircraft in those states.[112] Such language would probably not fully satisfy Russia (especially given past controversies about NATO expansion) but could be a useful first step.

- **Observation of exercises**

Another possibility, also suggested by Russian experts, is the exchange of observers at military exercises involving high-precision conventional weapons.[113] This could help each side to understand the other's doctrine for employing such weapons. For almost four decades, states within the OSCE (and its predecessors) have permitted observers at military exercises above a certain size.[114] The United States and Russia, or perhaps all OSCE states, could build upon this precedent by inviting, on a voluntary and reciprocal basis, observers to smaller exercises that focus on high-precision conventional weapons.

In principle, this measure could also be applied by China and the United States on a bilateral basis. These states have exchanged observers at military exercises before, although the practice has sometimes proved controversial within the United States due to accusations that Beijing has been less forthcoming than Washington.[115]

- **Joint studies**

There seems to be some genuine technical disagreement between Russia and the United States about the threat posed to silos by cruise missiles. The issues are technically complex because Russian experts raise concerns about a variety of warhead types, including shaped charges similar to those used in anti-tank weapons.[116]

To try to resolve these concerns, the U.S. and Russian national academies of science could conduct a joint study.[117] If they are not able to resolve the disagreement, they might be able to design joint experiments that could, such as actually detonating a conventional explosion near an empty silo that was due to dismantled under New START.[118]

One important caveat about confidence building is in order. As experience over the last few years has shown, it is much easier to advocate confidence building than to effect it. During the second term of the George W. Bush administration, for example, Washington offered Moscow inspections of planned missile defense facilities in Eastern Europe (for the purpose, among others, of demonstrating that the planned radar in the Czech Republic was oriented toward Iran and not Russian ICBM fields). Moscow argued that this proposal did not go far enough and instead made a counteroffer of providing the United States with data from two of its radars near Iran in return for a freeze on U.S. missile defense deployments in Europe.[119] A compromise could not be reached.

Similar dynamics occurred a few years later under the Obama administration. In October 2011, the United States invited Russia to observe a test of a Standard Missile-3 interceptor, using Russian sensors, to allow Moscow to verify the missile's capabilities (its "burn-out velocity" in particular).[120] Russia turned down the offer, with one senior official describing it as a "propagandistic step."[121] Moscow argued instead for binding limits on U.S. missile defenses.

Meanwhile, the Bush administration, in spite of various attempts, did not succeed in initiating meaningful official talks with Beijing on nuclear deterrence, and the Obama administration has similarly failed.[122] Such talks would be a prerequisite to defining Sino-U.S. confidence-building measures.

U.S. domestic politics could complicate matters further. Military cooperation with China and Russia can often prove controversial within the United States. Indeed, it is not hard to imagine how some of these confidence-building measures—such as data exchanges or inspections of CPGS weapons—could be branded as dangerous concessions. Although Senate ratification is not needed for confidence-building measures that do not limit military capabilities, Congress can sometimes still find ways to block or complicate the implementation of such steps. In 2011, for example, following suggestions that the Obama administration was considering providing Russia with information about the burn-out velocity of U.S. missile defense interceptors, Congress passed a law requiring the administration to provide it with sixty days advance notice of the transfer of any classified information to Russia.[123] While this law would not block such a transfer, it could raise its political costs. In other cases, Congress could potentially block the implementation of confidence-building measures by refusing funding.

In short, while confidence building could mitigate the potential risks of CPGS—to some extent at least—there is also a risk it would not be politically possible. The difficulties stem from both unhelpful Russian and Chinese attitudes, as well as U.S. domestic politics. Indeed, it would be extremely ironic—but hardly unimaginable—if, having blocked the Conventional Trident Modification on the grounds that it would have created unacceptable risks of nuclear war, Congress were to block confidence-building measures designed to mitigate similar risks.

ARMS CONTROL AND CPGS

The question of whether CPGS weapons should be regulated by any future arms control treaty is likely to be a key issue in U.S-Russian negotiations. Making CPGS weapons treaty accountable could help to build Russian confidence in the survivability of its nuclear forces. Although China will not, in all probability, be a party to any strategic arms reduction treaty for the foreseeable future, the inclusion of CPGS in bilateral U.S.-Russian treaties could nonetheless help to reassure Beijing and hence bolster Sino-U.S. strategic stability as well as U.S.-Russian strategic stability.[124]

New START provides a precedent in that it counts conventional ICBMs and SLBMs toward the treaty's central limits (or, at least, it would do if any such weapons were deployed). This arrangement was, in fact, not an innovation; conventional ICBMs and SLBMs would also have been accountable under the Strategic Arms Reduction Treaty I (START I). There is, however, disagreement between Russia and the United States about whether conventional boost-glide weapons would be accountable under New START. The United States argues that because the majority of a boost-glide vehicle's trajectory would be non-ballistic, such systems would not meet the treaty's definition of a ballistic missile—"a weapon-delivery vehicle that has a ballistic trajectory over most of its flight path"[125]—and would thus not be treaty accountable.[126] During negotiations, Russia argued that boost-glide weapons might constitute "a new kind of strategic offensive arm,"[127] in which case they would trigger bilateral discussions about whether and how they would be regulated by the treaty—a position rejected by the United States.[128]

This disagreement may turn out to be purely academic because there is virtually no prospect that the United States could actually deploy a boost-glide weapon before the treaty expires in 2021. But if the treaty is extended (and its provisions permit an extension of up to five years) then this issue may need to be resolved.

Looking forward, one possibility would be to make all CPGS systems (including boost-glide weapons and, conceivably, long-range hypersonic cruise missiles) accountable in a future treaty. Clearly, exactly how this was done would have to depend on the terms of the treaty. Assuming that a future treaty contains separate limits on launch vehicles and deployed warheads, CPGS systems could count toward both limits or, perhaps, simply just the former.

While conceptually straightforward, the acceptability of this approach is unclear. If the missions adopted for CPGS required only a small number of weapons—and U.S. officials have repeatedly stated that it would be a "niche" capability—then this approach should, in principle, be acceptable to the Pentagon. Moreover, if land-based CPGS systems were adopted, verification would probably be relatively straightforward.

Sea-based systems, by contrast, could create serious verification difficulties, unless SSBNs or SSGNs—the basing modes least favored by Congress—were used. Conventional intermediate-range ballistic missiles based onboard attack submarines would be particularly problematic. START I and New START set clear precedents for such missiles being treaty accountable and hence for subjecting the submarines on which they are deployed to inspections. There would, however, probably be strong resistance within the U.S. Navy to inspections of attack submarines. As a result, if the United States intends to deploy conventional ballistic missiles onboard attack submarines, it would presumably want to exempt such missiles from a future arms control agreement. Russia, however, would be unlikely to consent to such an arrangement, creating a serious—and possibly irresolvable—barrier to a new treaty.

One potential solution might be to exempt attack submarines from the treaty's verification regime but attribute to them an agreed number of ballistic missiles and conventional warheads that would count toward the treaty's limits. Such a solution would be far from ideal (not least because it would not allow for inspections to demonstrate the warheads were indeed non-nuclear) but might ultimately be deemed preferable to not having a treaty.[129]

Other sea-based CPGS weapons—naval boost-glide systems or conventional ballistic missiles deployed on surface ships—would create similar problems unless they were based on SSBNs or SSGNs (as would hypersonic cruise missiles unless they were delivered exclusively by treaty-accountable heavy bombers). Once again, even if the United States were to accept the principle of making such systems treaty accountable, the difficulty of facilitating inspections on surface ships or attack submarines would arise.

Yet, the precedents for making sea-based CPGS weapons other than submarine-launched conventional ballistic missiles treaty accountable are weak. While START I did ban the deployment of ballistic missiles (nuclear or conventional) on surface ships, New START does not (in this way, New START's regulation of conventional ballistic missiles is actually less onerous than START I's).[130] Meanwhile, Russia and the United States do not even agree on whether New START would require discussions about the accountability of boost-glide systems. It is, therefore, possible (but by no means certain) that, if Russia were convinced U.S. CPGS deployments would be small, it might consent to a treaty that exempted conventional ballistic missiles based on surface ships and naval boost-glide systems.

Political opposition within the United States to making CPGS weapons treaty accountable would also be likely (whatever basing mode was adopted). Recent experience demonstrates that limits on non-nuclear capabilities can prove extremely controversial in Congress (which is significant given that the U.S. Senate must provide its advice and consent for the ratification of any treaty). While the accountability of conventional ICBMs and SLBMs under New START was not nearly as controversial as the treaty's extremely minimal treatment of ballistic missile defense,[131] the issue was discussed on multiple occasions during the ratification debate and a number of Senators expressed concerns. For example, the five members of the Senate Foreign Relations Committee who opposed the treaty argued that "CPGS could offer an incredible capability to swiftly respond to a threat anywhere in the world, and eliminate the threat before it matures."[132] They went on to add that

> the unwillingness of the Obama administration to understand this changing dynamic or to protect American interests and flexibility is dangerous. [The treaty's] constraints are more troubling when President Obama argues that New START's reductions are acceptable because the United States has such a strong conventional force—endorsed by [De-

> fense] Secretary Gates in his written answers [sic]. Yet, Secretary Gates is also pushing to cut spending on U.S. conventional capabilities.[133]

It is certainly possible that such concerns could stymie the inclusion of all CPGS systems, or perhaps even just conventional ICBMs and SLBMs, in a future treaty. To be fair, there is also a legitimate question about whether Moscow would want to limit all CPGS systems. Given that Russia may be interested in developing its own CPGS-like weapons, it is possible that it might not seek to make them treaty accountable.

CONCLUSIONS AND RECOMMENDATIONS

The development and possible employment of CPGS weapons carry real benefits and real risks. Analysis of the risks has tended so far to focus narrowly on the warhead ambiguity problem, that is, the possibility that Russia—or China in the future—might launch a nuclear response after incorrectly identifying a CPGS weapon as nuclear armed. While this form of ambiguity certainly could be an issue in the event of CPGS strikes on China (or, much less likely, Russia), other risks of escalation—including to the nuclear level—would probably be more serious. These risks include:

- **Destination ambiguity**—uncertainty on the part of a state observing a CPGS launch about whether it was the target of the attack—arising from the use of CPGS systems capable of mid-course maneuvering. Destination ambiguity could exacerbate warhead ambiguity and introduce other risks.
- **Target ambiguity**—uncertainty about whether the United States was intending to attack a conventional or nuclear target—arising from strikes on "entangled" assets, such as dual-use command-and-control systems or nuclear weapons that were mistaken for visually similar conventional weapons.
- **Crisis instability**—pressures felt by an adversary to use or threaten to use weapons out of concern that they lacked survivability—arising from the real or perceived ability of CPGS to hold the adversary's nuclear or strategic conventional capabilities at risk.

Reducing these risks is a complex task. In theory, the following set of characteristics would be useful for risk mitigation (with the risk or risks addressed by each characteristic shown in parentheses):

- Separate deployment areas for CPGS and nuclear weapons (warhead ambiguity)

- Different trajectories for CPGS and nuclear weapons (warhead ambiguity)
- Use of boosters with no nuclear association for CPGS (warhead ambiguity)
- Predictable trajectories for CPGS weapons (destination ambiguity and target ambiguity)
- Observable mid-course trajectories for CPGS weapons (all risks)
- Limited CPGS deployments (crisis instability)

In practice, it would be impossible to meet all these requirements simultaneously—trade-offs would be inevitable. For example, the use of former nuclear-weapon delivery vehicles for CPGS boosters might exacerbate the warhead ambiguity problem. However, because such launch systems are limited in number, they might help persuade Russia and China that their nuclear forces will remain survivable, enhancing crisis stability. More importantly, boost-glide weapons and hypersonic cruise missiles would have trajectories that differ from ballistic missiles, which is desirable from the perspective of reducing warhead ambiguity. Yet, they would also fly at too low an altitude to be monitored by early-warning radars and would have significant cross-range maneuvering capability, making them both unobservable after the boost phase and unpredictable, tending to exacerbate all forms of ambiguity.

Potential Russian and Chinese countermeasures could also have mixed effects. For example, by developing an advanced missile early-warning capability, China might become more confident in the survivability of its nuclear forces, thus reducing the risk of crisis instability. At the same time, by allowing China to detect an incoming weapon much earlier in flight, it could exacerbate other escalatory risks, including warhead and target ambiguity.

While some risks of CPGS could be mitigated significantly, the only effective way to do so would be through cooperative confidence-building measures. Because of both Russian and Chinese attitudes, as well as U.S. domestic politics, there is a real danger that it would not be possible to implement such measures, even if the U.S. government supported them.

If cooperative confidence building were possible, trade-offs would, once again, be necessary. For example, sea-launched conventional ballistic missiles would have observable and predictable trajectories. But, unless they were based on SSBNs or SSGNs, it would be very difficult to subject them to inspection to verify that their warheads were indeed non-nuclear (although, as long as New START is in force, inspections of attack submarines carrying conventional ballistic missiles would be legally required). By contrast, land-based boost-glide systems have unobservable and unpredictable trajectories, but could be subject to inspection much more easily.

To complicate matters further, none of the risks outlined here is exclusively associated with CPGS systems. Russian and Chinese concerns about the survivability of their nuclear forces, which could generate crisis instability, relate to all U.S. high-precision conventional weapons, not just CPGS. Moreover, destination, target, and even warhead ambiguity could result from the use of non-prompt conventional weapons. While the risks may be less severe in the case of slower, shorter-range conventional weapons that are not launched by large rocket boosters, they should also not be neglected in comparing CPGS with possible non-prompt alternatives.

Finally, the unpredictability of a conflict in which CPGS weapons were used along with foreign perceptions of the effectiveness of these weapons could enhance deterrence and help prevent conflict. Indeed, CPGS provides an illustration of a more general dilemma with conventional weaponry: exactly the same capabilities that enhance deterrence can simultaneously undermine the possibility of escalation management.

Ultimately, whether the potential benefits of CPGS outweigh its risks is a matter for legitimate debate. But what is absolutely clear is that to have a meaningful debate it is necessary to broaden discussion of the risks beyond warhead ambiguity.

The following four recommendations would help reduce the strategic risks of CPGS:

1. The Department of Defense should examine all the risks of CPGS and not focus on the warhead ambiguity problem.

To better understand the full range of potential escalation risks and possible ways of mitigating them, the Pentagon should conduct a series of tabletop war games involving CPGS strikes. It should also subject its current models of escalation to scrutiny by an independent "red team" of experts from outside the Pentagon who hold the necessary security clearances. This analysis should be factored into the development of doctrine.

2. Before funding the acquisition of any CPGS system, Congress should require the Department of Defense to produce an unclassified report on (i) the escalation risks of CPGS, including but not limited to warhead ambiguity; and (ii) possible ways of mitigating them, including cooperative approaches.

The White House report on CPGS pursuant to the Senate's New START resolution of advice and consent to ratification focused narrowly on warhead ambiguity and failed to discuss cooperative mitigation approaches. To make an informed decision, Congress needs a more wide-ranging report.

3. Whichever technology is chosen, the United States should seek to pursue cooperative confidence-building measures with Russia and China.

A range of different confidence-building measures would be possible to mitigate the warhead ambiguity problem and build Russian and Chinese confidence in the survivability of their nuclear forces. Such measures would not be "favors" to China or Russia but would help manage modes of escalation that pose risks to the United States. Cooperation would only be possible if Beijing and Moscow chose to engage constructively. To maximize the possibility of such engagement, the United States should approach both states, sooner rather than later, with concrete suggestions in order to start a dialogue.

4. If it is not already doing so, the Department of Defense should explore the possibility of repurposing existing launch vehicles for use in deployed CPGS weapons.

The use of existing launch vehicles, if possible, would be cheaper and might ease Russian and Chinese concerns about the survivability of their nuclear forces (by demonstrating the U.S. intention to keep any CPGS deployment limited). If the Department of Defense moves ahead with CPGS acquisition and decides to develop a new launch vehicle, it should explain to Congress why it is not possible to repurpose an existing system.

FINAL THOUGHTS: BROADENING AND DEEPENING THE DEBATE

The proliferation of nuclear weapons, sophisticated anti-access/area-denial systems, and antisatellite capabilities are prominent features of today's changing security environment. Few would dispute the need for the U.S. response to these shifts to have a military dimension. Whether and how Conventional Prompt Global Strike (CPGS) can contribute to this response raises a series of complex, multidimensional, and nuanced questions. Unfortunately, the current debate around CPGS has none of these attributes. It needs broadening and deepening in five ways.

First, it is important to debate specific missions and, to the extent possible, specific scenarios in which CPGS weapons could be used. Government officials, as well as many nongovernmental analysts, tend to talk in abstract terms about using CPGS to hold at risk distant, high-value, fleeting targets. This degree of decontextualization—while understandable in the case of officials discussing politically sensitive subjects—is unhelpful because it obscures important differences between missions. Striking a meeting of terrorist leaders, eliminating or disabling the antisatellite capability of a sophisticated adversary that has just attacked a U.S. satellite, and preemptively destroying dispersed mobile nuclear-armed missiles in North Korea (to name but three possibilities) all have very different weapon requirements. Recognizing these differences is key to developing weapons capable of getting the job done.

Second, the differences between candidate CPGS technologies need to be recognized. All options have military strengths and weaknesses, and the weapon that would be the most effective in one circumstance could be the least effective in another.

Third, much closer attention must be paid to enabling capabilities, including command and control; intelligence, surveillance, and reconnaissance; and battle damage assessment. The missions for which CPGS might be acquired, the type of targets it might hold at risk, and the potentially short time lines for its employment place particular stress on these capabilities. Unless enabling capabilities become an integral part of the acquisition process, CPGS might not be usable, let alone transformative.

Fourth, a more careful comparison of CPGS with non-prompt alternatives is needed. The choice facing the United States is not simply which CPGS system to acquire but whether to procure any of them. Stealth technology offers one potential alternative for penetrating highly defended airspaces in a way that affords an adversary little or no warning of an attack. Forward-based systems deployed close to targets can also create prompt effects. To be sure, all these alternatives have disadvantages and risks—but so does CPGS.

At a time of serious downward pressure on the defense budget—pressure that is likely to continue for the foreseeable future—it is increasingly untenable to put off tough choices by arguing that all avenues should be pursued. Rather, clear priorities for research, development, and acquisition need to be established. And that requires comparing CPGS to the alternatives.

Fifth, in analyzing the potential international ramifications of CPGS, the debate must be broadened beyond the risk that Russia or China might misinterpret a CPGS weapon as a nuclear weapon. While this danger should not be neglected, other issues could arise that pose significantly greater risks of escalation. In considering how to mitigate these risks, greater attention must be given to cooperative approaches as opposed to unilateral measures. Moreover, the beneficial international ramifications of CPGS—most notably the possibility of enhanced deterrence—must be weighed against the risks.

The risks presented by different CPGS weapons can be divided into four categories (see table 10):

- Technical risk—failing to meet a project's objectives on time and on budget
- Political and bureaucratic risk—being unable to create the coalition necessary to support any major acquisition program
- Military risk—failing to meet mission requirements
- Strategic risk—triggering an undesirable reaction by an adversary or potential adversary, particularly unwanted escalation in a conflict

Clearly, table 10 cannot capture the full complexity of the CPGS debate. Because it does not compare the risks of CPGS to non-prompt alternatives, it does not speak to the question of whether to procure CPGS at all. However, it is helpful in comparing the risks of different CPGS systems. Even used in this way, some caution is needed since no attempt has been made either to estimate how much each attribute contributes to each risk or to assess the relative importance of these risks. Rather, it is hoped that this way of visualizing the risks will trigger a discussion of these issues.

The concrete recommendations made here (see appendix A for a summary) are largely focused on process in an effort to ensure that the U.S. Department of Defense, the U.S. Congress, and the American public focus on the full range of salient issues. At this stage, candidate CPGS technologies are too immature to make any recommendation about which one, if any, the United States should acquire. But it is not too early to identify the questions that need to be asked.

TABLE 10

Attributes of Different CPGS Technologies That Contribute Significantly to Risk

WEAPON **UNDERLYING TECHNOLOGY**	**GLOBAL LAND-BASED BOOST-GLIDE WEAPON** **HYPERSONIC TECHNOLOGY VEHICLE-2**	**INTERCONTINENTAL LAND-BASED BOOST-GLIDE WEAPON** **ADVANCED HYPERSONIC WEAPON**	**SEA-LAUNCHED INTERMEDIATE-RANGE BALLISTIC MISSILE (BOOST-GLIDE CONFIGURATION)** **ADVANCED HYPERSONIC WEAPON**
Technical risks	• Inherently complex • Not a direct descendant of a tested design (non-evolutionary) • Unproven in testing	• Inherently complex	• Inherently complex
Political and bureaucratic risk	• High cost • Unproven in testing	• High cost	• High cost • Sea based
Military risk	• Potentially vulnerable to missile defenses • Relatively long flight times • Unsuitable for signaling	• Potentially vulnerable to missile defenses • May be unable to accept midcourse target updates • Unsuitable for signaling	• Potentially vulnerable to missile defenses • May be unable to accept midcourse target updates
	• Launch detectable by early-warning satellites • Potentially vulnerable to GPS denial • Limited capability against mobile targets in the absence of surveillance assets deployed in theater		
Strategic risk	• Unobservable after boost phase and unpredictable midcourse trajectory	• Unobservable after boost phase and unpredictable midcourse trajectory	• Unobservable after boost phase and unpredictable midcourse trajectory • Similar deployment areas to nuclear weapons • Very hard to facilitate inspections (unless based on SSBNs or SSGNs)
	• Perceived ability to hold Russian and Chinese strategic targets at risk		

SEA-LAUNCHED INTERMEDIATE-RANGE BALLISTIC MISSILE (TERMINALLY GUIDED CONFIGURATION) STEERABLE REENTRY VEHICLE	HIGH SPEED STRIKE WEAPON (HYPERSONIC CRUISE MISSILE) SCRAMJET
	• Inherently complex • May be non-evolutionary and unproven in testing (depending on design)
• Sea based • Ballistic trajectory	• High cost • May be unproven in testing (depending on design)
• Detectable early in flight by missile early-warning radars • Potential need to relocate before use	• Vulnerable to advanced air defenses • Relatively short range • Need for large number of platforms • Need to deploy before use
• Similar deployment areas to nuclear weapons • Ballistic trajectory • Very hard to facilitate inspections (unless based on SSBNs or SSGNs)	• Unobservable after boost phase and unpredictable midcourse trajectory • Very hard to facilitate inspections unless delivered by nuclear-capable bombers

Clearly, a judgment call is needed to assess significance. For example, any sea-based system might need to be relocated before use. However, because this problem is much more likely to arise with the Sea-Launched Intermediate-Range Ballistic Missile in its terminally guided configuration (range of 3,500 km) than in its boost-glide configuration (range of more than 8,000 km), this attribute has been listed as contributing to risk in the former case but not the latter.

Key: GPS=Global Positioning System; SSBN=ballistic missile submarine; SSGN=SSBN converted to carry cruise missiles

APPENDIX

APPENDIX A: SUMMARY OF RECOMMENDATIONS

- If it is not already doing so, the U.S. Department of Defense should adopt a scenario-based approach for developing doctrine for and making acquisition decisions about Conventional Prompt Global Strike.
- The U.S. Congress should continue to press the Department of Defense to explain its thinking about the potential roles for CPGS. In addition, before funding any CPGS acquisition request, Congress should require the Department of Defense to produce an unclassified statement on the specific missions for which CPGS might be acquired.
- The Department of Defense should establish whether there is a potential role for long-range hypersonic cruise missiles that is distinct from CPGS. If there is not, these weapons should directly compete for funding with ballistic and boost-glide systems.
- In scrutinizing the CPGS program, Congress should take a holistic view and compare the benefits and risks of different technologies, rather than focusing almost exclusively—as it has done so far—on the risks of sea-based systems.
- Congress should recognize the reduced technical risks associated with "evolutionary" development pathways.

- Before deciding which, if any, CPGS technology to procure, the Department of Defense should conduct classified studies into possible adversary countermeasures over the next two or three decades, including a comparison of the effect of such countermeasures on non-prompt alternatives.

- Before funding the acquisition of any CPGS technology, Congress should require that the Department of Defense conduct the studies suggested above, if it has not already done so.

- Before funding the acquisition of any CPGS technology, Congress should require an unclassified statement from the Department of Defense comparing CPGS weapons and non-prompt alternatives in terms of their ability to hold mobile targets, and hard and deeply buried targets at risk; their relative unit cost; and their capability to successfully prosecute each of the missions for which the Department of Defense is considering acquiring CPGS weapons.

- Before funding the acquisition of any CPGS technology, Congress should require that the Department of Defense conduct a comprehensive and dedicated examination of gaps in enabling capabilities; and develop plans, with cost estimates, to fill these gaps.

- The U.S. agencies involved in counterterrorism should attempt to identify historical examples of occasions when the United States has failed to capitalize on intelligence that would have enabled it to kill or capture an important terrorist because it lacked a CPGS capability.

- The Department of Defense should examine all the risks of CPGS and not focus on the warhead ambiguity problem.

- Before funding the acquisition of any CPGS system, Congress should require the Department of Defense to produce an unclassified report on (i) the escalation risks of CPGS, including but not limited to warhead ambiguity; and (ii) possible ways of mitigating them, including cooperative approaches.

- Whichever technology is chosen, the United States should seek to pursue cooperative confidence-building measures with Russia and China.

- If it is not already doing so, the Department of Defense should explore the possibility of repurposing existing launch vehicles for use in deployed CPGS weapons.

APPENDIX B: THE COST OF THE CONVENTIONAL TRIDENT MODIFICATION

In its 2008 study, the National Research Council of the U.S. National Academies gave estimates for the cost of an initial operational capability and the twenty-year cost of candidate Conventional Prompt Global Strike technologies *relative* to the costs of the Conventional Trident Modification (CTM). This appendix presents the methodology used to estimate the absolute costs of the CTM. These estimates were used to translate the National Research Council's estimates into the dollar figures that appear in chapter 2.

The U.S. Navy gave cost estimates for developing and deploying the CTM in its fiscal year (FY) 2007 budget request. These costs were divided into three categories:

- Research, development, and fight testing[1]
- Modifying submarines[2]
- Procuring warheads and modifying Trident D5 missiles[3]

Costs estimates in each year to FY 2010 were provided for the first two of these categories. For the third category, only the FY 2007 costs were given. Separately, however, the total cost for each year of the program was reported by InsideDefense.com using data from a leaked Pentagon study.[4] Using this information, the planned costs for procuring warheads and modifying missiles can be inferred straightforwardly for fiscal years 2008 to 2010. The cost of the program, disaggregated by both activity and year, can hence be determined (see table 11).

TABLE 11

Planned Costs of the Conventional Trident Modification

	RESEARCH, DEVELOPMENT, AND FLIGHT TESTING (MILLIONS OF DOLLARS)	MODIFICATIONS TO SUBMARINES (MILLIONS OF DOLLARS)	PROCUREMENT OF WARHEADS AND MODIFICATIONS TO MISSILES (MILLIONS OF DOLLARS)	TOTAL BY YEAR (MILLIONS OF DOLLARS)
FY 2007	77	12	38	**127**
FY 2008	69	10	146	**225**
FY 2009	0	6	112	**118**
FY 2010	0	2	31	**33**
Total by activity	**146**	**30**	**327**	—

Key: FY=fiscal year

The methodology used to obtain the data in this table is described in this appendix.

The U.S. Navy's plans called for the modification of 12 submarines and 24 missiles (each of which was to carry 4 warheads). To a first approximation, therefore, the costs to convert one submarine and two missiles would have been just shy of $30 million. When added to the costs for research, development and flight tests, the cost of a CTM initial operational capability can be estimated at $175 million.

This figure is probably a slight underestimate for two reasons. First, because experience would have been gained in modifying missiles and submarines, the marginal cost could have been expected to decrease as more modifications were performed. Second, the budget for modifying submarines contained an unspecified, but presumably small, overhead for research that would have been required before any submarines were modified.

The total cost from FY 2007 to FY 2010 of just over $500 million would have represented all expenditure on research, development, procurement, and deployment. The total twenty-year cost, which would also have to include operations and maintenance expenses, would have been higher, but probably only modestly so since Ohio-class ballistic missile submarines and Trident missiles are operated and maintained anyway. The twenty-year cost of CTM is, therefore, taken as $500 million—although, once again, this figure is an underestimate.

APPENDIX C: SEA-LAUNCHED INTERMEDIATE-RANGE BALLISTIC MISSILE

In early 2012, the U.S. Department of Defense expressed an interest in developing the Sea-Launched Intermediate-Range Ballistic Missile (SLIRBM), an apparently similar concept to the Sea-Launched Global Strike Missile analyzed in the mid-2000s, including by the National Research Council (NRC) of the U.S. National Academies. Its 2008 report can be used to estimate what the range of the Sea-Launched Intermediate-Range Ballistic Missile might be.

The Virginia-class hull can probably not accommodate a missile longer than about 11 m (36 ft.).[5] The planned Sea-Launched Global Strike Missile, which was designed to fit into an Ohio-class hull, was almost certainly intended to be longer than this. According to the 2008 NRC report, the Sea-Launched Global Strike Missile was to have a diameter of 0.97 m (38 in.) and a length-to-diameter ratio of "substantially greater than 12," probably making it similar in length to a 13.4 m (44.0 ft.) Trident D5 missile.[6] It would, therefore, have to be shortened to fit inside a Virginia-class submarine.

All other things being equal, shortening a missile's length reduces its range. However, this effect can be counteracted by increasing the missile's diameter at the expense of being able to fit fewer missiles in each launch tube. Indeed, the NRC studied exactly this trade-off for Ohio-class submarines in its report.[7] This research would appear to be relevant to SLIRBM because the diameter of the launch tube in the planned Virginia Payload Module appears to be identical to the diameter of launch tubes of Ohio-class SSGNs (ballistic missile submarines converted to carry cruise missiles).[8] Moreover, a number of the configurations that the NRC considered involved missiles short enough to fit inside Virginia-class submarines.

For example, with four missiles (each of 10.4 m or 34.1 ft. in length) per tube, each missile could carry a payload of 700 kg (1,500 lb.) over about 2,400 km (1,500 mi.). With three missiles (each of 11.6 m or 38.1 ft.) per tube, each missile would be able to carry the same payload over a distance of about 3,700 km (2,300 mi.). This latter missile might be slightly too large for a Virginia-class submarine. However, given the curve of range against missile length is quite flat, the range penalty from shortening the missile slightly would be rather modest. For this reason, a range of 3,500 km (2,200 mi.) is assumed for three missiles per tube (which is, in fact, the traditional range threshold between medium- and intermediate-range ballistic missiles).

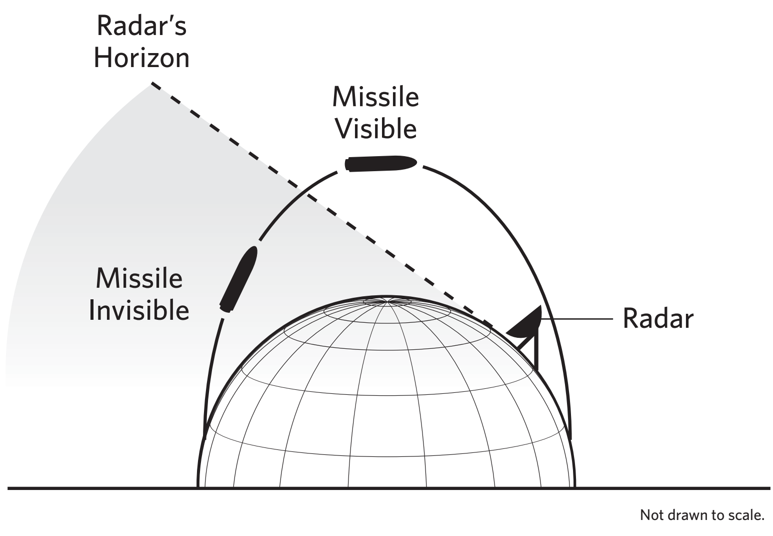
These figures assume that SLIRBM, like the Sea-Launched Global Strike Missile, would be a two-stage design with a steerable reentry vehicle. A three-stage design (which would be somewhat more expensive and complex) would increase the range by about 25 percent, according to the NRC's calculations. Replacing the steerable reentry vehicle by a hypersonic glider could increase the range dramatically but would be much more expensive, complex, and technically risky.

Virginia-class submarines equipped with the Virginia Payload Module are unlikely to be available before the early to mid-2020s. SLIRBM could almost certainly be developed significantly sooner, if it is equipped with a steerable reentry vehicle. Assuming that the launch tubes in Ohio-class SSGNs and the Virginia Payload Module have identical diameters, and given that the Virginia-class hull is smaller than the Ohio-class hull, then there would appear to be no *technical* barrier to deploying SLIRBM in Ohio-class SSGNs in the interim. As discussed in chapter 2, however, there may be significant *political* barriers.

Chapter 3 discusses how much tactical warning an adversary might have of a Conventional Prompt Global Strike attack. The limiting factor is how soon after launch a powerful early-warning radar can detect a ballistic missile is the radar's horizon. The concept of a horizon is a familiar one. Because the earth is curved, tall mountains appear to rise above the horizon—and hence become visible—as one approaches them. In the same way, a missile can only be detected by a radar when it is close enough to be situated above the radar's horizon (see figure 7).[9]

FIGURE 7

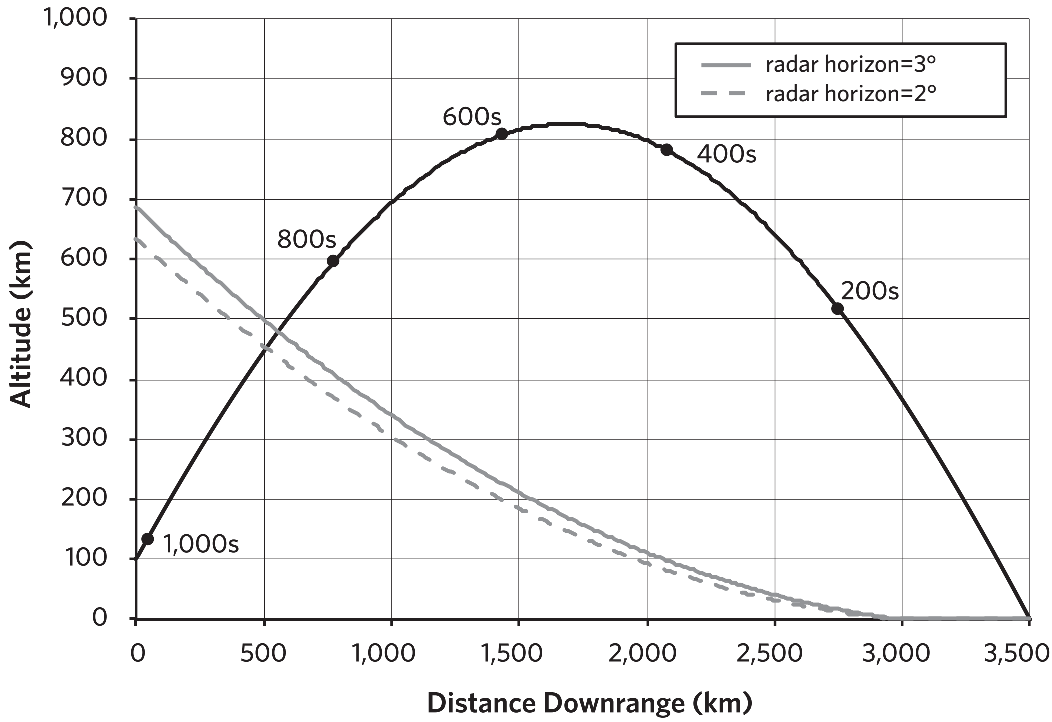
How a Missile Only Becomes Visible to a Powerful Radar Once It Has Passed Through the Radar's Horizon



The trajectory of a ballistic missile with a range of 3,500 km and the horizon of a powerful early warning radar located 500 km (310 mi.) forward of the impact point are shown in figure 8. As can be seen, the missile only rises above the radar's horizon when it travels to within about 2,500 km (1,600 mi.) of the radar, resulting in about fourteen minutes of tactical warning. By contrast, because hypersonic gliders and hypersonic cruise missiles would fly at much lower altitudes, they would only become visible to even the most powerful radar after travelling to within about 500 km of it, resulting in much shorter margins of warning.

FIGURE 8

The Trajectory of a Ballistic Missile With a Range of 3,500 km and the Horizon of a Powerful Early-Warning Radar for Two Different Angles of Elevation



The missile is travelling from left to right and the time until impact is shown in increments of 200 secs. The radar is located 500 km in front of the missile's impact point. Author calculation.

A modified air-defense radar would provide much less warning of a ballistic missile attack. In fact, a ballistic missile with a range of 3,500 km would probably pass undetected over such a radar, if the radar were located 500 km ahead of the target. A radar based at the target could detect the incoming missile, but the warning time would be very short (substantially less than a minute).

NOTES

INTRODUCTION

1 Amy F. Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, CRS Report for Congress, R41464 (Washington, DC: Congressional Research Service, February 13, 2012), 3 (the latest version of this report is available from www.fas.org/sgp/crs/nuke/R41464.pdf).

2 U.S. Department of Defense, *Quadrennial Defense Review Report*, February 6, 2006, 50, www.defense.gov/qdr/report/report20060203.pdf. As discussed in appendix B, the initial operational capability represented about $175 million out of a total program cost of $500 million.

3 Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 139, www.nap.edu/catalog.php?record_id=12061.

4 Joshua Pollack, "Emerging Strategic Dilemmas in U.S.-Chinese Relations," *Bulletin of the Atomic Scientists* 65, no. 4 (July/August 2009): 57–58, http://bos.sagepub.com/content/65/4/53.full.pdf+html.

5 See, for example, the comments by then secretary of defense Robert Gates in U.S. Senate Foreign Relations Committee, *The New START Treaty*, S. HRG. 111-738, 111th Cong., 2nd sess., May 18, 2010, 44, www.gpo.gov/fdsys/pkg/CHRG-111shrg62467/pdf/CHRG-111shrg62467.pdf.

6 Elaine M. Grossman, "U.S. Military Could Redefine Global-Strike Weapons," Global Security Newswire, January 24, 2013, www.nti.org/gsn/article/us-military-could-redefine-global-strike-weapons.

7 See, for example, Madelyn R. Creedon, remarks, U.S. Strategic Command Deterrence Symposium, Omaha, NE, August 3–4, 2012.

8 Within the fiscal year 2014 Budget Request, for instance, the "Conventional Prompt Global Strike" program includes the Advanced Hypersonic Weapon, which does not have global range.

9 Technically, accuracy is measured by the circular error probable, that is, the radius of a circle containing the end points of 50 percent of all weapon trajectories. Reportedly, the accuracy of the Minuteman III missile is 120 m (390 ft.), and the accuracy of the Trident D5 missile is 90 m (300 ft.). Duncan Lennox, *Jane's Strategic Weapon Systems*, 55th issue (Coulsdon: IHS Global, July 2011), 211 and 225.

10 Committee on Conventional Prompt Global Strike Capability, et al., *U.S. Conventional Prompt Global Strike*, 122.
11 Fractional orbit bombardment systems (usually know as FOBS), which were explored during the Cold War, particularly by the Soviet Union, have some similarities to hypersonic boost-glide weapons. These systems would have placed nuclear-armed reentry vehicles into orbital trajectories, allowing them to approach their target from a direction that avoided radar detection. The reentry vehicles would have been de-orbited, onto their targets, before completing their first orbit (that is, after a "fractional orbit"). The development, testing, and deployment of fractional orbit bombardment systems would have been banned (at least temporarily) by the 1979 Strategic Arms Limitation Treaty II, but this treaty did not enter into force. Their use *may*, however, be prohibited by the 1967 Outer Space Treaty, which bans placing "in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction," depending on the interpretation of "orbit." Current U.S. boost-glide weapon concepts would clearly not be prohibited by this treaty because (i) their payloads would be conventional; and (ii) their trajectories would differ significantly from orbital trajectories. In theory, a nuclear-armed boost-glide weapon injected at speeds very close to 7.9 km/sec. (or low earth orbital speed) into a near-orbital trajectory could raise questions about compliance with the Outer Space Treaty. Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 214.

CHAPTER 1

1 Richard Mesic, Roger Molander, and Peter A. Wilson, *Strategic Futures: Evolving Missions for Traditional Strategic Delivery Vehicles* (Santa Monica, CA: RAND, 1995), 56, www.rand.org/content/dam/rand/pubs/monograph_reports/2007/MR375.pdf.
2 The idea of putting a conventional warhead on a short-range ballistic missile is obviously much older. Indeed, the world's first operational ballistic missile, the German V-2, used during World War II, was armed with a conventional warhead. It was essentially a weapon of terror, like many of today's short-range ballistic missiles. The conceptual innovation behind CPGS was not simply the idea of placing a conventional warhead on an ICBM but of imagining a weapon so accurate that it could destroy point targets from a distance of thousands of kilometers.
3 C. H. Builder, D. C. Kephart, and A. Laupa, *The U.S. ICBM Force: Current Issues and Future Options*, R-1754-PR (Santa Monica, CA: RAND, October 1975), 83, www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB43/doc19.pdf. I am grateful to Joshua Pollack for drawing my attention to this study.
4 Ibid., 80.
5 Ibid., 82.
6 The specific term "leverage" appears in, for example, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, U.S. Department of Defense, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*, February 2004, 5-11, www.acq.osd.mil/dsb/reports/ADA421606.pdf.
7 Mesic et al., *Strategic Futures*, 53.
8 Ibid., 56.
9 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*, 5-11. See also Eric A. Miller and Willis A. Stanley, *The Future of Ballistic Missiles* (Fairfax, VA: National Institute for Public Policy, October 2003), 11–12.
10 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills,* 5-11.

11 U.S. Department of Defense, *Quadrennial Defense Review Report*, February 6, 2006, 49–50, www.defense.gov/qdr/report/report20060203.pdf.

12 See also Dennis M. Gormley, *The Path to Deep Nuclear Reductions: Dealing With American Conventional Superiority*, Proliferation Papers 29 (Paris: Ifri, 2009), www.ifri.org/downloads/pp29gormley1.pdf, 32.

13 Madelyn R. Creedon, remarks, U.S. Strategic Command Deterrence Symposium, Omaha, NE, August 3–4, 2012. To be fair, she also argued that the technology development was at an early stage too.

14 Builder et al., *The U.S. ICBM Force*, 82–84. The specific mission proposed in this study is termed "limited strategic operations." Because the report is so heavily redacted (less than 20 percent has been released), even the definition of this term does not appear. However, limited strategic operations probably refer to small-scale nuclear strikes against military targets—usually termed limited nuclear options or just LNOs—in an effort to keep a nuclear war limited. See, for example, Lawrence Freedman, *The Evolution of Nuclear Strategy*, 3rd ed. (Basingstoke: Palgrave Macmillan, 2003), ch. 25.

15 D. A. Paolucci, *Summary Report of the Long Range Research and Development Planning Program*, draft (Falls Church, VA: Lulejian & Associates, February 7, 1975), 32–33, www.albertwohlstetter.com//writings/19750207-PaolucciEtAl-Draft-LRRDPP.pdf. For an excellent overview of this program see Robert Zarate, "Albert and Roberta Wohlstetter on Nuclear-Age Strategy," in *Nuclear Heuristics: Selected Writings of Albert and Roberta Wohlstetter*, eds. Robert Zarate and Henry Sokolski, (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, 2009), 52–55, www.strategicstudiesinstitute.army.mil/pdffiles/PUB893.pdf.

16 Paolucci, *Summary Report of the Long Range Research and Development Planning Program*, 8.

17 Scott D. Sagan, *Moving Targets: Nuclear Strategy and National Security* (Princeton, NJ: Princeton University Press, 1989), 42–48.

18 Fred C. Iklé, Albert Wohlstetter, et al., *Discriminate Deterrence: Report of the Commission of Integrated Long-Term Strategy*, 1988, 36, http://usacac.army.mil/cac2/CSI/docs/Gorman/06_Retired/01_Retired_1985_90/26_88_IntegratedLongTermStrategy_Commission/01_88_DiscriminateDeterrence_Jan.pdf.

19 Paul H. Nitze, "Is It Time to Junk Our Nukes?" *Washington Post*, January 16, 1994.

20 Ibid.

21 See, for example, C. Robert Kehler, "Nuclear-Armed Adversaries and the Joint Commander," *Naval War College Review* XLIX, no. 1 (Winter 1996): 7–18, www.usnwc.edu/NavalWarCollegeReviewArchives/1990s/1996%20Winter.pdf. The author is now the commander of U.S. Strategic Command.

22 Marc Dean Millot, "Facing the Emerging Reality of Regional Nuclear Adversaries," *Washington Quarterly* 17, no. 3 (Summer 1994): 62. See also Thomas C. Reed and Michael O. Wheeler, "The Role of Nuclear Weapons in the New World Order," in U.S. Senate Armed Services Committee, *Threat Assessment, Military Strategy, and Defense Planning*, 194–95, S. HRG. 102-755, 102nd Cong., 2nd sess., 1992.

23 Millot, "Facing the Emerging Reality of Regional Nuclear Adversaries," 62.

24 Although there is no definitive recent public statement of U.S. employment policy, there appear to be three basic target categories in U.S. nuclear planning: (i) "weapon of mass destruction" targets, including but not limited to nuclear weapon targets; (ii) military and national leadership, command and control, and other war-supporting infrastructure; and (iii) war-supporting industry. See, for example, Hans M. Kristensen, Robert S. Norris, and Ivan Oelrich, *From Counterforce to Minimal Deterrence: A New Nuclear Policy on the Path Toward Eliminating Nuclear Weapons*, Occasional Paper 7 (Washington, DC: Federation of American Scientists/Natural Resources Defense Council, 2009), 11, www.fas.org/pubs/_docs/occasionalpaper7.pdf; Linton F. Brooks, "America's Nuclear Posture," in *Rebuilding the NPT Consensus*, ed. Michael May (Palo Alto, CA: Center for International Security and Cooperation, Stanford University, 2007), 74–75, http://iis-db.stanford.edu/pubs/22218/RebuildNPTConsensus.pdf. Although the balance between the three categories has changed over time, this basic pattern appears to have remained constant for almost as long as the United States

has had nuclear weapons. The one exception is that, during the Cold War, the United States targeted conventional military forces, but now appears to have largely, if not entirely, dropped this category from nuclear war plans. Sagan, *Moving Targets*, ch. 1.

25 Gormley, *The Path to Deep Nuclear Reductions*, 15–16.

26 Although secret, the Mission Need Statement has been cited in an unclassified document. See Nancy F. Swinford and Dean A. Kudlick, *A Hard and Deeply Buried Target Defeat Concept* (Sunnyvale, CA: Lockheed Martin Missiles & Space, 1996), www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA318768, 1. See also Gormley, *The Path to Deep Nuclear Reductions*, n. 27.

27 A 1992 study by personnel from Lawrence Livermore National Laboratory, for instance, focused on precision-guided munitions, such as laser-guided bombs, delivered by aircraft. A. L. Latter, E. A. Martinelli, and R. D. Speed, *Conventional Strategic Deterrence* (Livermore, CA: Lawrence Livermore National Laboratory, August 1992).

28 In 2002, for instance, then U.S. Air Force Chief of Staff, General John Jumper, was quoted as saying that at sufficiently high speeds "you can hit something with Quaker Puffed Wheat and do a pretty good amount of damage." Elaine M. Grossman, "Pentagon Eyes Bunker-Busting Conventional Ballistic Missile for Subs," *Inside the Pentagon*, June 27, 2002.

29 See, for example, Mesic et al., *Strategic Futures*, 68–69.

30 Ibid., 67. Why this plan did not move forward cannot, unfortunately, be ascertained from the unclassified literature.

31 David C. Isby, "USAF Wants Proposals for Non-Nuclear ICBM Warheads," *Jane's Missiles and Rockets* 3, no. 3 (March 1, 1999): 56. The second test is described in Elaine M. Grossman, "Potential Weapon vs. Hard, Buried Targets: In Test, Ballistic Missile Penetrator Plowed Through 30 Feet of Granite," *Inside the Pentagon*, May 16, 1996: 5–7. A fourth test was planned, but appears not to have taken place.

32 Isby, "USAF Wants Proposals for Non-Nuclear ICBM Warheads."

33 U.S. Department of Defense, *Quadrennial Defense Review Report*, September 30, 2001, 14, www.defense.gov/pubs/qdr2001.pdf.

34 Ibid.

35 What claim to be leaked fragments of the 2001 Nuclear Posture Review are available from U.S. Department of Defense, *Nuclear Posture Review Report*, excerpts, December 31, 2001, www.stanford.edu/class/polisci211z/2.6/NPR2001leaked.pdf. The other two legs of the new triad were active and passive defenses, and a revitalized defense infrastructure.

36 This particular definition is from U.S. Department of Defense, *Deterrence Operations: Joint Operating Concept*, version 2.0, December 2006, 39, www.dtic.mil/futurejointwarfare/concepts/do_joc_v20.doc. One criticism of Global Strike is the absence of a single definition. See Government Accountability Office, *Military Transformation: DoD Needs to Strengthen Implementation of Its Global Strike Concept and Provide a Comprehensive Investment Approach for Acquiring Needed Capabilities*, GAO-08-325, April 2008, 13–15, www.gao.gov/new.items/d08325.pdf. For a history of the concept see Hans M. Kristensen, "U.S. Strategic War Planning After 9/11," *Nonproliferation Review* 14, no. 2 (July 2007): 373–90, http://cns.miis.edu/npr/pdfs/142kristensen.pdf.

37 In 2005, in support of Global Strike, Strategic Command stood up the Joint Functional Component Command for Space and Global Strike. In 2006, it decided to split it into Joint Functional Component Command for Global Strike and Integration, and Joint Functional Component Command for Space.

38 Amy F. Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, CRS Report for Congress, R41464 (Washington, DC: Congressional Research Service, February 13, 2012), 3.

39 For an incisive analysis of the 2001 Nuclear Posture Review and its focus on conventional forces see Gormley, *The Path to Deep Nuclear Reductions*, 16–18.

40 Grossman, "Pentagon Eyes Bunker-Busting Conventional Ballistic Missile for Subs." The Bush administration pursued other similar research programs. For example, in 2004 a penetrator based

on the Army's ATACMS ballistic missile was tested. Michael Padilla, "Sandia Tests Conventional Weapon Created to Penetrate Hardened, Buried Targets: TACMS-P Successful in First Flight Test in Range, Accuracy and Precision," *Sandia Lab News* 56, no. 9 (April 30, 2004): 1 and 4–5, www .sandia.gov/LabNews/LN04-30-04/labnews04-30-04.pdf.

41 U.S. Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 2007: Strategic Forces*, S. HRG. 109-827, part 7, 109th Cong., 2nd sess., March 29, 2006, 85, www.gpo.gov/fdsys/pkg/CHRG-109shrg30353/pdf/CHRG-109shrg30353.pdf. See also U.S. House of Representatives Armed Services Committee, *National Defense Authorization Act for Fiscal Year 2008 and Oversight of Previously Authorized Programs: Budget Request from the U.S. Strategic Command, Northern Command, Transportation Command, and Southern Command,* HASC no. 110-40, 110th Cong., 1st sess., March 21, 2007, 32, www.gpo.gov/fdsys/pkg/CHRG-110hhrg37320/pdf/CHRG-110hhrg37320.pdf.

42 See also National Institute for Public Policy, *Strategic Offensive Forces and the Nuclear Posture Review's "New Triad"* (Fairfax, VA: National Institute for Public Policy, 2003), 14–15, www.nipp.org /National%20Institute%20Press/Archives/Publication%20Archive%20PDF/Strategic% 20Offensive.pdf.

43 White House, *Report on Conventional Prompt Global Strike in Response to Condition 6 of the Resolution of Advice and Consent to Ratification of the New START Treaty*, February 2, 2011, 7. See also U.S. House of Representatives Armed Services Committee, Strategic Forces Subcommittee, *The Status of United States Strategic Forces*, HASC no. 112-12, 112th Cong., 1st sess., March 2, 2011, 76, www .gpo.gov/fdsys/pkg/CHRG-112hhrg65112/pdf/CHRG-112hhrg65112.pdf. The 2010 Nuclear Posture Review was notably vague about the justification for CPGS, merely stating that "these capabilities may be particularly valuable for the defeat of time-urgent regional threats." U.S. Department of Defense, *Nuclear Posture Review Report*, April 2010, 34, www.defense.gov/npr/docs/2010%20nuclear%20posture%20review%20report.pdf.

44 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, U.S. Department of Defense, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, March 2009, 81–84, www.acq.osd.mil/dsb/reports/ADA498403.pdf. In a similar vein see Jeffrey A. Larsen, Justin V. Anderson, Darci Bloyer, Thomas Devine IV, Rebecca Davis Gibbons, and Christina Vaughan, *Qualitative Considerations of Nuclear Forces at Lower Numbers and Implications for Future Arms Control Negotiations*, INSS Occasional Paper 68 (Colorado Springs, CO: U.S. Air Force Institute for National Security Studies, U.S. Air Force Academy, July 2012), 42, www.usafa.edu/df/inss/OCP/OCP68.pdf.

45 For the earlier report see Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*.

46 Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 31–32, www.nap.edu/catalog.php?record_id=12061; Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills,* 2-7 to 2-14; Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 1–2. Some congressional testimony also suggests that the 2001 Nuclear Posture Review made a similar connection. See U.S. Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 2007*, 90. Although the 2010 Nuclear Posture Review Report frequently mentioned terrorism—specifically nuclear terrorism—the context, which was building an international regime to deny terrorists access to nuclear materials, is quite different from the other reports cited here.

47 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike,* 31.

48 Ibid., n. 5 on 31.

49 Joshua Pollack, "Evaluating Conventional Prompt Global Strike," *Bulletin of the Atomic Scientists* 65, no. 1 (January/February 2009): 17–18, http://bos.sagepub.com/content/65/1/13.full.pdf+html. An eyewitness account by Osama bin Laden's son, Omar, published since Pollack's article, is confusing. He states that on August 20, 1998 (the day of the strikes), bin Laden received "a highly secret communication" while at a training camp near Khost, prompting the family to relocate immediately to Kabul where, "only two hours" later, they heard the camp had been struck by missiles. The terrorist camps near Khost were, however, more than 200 km from Kabul by a road that is not paved along the whole of its length. Sarah Chayes, a U.S. expert on Afghanistan who spent about ten years living in the country, estimates that it would take "at least 12 to 24 hours" to travel from Khost to Kabul (personal communication, June 2013). It therefore appears likely that more than two hours passed between the warning and the strike, meaning that bin Laden probably received the warning *before* the missiles were fired. This version of events is consistent with bin Laden's failure to evacuate the camp, which may imply that he was expecting something other than a missile strike (such as a special forces operation). See Najwa bin Laden, Omar bin Laden, and Jean Sasson, *Growing Up bin Laden: Osama's Wife and Son Take Us Inside Their Secret World* (New York: St. Martin's Press, 2009), 238–39. For the location of the camp see "The 1998 Attack," *Washington Post*, October 3, 2001, www.washingtonpost.com/wp-srv/nation/graphics/attack/zone_8.html.

50 U.S. Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 2007,* 108.

51 Ibid., 108–109.

52 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 73.

53 Ibid., 69–72; direct quote from U.S. Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 2008: Strategic Forces*, S. HRG. 110-201, part 7, 110th Cong., 1st sess., March 28, 2007, 62, www.gpo.gov/fdsys/pkg/CHRG-110shrg39441/pdf/CHRG-110shrg39441.pdf.

54 In 2007, for instance, Senator Jack Reed, while questioning General James Cartwright, stated "[we] are really talking about—and correct me if I am wrong—non-state actors." Cartwright's reply was "No, sir." U.S. Senate Armed Services Committee, *Department of Defense Authorization for Appropriations for Fiscal Year 2008*, 23.

55 See, for example, Michael T. Flynn, "Annual Threat Assessment," statement before the U.S. Senate Armed Services Committee, April 18, 2013: 18 and 31, www.armed-services.senate.gov/statemnt/2013/04%20April/Flynn_04-18-13.pdf. Apart from the United States and China, only Russia has tested an ASAT weapon. However, for at least two reasons, Russia's ASAT capabilities are of significantly less concern to the United States than China's. First, conflict with Russia is generally regarded as significantly less likely than conflict with China. Second, many U.S. officials and analysts believe that, based on Cold War experience, Washington and Moscow have a (largely tacit) mutual understanding about the dangers of using ASAT weapons against one another. All other states that could plausibly demonstrate an antisatellite capability in the short- or medium-term are U.S. friends or allies. Specifically, India has openly expressed an interest in ASAT technology, and Japan and the European Space Agency have space-faring technologies that could be adapted for this purpose. For a general overview see Laura Grego, "A History of Anti-Satellite Programs," Union of Concerned Scientists, January 2012, www.ucsusa.org/assets/documents/nwgs/a-history-of-ASAT-programs_lo-res.pdf. On India see Bharath Gopalaswamy and Gaurav Kampani, "Piggybacking Anti-Satellite Technologies on Ballistic Missile Defense: India's Hedge and Demonstrate Approach," *Proliferation Analysis*, Carnegie Endowment for International Peace, April 19, 2011, http://carnegieendowment.org/2011/04/19/323z.

56 David C. Gompert and Phillip C. Saunders, *The Paradox of Power, Sino-American Strategic Restraint in an Age of Vulnerability* (Washington, DC: National Defense University Press, 2011), 58–60, www.ndu.edu/inss/docuploaded/Paradox%20of%20Power.pdf.

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CHAPTER 2

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57 Ibid., 2–3. The critical point here is not the difference in ranges *per se*, but that this difference resulted from the smaller lift-to-drag ratio of the HTV-1 compared to the HTV-2. These gliders were, at that time, known as the Common Aero Vehicle (CAV) and the Enhanced Common Aero Vehicle (ECAV).

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59 Jess Sponable, "Reusable Space Systems: 21st Century Technology Challlenges [Sic]," DARPA, June 17, 2009, 20, www.nianet.org/getattachment/resources/Education/Continuining-Education/Seminars-and-Colloquia/Seminars-2009/Reusable-Space-Systems,-LaRC,-17-Jun-09.pptx.aspx describes the HTV-1 as being used for "ground demonstrations."

60 Warwick, "Darpa Refocuses Hypersonics Research on Tactical Missions;" Interview with senior U.S. official, Arlington, VA, July 2012.

61 Graham Warwick, "DARPA's HTV-2 Didn't Phone Home," Ares, *Aviation Week*, April 24, 2010, www.aviationweek.com/Blogs.aspx?plckBlogId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7&plckPostId=Blog:27ec4a53-dcc8-42d0-bd3a-01329aef79a7Post:70769585-4348-4701-889a-f02c58-f38314. Note that the key picture is very similar to a declassified one in Sponable, "Reusable Space Systems," 20.

62 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 115.

63 DARPA, "Engineering Review Board Concludes Review of HTV-2 Second Test Flight."

64 Kenneth W. Iliff and Mary F. Shafer, *A Comparison of Hypersonic Vehicle Flight and Prediction Results*, Technical Memorandum 104313 (NASA, October 1995), 29, www.nasa.gov/centers/dryden/pdf/88389main_H-2074.pdf.
65 U.S. Army Space and Missile Defense Command and Army Forces Strategic Command, *Advanced Hypersonic Weapon Program: Environmental Assessment*, June 2011, 2-15, www.smdcen.us/pubdocs/files/AHW%20Program%20FEA--30Jun11.pdf.
66 Grossman, "House Panel Urges Competition for Conventional Prompt-Strike Weapons."
67 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 40; Congressional Budget Office, U.S. Congress, *Alternatives for Long-Range Ground-Attack Systems*, March 2006, 28, www.cbo.gov/sites/default/files/cbofiles/ftpdocs/71xx/doc7112/03-31-strikeforce.pdf.
68 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 40.
69 The costs for research, development, test and evaluation would constitute the vast majority of the costs associated with reaching an initial operational capability.
70 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 45.
71 Ronald O'Rourke, *Navy Virginia (SSN-774) Class Attack Submarine Procurement: Background and Issues for Congress*, CRS Report for Congress, RL32418 (Congressional Research Service, March 1, 2012), 7 (the latest version of this report is available from www.fas.org/sgp/crs/weapons/RL32418.pdf).
72 The 2006 Navy budget request for the CTM asked for $30 million to modify 12 ballistic missile submarines (see appendix B). The cost of converting four SSGNs to carry SLIRBM would presumably be significantly lower. While this is a relatively small amount of money, especially compared to the overall CPGS program cost, the Navy's budget for ship building and conversion is already so oversubscribed that there would be likely to be serious resistance to using it to pay for SSGN modifications.
73 See, for example, Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles*, 24–25; Grossman, "Controversial Missile Idea Lingers."
74 Interviews with senior U.S. officials, Arlington, VA, June and July 2012.
75 Hypersonic cruise missile development is principally funded through the Air Force research, development, test, and evaluation budget. CPGS is largely funded from a dedicated account that is part of the defense-wide research, development, test and evaluation budget. DARPA and NASA do, however, contribute to both efforts.
76 Interview with senior U.S. official, Arlington, VA, July 2012.
77 U.S. House of Representatives Armed Services Committee, Intelligence, Emerging Threats and Capabilities Subcommittee, *FY2014 National Defense Authorization Budget Request for Department of Defense (DOD) Science and Technology Programs*, April 16, 2013, Federal News Service transcript.
78 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 118.
79 For a summary of past efforts see Richard P. Hallion, *Hypersonic Power Projection*, Mitchell Paper 6 (Portland, ME: Mitchell Institute Press, 2010), www.afa.org/mitchell/reports/MP6_Hypersonics_0610.pdf.
80 U.S. House of Representatives Science Committee, Space and Aeronautics Subcommittee, *Space Planes and X-Vehicles*, Serial No. 107–22, 107th Cong., 1st sess., October 11, 2001, http://commdocs.house.gov/committees/science/hsy75831.000/hsy75831_0.htm. Cooper was a strong supporter of the spaceplane concept, but a strong critic of how it had been managed.
81 Guy Norris, "Hyper Activity," Flightglobal, August 2, 2005, www.flightglobal.com/news/articles/hyper-activity-200623. See also Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, U.S. Department of Defense, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, March 2009, 36–37, www.acq.osd.mil/dsb/reports/ADA498403.pdf.

82 DARPA and U.S. Air Force, “FALCON (Force Application and Launch from CONUS) Technology Demonstration Program,” 1.

83 NASA, “Guinness World Records Recognizes NASA Speed Record,” Press Release 04-279, August 30, 2004, www.nasa.gov/home/hqnews/2004/aug/HQ_04279_guinness_record.html.

84 In March 2011, the Air Force announced plans to “begin weaponizing” the X-51A, but these appear to have been dropped. Steven H. Walker, “Fiscal Year 2012 Air Force Science and Technology,” statement before the U.S. House of Representatives Armed Services Committee, Emerging Threats and Capabilities Subcommittee, March 1, 2011, 12, www.acq.osd.mil/chieftechnologist/publications/docs/Air_Force_TE_Testimony%202011.pdf.

85 Steven H. Walker, “Fiscal Year 2013 Air Force Science and Technology,” statement before the U.S. House of Representatives Armed Services Committee, Emerging Threats and Capabilities Subcommittee, February 29, 2012, 9, www.defenseinnovationmarketplace.mil/resources/Walker_Testimony_2013.pdf.

86 Interview with senior U.S. official, Arlington, VA, July 2012.

87 David E. Walker, “Fiscal Year 2014 Air Force Science and Technology,” statement before the U.S. House of Representatives Armed Services Committee, Emerging Threats and Capabilities Subcommittee, April 16, 2013, 9–10, www.defenseinnovationmarketplace.mil/resources/FY14_AF_ST-Testimony.pdf; Air Force Research Laboratory, “High Speed Strike Weapon (HSSW) Demonstration,” Broad Agency Announcement, draft, BAA-RWK-2013-0002, 2013, www.fbo.gov/utils/view?id=adf2fe7148be0520aa0d5b62cc5dfb4c. Funding is requested for the High Speed Strike Weapon program, as well as scramjet technology generally, in the FY 2014 budget request. U.S. Department of the Air Force, *Department of Defense Fiscal Year (FY) 2014 President’s Budget Submission: Research, Development, Test & Evaluation, Air Force*, vol. 1, April 2013, 216 (PE 0603211F) and 232–33 (PE 0603216F, subprogram 635098), www.saffm.hq.af.mil/shared/media/document/AFD-130408-064.pdf. See also 78–79 (PE 0602203F, subprogram 623012).

88 The total distance covered in each test, including while the booster rocket was firing, was longer. According to media reports, for instance, the May 2013 test covered a total of 430 km. Guy Norris, “X-51A Waverider Achieves Hypersonic Goal on Final Flight,” *Aviation Week*, May 2, 2013, www.aviationweek.com/Article.aspx?id=/article-xml/awx_05_02_2013_p0-575769.xml.

89 “A Conversation with Dr. Mark Lewis United States Air Force Chief Scientist,” *AIAA HyTASP Newsletter* 1, no. 1 (April 2008): 21–22, https://info.aiaa.org/tac/pc/HYTAPC/Newsletter/April_2008_HyTASP_Newsletter.pdf.

90 Graham Warwick, “Hyper Activity: Hypersonics Research in the USA,” *Flightglobal*, August 29, 2006, www.flightglobal.com/news/articles/hyper-activity-hypersonics-research-in-the-usa-208680.

91 Personal communication, senior U.S. official, Arlington, VA, July 2012.

92 Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, Air Force Science and Technology Board, and Commission on Engineering and Technical Systems, National Research Council, *Review and Evaluation of the Air Force Hypersonic Technology Program* (Washington, DC: National Academies Press, 1998), 27–28, www.nap.edu/catalog.php?record_id=6195. This NRC report suggested that about seven years would be needed between the demonstration flight of a prototype and an initial operational capability.

93 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 40. This 2008 report suggests a long-range hypersonic cruise missile could become operational around 2020–2024. For a program initiated in 2012, this would translate to 2024–2028.

94 Department of Defense, “Upcoming Flight of the X-51A WaveRider Hypersonic Flight Test Demonstrator,” transcript of bloggers roundtable, March 15, 2011, 12, www.defense.gov/Blog_files/Blog_assets/0315x51a.pdf. Unlike ballistic and boost glide systems, hypersonic cruise missile programs are not isolated entities in either the Air Force or DARPA budget requests.

95 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 40. See also appendix B.

96 DARPA, "Falcon HTV-2."
97 DARPA, "DARPA Concludes Review of Falcon HTV-2 Flight Anomaly."
98 DARPA, "Engineering Review Board Concludes Review of HTV-2 Second Test Flight."
99 In fact, only three missiles do (or did) not rely solely on inertial navigation. Trident D5 missiles use a star sighting to enhance the accuracy of the inertial navigation system. Trident C4 missiles used a similar technique. Pershing II reentry vehicles were equipped with an active radar for homing during the reentry phase.
100 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 26–28.
101 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 121–22.
102 Ibid., 122.
103 For example, U.S. Air Force, "X-51 WaveRider Makes Historic Hypersonic Flight," May 26, 2010, www.af.mil/news/story.asp?id=123206525.
104 Zach Rosenberg, "Second X-51 Hypersonic Flight Ends Prematurely," *Flightglobal*, June 15, 2011, www.flightglobal.com/news/articles/second-x-51-hypersonic-flight-ends-prematurely-358056.
105 Committee on Review and Evaluation of the Air Force Hypersonic Technology Program et al., *Review and Evaluation of the Air Force Hypersonic Technology Program*, 6.
106 Department of Defense, "Upcoming Flight of the X-51A WaveRider Hypersonic Flight Test Demonstrator," 2.
107 NASA, "X-43A Mishap Investigation Board Convenes," Press Release 01-116, June 6, 2001, www.nasa.gov/home/hqnews/2001/01-116.txt.
108 U.S. Air Force, "X-51A Flight Ends Prematurely," August 15, 2012, www.af.mil/news/story.asp?id=123314235.

CHAPTER 3

1 U.S. Senate Armed Services Committee, Strategic Forces Subcommittee, *Military Space Programs and Views on Department of Defense Usage of the Electromagnetic Spectrum in Review of the Defense Authorization Request for FY 2014 and the Future Years Defense Program*, April 24, 2013, Federal News Service transcript.
2 See, for example, Congressional Budget Office, *Alternatives for Long-Range Ground-Attack Systems*, March 2006, 21, www.cbo.gov/sites/default/files/cbofiles/ftpdocs/71xx/doc7112/03-31-strikeforce.pdf.
3 If only Russian intercontinental ballistic missiles were used the warning time would have been about thirty minutes. If sea-launched ballistic missiles were involved, the warning time could have been less than ten minutes. Bruce G. Blair, *The Logic of Accidental Nuclear War* (Washington, DC: Brookings Institution Press, 1993), 187–91.
4 Ibid., 187–91.
5 A third possibility would be detecting launch preparations. It is hard to say much about whether such preparations would be detectable, partly because any indicators are unquestionably classified, but also because development of the technology has not yet progressed far enough for detailed operational arrangements to have been developed. Nonetheless, as CPGS technology and its associated operational concepts mature, the issue of the detectability of launch preparations should be addressed, not least because such detection would afford an adversary more warning time—potentially significantly more—than detection after launch.
6 For an informative discussion of the underlying technology see Geoffrey Forden, *A Constellation of Satellites for Shared Missile Launch Surveillance* (Program on Science, Technology, and Society, Mas-

sachusetts Institute of Technology, July 9, 2006), http://web.mit.edu/stgs/pdfs/white%20paper--%20A%20Multinational%20Missile%20Launch%20Surveillance%20Network.pdf.

7 For slightly dated, but still useful discussions of U.S. and Russian systems see Forden, *A Constellation of Satellites for Shared Missile Launch Surveillance*; Zia Mian, R. Rajaraman, and M. V. Ramana, "Early Warning in South Asia—Constraints and Implications," *Science and Global Security* 11, nos. 2–3 (2003): 124–26, www.princeton.edu/sgs/publications/sgs/pdf/11%202-3%20Mian%20p109-150.pdf. The United States is currently replacing the Defense Support Program constellation of satellites with the Space-Based Infrared System.

8 In addition, the possibility that a state with space-based early-warning assets could alert a third party to an impending attack cannot be ruled out, although the practical challenges to such cooperation would be daunting.

9 Mark A. Stokes, *China's Strategic Modernization: Implications for the United States* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, September 1999), 41–42, www.fas.org/nuke/guide/china/doctrine/chinamod.pdf.

10 Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2011, Annual Report to U.S. Department of Defense, Congress, 36, www.defense.gov/pubs/pdfs/2011_cmpr_final.pdf.

11 Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, Annual Report to Congress, 67–68, www.defense.gov/pubs/2013_China_Report_FINAL.pdf.

12 Ibid., 67–68.

13 If they cannot, margins of warning against hypersonic cruise missiles would be smaller.

14 Duncan Lennox, *Jane's Strategic Weapon Systems*, 55th issue (Coulsdon: IHS Global, July 2011), 235–37 and 317–21.

15 Stepan Kravchenko and Henry Meyer, "Russia Hails 'Stabilizing' Sale of Missiles to Syria," Bloomberg, May 28, 2013, www.bloomberg.com/news/2013-05-28/russia-says-s-300-missile-sale-to-syria-will-stabilize-region.html.

16 "Kremlin Bans Sale of S-300 Missile Systems to Iran," BBC News, September 22, 2010, www.bbc.co.uk/news/world-europe-11388680.

17 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff* (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, March 2009), 52–53, www.acq.osd.mil/dsb/reports/ADA498403.pdf.

18 Another possibility, not considered further here, is GPS spoofing—broadcasting fake and misleading GPS signals.

19 Forrest E. Morgan, *Deterrence and First-Strike Stability in Space: A Preliminary Assessment* (Santa Monica, CA: RAND Corporation, 2010), 16, www.rand.org/content/dam/rand/pubs/monographs/2010/RAND_MG916.pdf. During the 2003 Gulf War, Iraq used GPS jammers that were reportedly purchased from Russia, but with very little effect. "Military Wipes Out Iraqi GPS Jammers," Fox News, March 25, 2003, www.foxnews.com/story/0,2933,82018,00.html.

20 "N. Korea's Jamming of GPS Signals Poses New Threat: Defense Minister," Yonhap News Agency, October 5, 2010, http://english.yonhapnews.co.kr/national/2010/10/05/67/0301000000AEN20101005005900315F.HTML.

21 Shin Hyon-hee, "GPS Jamming Highlights N.K. Cyber War Threat," *Korea Herald*, May 8, 2012, www.koreaherald.com/view.php?ud=20120508001326.

22 Charles R. Smith, "China Takes Aim at U.S. GPS," *Geopolitical Monitor*, November 23, 2007, www.geopoliticalmonitor.com/china-takes-aim-at-us-gps-054.

23 Congressional Budget Office, U.S. Congress, *The Global Positioning System for Military Users: Current Modernization Plans and Alternatives*, October 2011, 33–36, www.cbo.gov/sites/default/files/cbofiles/attachments/10-28-GPS.pdf.

24 Ibid, 9–16. These figures were derived for a 10 W jammer.

25 A 100 kW truck-based jammer is estimated to cost $1.5 million. Ibid., 42. Since the jamming radius is proportional to the square root of power, a 100 kW jammer would have a range 100 times greater than the 10 W jammer considered as the baseline case in Congressional Budget Office, *The Global Positioning System for Military Users*.

26 Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 121–23, www.nap.edu/catalog.php?record_id=12061.

27 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 26–28. It states (in the context of maintaining GPS reception in plasma formation) that a deeply integrated inertial navigation system with GPS "has not been flight tested" but "merits some analysis and lab testing."

28 Congressional Budget Office, *The Global Positioning System for Military Users* discusses steps the United States could take. It is unclear whether the Department of Defense has adapted its plans based on this report. It would certainly be possible for an adversary to build jammers more powerful than 100 kW. The real challenge would probably be powering them for long periods of time. However, if an adversary gained even a few minutes of tactical warning of an attack it could circumvent this problem by not having to operate the jammers continually in a crisis.

29 This is an issue of both resources and geography. China has more resources it could devote to jamming as well as antisatellite weapons that are potentially capable of holding GPS satellites at risk. Additionally, China's size is an advantage. The U.S. High Integrity GPS program (iGPS) is intended to help receivers lock onto a weak GPS signal by using a much stronger signal from a communications satellite. However, iGPS requires a ground-based station within 1,200 km of the receiver. This would severely limit its utility in western China. Congressional Budget Office, *The Global Positioning System for Military Users*, 25–27.

30 Because they fly at such a high altitude, CPGS weapons could almost certainly not navigate by Terrain Contour Matching (TERCOM). Another theoretical possibility would be some form of terminal sensor, but the Defense Science Board argues that this "would likely be expensive, heavy and brings a host of other potential problems such as target signature temporal stability." Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 27.

31 Because hypersonic gliders travel at much lower altitudes than ICBMs, they must be closer to a radar before they can be detected.

32 See note 82.

33 According to the NRC, the CPGS Analysis of Alternatives assumed boost-glide systems would slow to Mach 5 to dispense submunitions. It worried, however, that this speed would be "aggressively high." Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike,* 145. A diagram in the 2009 Defense Science Board report showed submunitions being dispensed at 400 m/sec., which is equivalent to Mach 1.2. Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 28.

34 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 145.

35 Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, Air Force Science and Technology Board, and Commission on Engineering and Technical Systems, National Research Council, *Review and Evaluation of the Air Force Hypersonic Technology Program* (Washington, DC: National Academies Press, 1998), 57, www.nap.edu/catalog.php?record_id=6195. Interpolation is required since the cases of a Mach 4, Mach 6.5, and Mach 8 missile are shown. The stated range refers only to the forward sector of the defense.

36 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 145.

37 For example, as of June 2013, the Terminal High Altitude Area Defense (THAAD) system has successfully intercepted ten out of ten test missiles since 2005, including a medium-range ballistic missile in October 2012. As the name suggests, THAAD is more than just a point defense (even though it is a terminal interceptor) because it has both endo-atmospheric and exo-atmospheric intercept capability. Missile Defense Agency, "Ballistic Missile Defense Intercept Flight Test Record," fact sheet, May 16, 2013 (latest version available from www.mda.mil/global/documents/pdf/testrecord.pdf); Missile Defense Agency, "FTI-01 Mission Data Sheet: Ballistic Missile Defense System," 12-MDA-7039, October 15, 2012, www.mda.mil/global/documents/pdf/FTI_01_factsheet.pdf.

38 Unlike most U.S. terminal defenses, these systems are not hit-to-kill (that is, designed to destroy an oncoming missile simply by colliding with it) but, instead, use an explosive warhead. For a detailed discussion of these systems see Lennox, *Jane's Strategic Weapon Systems*, 323–30.

39 Lennox, *Jane's Strategic Weapon Systems*, 326, 330.

40 Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, 67; "Russia, China Plan to Boost Cooperation on Missile Defense," RIA Novosti, January 9, 2013, www.en.rian.ru/military_news/20130109/178663401.html?id. Various Chinese air defense systems appear to have been bought directly from Russia, built in China under Russian license or indigenized from Russian designs. Examples include HQ-9, HQ-10, HQ-12, HQ-15, HQ-16, HQ-17, HQ-18 and HQ-19. See, for example, Lennox, *Jane's Strategic Weapon Systems*, 235–43.

41 "China to Buy Russian Fighters, Subs: State Media," *Global Post*, March 25, 2013, www.globalpost.com/dispatch/news/afp/130325/china-buy-russian-fighters-subs-state-media; "Russia Looking at China S-400 Deliveries in 2017," RIA Novosti, June 27, 2012, http://en.rian.ru/world/20120627/174264185.html; "China Orders Russian Air-Defense Batteries," Global Security Newswire, May 11, 2012, www.nti.org/gsn/article/china-orders-russian-air-defense-batteries. Separately, there are reports that China helped finance the development of the S-400 and that its own indigenously manufactured equivalent, HQ-19, entered into service in 2006. Lennox, *Jane's Strategic Weapon Systems*, 243.

42 For a recent overview of Chinese air and missile defense efforts see Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, 35–36 and 67–68.

43 A more ambitious HTV-2 test flight with a reentry speed of about 7,200 m/sec. was planned but never conducted. See the "B" trajectory in Jess Sponable, "Reusable Space Systems: 21st Century Technology Challlenges [Sic]," DARPA, June 17, 2009, 20, www.nianet.org/getattachment/resources/Education/Continuining-Education/vSeminars-and-Colloquia/Seminars-2009/Reusable-Space-Systems,-LaRC,-17-Jun-09.pptx.aspx.

44 James M. Acton, "Hypersonic Boost-Glide Weapons," (forthcoming).

45 These countermeasures are ineffective in the atmosphere because only in the vacuum of space, where there is no air resistance, do objects of different masses accelerate at the same rate.

46 The conical Advanced Hypersonic Weapon, in particular, is very similar in shape to a reentry vehicle, whereas the HTV-2 is more flattened.

47 Indeed, the HTV-2 flights were monitored by a number of radars, including a modestly sized air-transportable system that, superficially at least, appears similar to an air-defense surveillance radar. Acquisition Civil/Environmental Engineering, Space and Missile Systems Center, *Environmental Assessment for Hypersonic Technology Vehicle 2 Flight Tests*, April 2009, 18–21, www.dtic.mil/dtic/tr/fulltext/u2/a544343.pdf.

48 *HTV-2 Test Footage* (DARPA, 2011), 1 min., 10 secs., www.youtube.com/watch?v=uVFNLdTuN-s. This video was taken with a hand-held camera by a sailor on one of the ships monitoring the HTV-2 flight. Interceptors in missile defense systems like the S-300V and S-400 use radar for terminal homing. However, the use of an infrared seeker for terminal homing has been successfully demonstrated in the U.S. THAAD system.

49 U.S. Air Force, "B-2 Sprit," January 29, 2013, www.af.mil/information/factsheets/factsheet.asp?fsID=82; Thom Shanker and Choe Sang-Hun, "U.S. Runs Practice Sortie in South Korea,"

New York Times, March 28, 2013, www.nytimes.com/2013/03/29/world/asia/us-begins-stealth-bombing-runs-over-south-korea.html.

50 Jan van Tol, with Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), 59, www.csbaonline.org/wp-content/uploads/2010/05/2010.05.18-AirSea-Battle.pdf.

51 An AHW system based in Europe could achieve this goal. One based in Diego Garcia could not provide coverage of West Africa.

52 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike Issues for 2008 and Beyond*, 127–31.

53 Ibid., 127–29.

54 This weapon was planned to have a total mass of about 400 kg, including about 70 to 90 kg of high explosive along with "several thousand debris particles, each measuring no more than a few centimeters in diameter." Acquisition Civil/Environmental Engineering, Space and Missile Systems Center, *Environmental Assessment for Conventional Strike Missile Demonstration*, draft, June 2010, 9, www.csm-ea.com/CSM%20Demo%20Draft%20EA--Part%201of2%20(10Jun10).pdf.

55 To be sure, a detailed analysis of specific targets would probably reveal minor differences in effectiveness between the use of particle dispersion weapons delivered by CPGS systems and high explosives delivered by bomb or cruise missile. However, these differences are unlikely to be sufficient to constitute a significant argument for or against CPGS.

56 On Iran see International Institute for Strategic Studies, "Iran's Ballistic Missile Capabilities: A Net Assessment," *Strategic Dosser* (London: IISS, 2010), 117–19. On North Korea see Daniel A. Pinkston, *The North Korean Ballistic Missile Program* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, February 2008), especially vi–vii, www.strategicstudiesinstitute.army.mil/pdffiles/pub842.pdf; Thom Shanker and David E. Sanger, "Movement of Missiles by North Korea Worries U.S.," *New York Times*, January 17, 2013, www.nytimes.com/2013/01/18/world/asia/north-koreas-missile-movements-worry-us.html?_r=0. For the latest detailed official U.S. estimate of China's missile force see Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2010, Annual Report to Congress, 66, www.defense.gov/pubs/pdfs/2010_cmpr_final.pdf. Note that all the missiles listed in this reference are road-mobile, except for DF-5 (CSS-4), which is silo-based; DF-4 (CSS-3), which is a "roll out to launch" weapon; the submarine-launched JL-2; and some air-launched DH-10 cruise missiles.

57 U.S. Senate Armed Services Committee, *Military Space Programs and Views on Department of Defense Usage of the Electromagnetic Spectrum in Review of the Defense Authorization Request for FY 2014 and the Future Years Defense Program*.

58 Thomas A. Keaney and Barry D. Watts, "Effects and Effectiveness" in *Gulf War Air Power Survey*, vol. II, part II (Washington, DC: U.S. Government Printing Office, 1993), 330–32, www.afhso.af.mil/shared/media/document/AFD-100927-067.pdf.

59 Dennis M. Gormley, *The Path to Deep Nuclear Reductions: Dealing With American Conventional Superiority*, Proliferation Papers 29 (Paris: Ifri, 2009), 21–23, www.ifri.org/downloads/pp29gormley1.pdf.

60 Pinkston, *The North Korean Ballistic Missile Program*, 47 and n. 192.

61 Acton, "Hypersonic Boost-Glide Weapons."

62 U.S. Department of Defense, *Department of Defense Fiscal Year (FY) 2014 President's Budget Submission: Research, Development, Test & Evaluation, Defense-Wide*, vol. 3, *Office of the Secretary of Defense*, April 2013, 583 and 590 (PE 0604165D8Z), http://comptroller.defense.gov/defbudget/fy2014/budget_justification/pdfs/03_RDT_and_E/Office_of_the_Secretary_of_Defense_PB_2014.pdf.

63 While human and signals intelligence could certainly be of considerable help in identifying the number of mobile missile possessed by an adversary as well as their organization, command and control arrangements and patrol areas, it is highly unlikely that these sources could provide reliable, accurate, real-time data on the location of individual weapons.

64 Modern reconnaissance satellites are reportedly able to detect infrared radiation as well as visible light. This enables them to function at night but does not solve the problem of cloud cover. For an excellent, if somewhat dated, discussion see Jeffrey T. Richelson, ed., "U.S. Satellite Imagery, 1960–1999," National Security Archive Electronic Briefing Book no. 13, April 14, 1999, www.gwu.edu/~nsarchiv/NSAEBB/NSAEBB13.

65 Reconnaissance satellites must be in low earth orbit to produce detailed images. A satellite in such an orbit moves continuously relative to the earth's surface; it cannot "hover" above a point of interest. The nonmilitary U.S. Landsat 7 satellite, which occupies a similar orbit to military reconnaissance satellites, revisits each point on the earth's surface once every sixteen days. The number of military reconnaissance satellites owned by the U.S. government has not officially been disclosed. However, even if Washington had fifteen military and civilian reconnaissance satellites at its disposal (which is almost certainly higher than the true number), there would be about twenty-six hours, on average, between successive images of any given point on the earth's surface. See David Wright, Laura Grego, and Lisbeth Gronlund, *The Physics of Space Security: A Reference Manual* (Cambridge, MA: American Academy of Arts and Sciences, 2005), 40–45, www.amacad.org/publications/Physics_of_Space_Security.pdf; and NASA, "The Worldwide Reference System," http://landsat.gsfc.nasa.gov/about/wrs.html.

66 The relevant technology is synthetic aperture radar. For an excellent account of its potential use in tracking mobile targets see Li Bin, "Tracking Chinese Strategic Mobile Missiles," *Science and Global Security* 15, no. 1 (2007): 11–25, http://scienceandglobalsecurity.org/archive/sgs15libin.pdf. Li ultimately concludes that satellite-based radar is too vulnerable to countermeasures to provide a reliable capability.

67 The United States appears to have five or six satellite-based radars at present. See Jeffrey T. Richelson, "Ups and Downs of Space Radars," *Air Force Magazine* 92, no. 1 (January 2009), 67–70, www.airforcemag.com/MagazineArchive/Documents/2009/January%202009/0109radars.pdf; William Graham, "ULA Delta IV Launches the NROL-25 Military Satellite From VAFB," April 3, 2012, www.nasaspaceflight.com/2012/04/live-ula-delta-iv-launch-nrol-25-military-satellite-vafb; Li, "Tracking Chinese Strategic Mobile Missiles," 14, discusses the requirements for continuous coverage.

68 The whole tortuous story is recounted in Richelson, "Ups and Downs of Space Radars;" Dwayne A. Day, "Radar Love: The Tortured History of American Space Radar Programs," *Space Review*, January 22, 2007, www.thespacereview.com/article/790/1.

69 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 54.

70 Megan Scully, "National Reconnaissance Office Cancels Contracts for Proposed Space Radar Projects," *Government Executive*, April 4, 2008, www.govexec.com/defense/2008/04/national-reconnaissance-office-cancels-contracts-for-proposed-space-radar-project/26644/.

71 After the cancellation of the Space Radar program, there was some discussion of the U.S. government's making greater use of commercially available imagery. However, it seems very unlikely that this approach would be appropriate for the purposes discussed here. See David Perera, "Space Radar Plans Stay in Flux," *Defense Systems*, March 3, 2009, http://defensesystems.com/articles/2009/03/11/space-radar-in-flux.aspx.

72 Uzi Rubin, *The Rocket Campaign Against Israel During the 2006 Lebanon War*, Mideast Security and Policy Studies 71 (Ramat Gan: The Begin-Sadat Center for Strategic Studies, Bar-Ilan University, June 2007), 19–21, www.biu.ac.il/Besa/MSPS71.pdf. The most important U.S. airborne asset for tracking mobile targets would probably be the ageing E-8 Joint Surveillance Targeting and Attack Radar System (JSTARS) aircraft. Plans to replace this system have recently been shelved. Ben Iannotta, "With No Replacement in Sight, Joint STARS Feel Strain," Defensenews.com, October 9, 2012, www.defensenews.com/article/20121009/C4ISR01/310090012/With-No-Replacement-Sight-Joint-STARS-Feel-Strain.

73 For further discussion about the challenge of hunting nuclear-armed missiles see James M. Acton, *Deterrence During Disarmament: Deep Nuclear Reductions and International Security*, Adelphi 417 (Abingdon: Routledge for the IISS, 2011), 44–49. In its 2006 war against Hezbollah, Israel located many of the launchers it destroyed by detecting the plumes from rockets after launch. Clearly, this technique would not be acceptable if the United States were attempting to hunt down nuclear-armed missiles. It might be acceptable (though far from optimal) against conventional missiles. In this case, U.S. early warning satellites could help locate transporter-erector launchers, although they would not be sufficiently accurately to do so unaided.

74 Congressional Budget Office, *Alternatives for Long-Range Ground-Attack Systems*, 21.

75 Matthew Hallex, "Chinese Mobile Ballistic Missiles: Implications for U.S. Counterforce Operations," http://csis.org/images/stories/poni/111007_Hallex.pdf, 41–42.

76 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 131.

77 Li, "Tracking Chinese Strategic Mobile Missiles," 15–24. Some countermeasures against space-based radar, such as driving transporter-erector launchers in a direction that made them virtually invisible to movement-sensing radar, would only be available to states with advanced space situation awareness, such as China. However, other countermeasures, such as driving transporter-erector launchers along roads lined by buildings or trees to reduce their visibility to satellites, would be open to any state.

78 Committee on the Effects of Nuclear Earth-Penetrator and Other Weapons and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *Effects of Nuclear Earth-Penetrator and Other Weapons* (Washington, DC: National Academies Press, 2005), 14–15, http://books.nap.edu/catalog.php?record_id=11282.

79 Ibid., 13.

80 Ibid., 14.

81 "GBU-57A/B Massive Ordnance Penetrator (MOP)," *Jane's Air-Launched Weapons* (IHS Global, February 25, 2013).

82 The curve of penetration depth against impact velocity has a maximum at around 1,000 m/sec. (although this can vary significantly depending on the design of the penetrator and the characteristics of the target). Because CPGS weapons generally travel significantly faster than 1,000 m/sec., they must slow down before impact to maximize penetrator efficiency. See, for example, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 26; Robert W. Nelson, "Low-Yield Earth-Penetrating Nuclear Weapons," *Science and Global Security* 10, no. 1 (2002): 5–7, http://scienceandglobalsecurity.org/archive/sgs10nelson.pdf; Nancy F. Swinford and Dean A. Kudlick, *A Hard and Deeply Buried Target Defeat Concept* (Sunnyvale, CA: Lockheed Martin Missiles & Space, 1996), 1–2, www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA318768.

83 Acton, "Hypersonic Boost-Glide Weapons."

84 "GBU-57A/B Massive Ordnance Penetrator (MOP)."

85 The maximum mass of the HTV-2 is 1,500 kg. Acquisition Civil/Environmental Engineering, *Environmental Assessment for Conventional Strike Missile Demonstration*, 9. Typically, around 15 percent of the mass of a small penetrator is explosive, resulting in an upper bound of 225 kg for the mass of the explosive. In practice, it would almost certainly be smaller.

86 Yevgeny Miasnikov, "Precision-Guided Conventional Weapons" in *Nuclear Reset: Arms Reduction and Nonproliferation*, eds. Alexei Arbatov and Vladimir Dvorkin, trans. ed. Natalia Bubnova, (Moscow: Carnegie Moscow Center, 2012), 443–46, http://carnegieendowment.org/files/nuclear_reset_Book2012_web.pdf.

87 John R. Matzko, *Inside a Soviet ICBM Silo Complex: The SS-18 Silo Dismantlement Program at Derzhavinsk, Kazakhstan*, DTRA-TR-99-15 (Dulles, VA: Defense Threat Reduction Agency, August 2000), 7–8, www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA388848.

88 Ibid., 8 and 27.

89 The result of cratering experiments with conventional explosives are reported in J. Toman, “Results of Cratering Experiments,” IAEA-PL-388/16 in *Peaceful Nuclear Explosions: Phenomenology and Status Report 1970* (Vienna: International Atomic Energy Agency, 1970), 368. Details of their application to modern penetrating weapons are discussed in Acton, “Hypersonic Boost-Glide Weapons.”

90 For informative discussions based on actual counterterrorism missions see Austin Long, Dinshaw Mistry, and Bruce M. Sugden, “Going Nowhere Fast: Assessing Concerns About Long-Range Conventional Ballistic Missiles,” *International Security* 34, no. 4 (Spring 2010): 167–71; Pollack, “Evaluating Conventional Prompt Global Strike,” 15–18.

91 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 54.

92 Long, Mistry, and Sugden, “Going Nowhere Fast,” 168–69; Mark Bowden, “The Hunt for ‘Geronimo,’” *Vanity Fair*, November 2012, www.vanityfair.com/politics/2012/11/inside-osama-bin-laden-assassination-plot. In arguing that CPGS could be needed to take advantage of intelligence, the NRC appears to undermine its own argument by stating that “in the 1990s, it was sometimes known that al-Qaeda leaders would be meeting, but the time and place were not known precisely until late in the game.” Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 31. This observation once again suggests that intelligence collection is likely to be a process culminating in sufficiently detailed information to authorize a strike.

93 Some have argued that, in this scenario, CPGS might still be useful if the United States does not have access to nearby overseas bases or cannot secure overflight rights. See, for example, Long, Mistry, and Sugden, “Going Nowhere Fast,” 180. While the lack of a convenient overseas base might preclude the use of special forces or UAVs, it would not preclude the use of manned aircraft, such as the B-2, which has an effectively unlimited range when aerial refueling is possible. Moreover, manned aircraft are probably more adept than CPGS systems at flying circuitous routes that avoid particular regions of airspace.

94 M. Elaine Bunn and Vincent A. Manzo, *Conventional Prompt Global Strike: Strategic Asset or Unusable Liability?* Strategic Forum 263 (Institute for National Security Studies, National Defense University, February 2011), 8–9, http://csis.org/files/media/csis/pubs/110201_manzo_sf_263.pdf.

95 See, for example, Michael A. Levi, *Fire in the Hole: Nuclear and Non-Nuclear Options for Counter-Proliferation*, Working Paper 31 (Washington, DC: Carnegie Endowment for International Peace, November 2002), 9–11, http://carnegieendowment.org/files/wp31.pdf.

96 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 50.

97 Levi, *Fire in the Hole*, 20–21.

98 Bowden, “The Hunt for ‘Geronimo.’” Mike Leiter, the director of the National Counterterrorism Center, also reportedly advised the use of an aircraft.

99 Jeffrey A. Larsen, Justin V. Anderson, Darci Bloyer, Thomas Devine IV, Rebecca Davis Gibbons, and Christina Vaughan, *Qualitative Considerations of Nuclear Forces at Lower Numbers and Implications for Future Arms Control Negotiations*, INSS Occasional Paper 68 (Colorado Springs, CO: U.S. Air Force Institute for National Security Studies, U.S. Air Force Academy, July 2012), n. 54, www.usafa.edu/df/inss/OCP/OCP68.pdf.

100 Gates, who initially favored the use of an aircraft, reportedly acknowledged that one disadvantage of this option was that they would not know whether they “had gotten” bin Laden. Bowden, “The Hunt For ‘Geronimo.’”

101 See Government Accountability Office, *Military Transformation: DoD Needs to Strengthen Implementation of Its Global Strike Concept and Provide a Comprehensive Investment Approach for Acquiring Needed Capabilities*, GAO-08-325, April 2008, 28, www.gao.gov/new.items/d08325.pdf. This report gives other examples of similar studies affected by the same problem.

102 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, 1–6; Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 51–59;Office of the Under Secretary of Defense for Acquisition, Technology, and

Logistics, U.S. Department of Defense, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*, February 2004, chs. 3 and 4, www.acq.osd.mil/dsb/reports/ADA421606.pdf.

103 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 54, 98.

104 Long, Mistry, and Sugden, "Going Nowhere Fast," 167–68; Pollack, "Evaluating Conventional Prompt Global Strike," 16.

105 Government Accountability Office, *Military Transformation*, 27–28. This specific criticism was made in reference to the Air Force–led Prompt Global Strike Analysis of Alternatives and the Next Generation Long-Range Strike Analysis of Alternatives. However, a very similar criticism was made of other studies.

106 Ibid., 6.

107 Ibid., 54–55.

CHAPTER 4

1 "Russia to Resume Hypersonic Missile Activities," *Flightglobal*, May 15, 2012, www.flightglobal.com/news/articles/russia-to-resume-hypersonic-missile-activities-371910.

2 U.S. National Intelligence Council, G*lobal Trends 2030: Alternative Worlds*, NIC 2012-001, December 2012, 67, www.dni.gov/files/documents/GlobalTrends_2030.pdf.

3 Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, Annual Report to Congress, 5–6 and 42, www.defense.gov/pubs/2013_China_Report_FINAL.pdf. For a discussion of the credibility of news reports suggesting a longer range see Ronald O'Rourke, *China Naval Modernization: Implications for U.S. Navy Capabilities—Background and Issues for Congress*, CRS Report for Congress, RL33153 (Congressional Research Service, October 17, 2012), n. 22 (the latest version of this report is available from www.fas.org/sgp/crs/row/RL33153.pdf).

4 Keith Payne, Thomas Scheber, Mark Schneider, David Trachtenberg, and Kurt Guthe, C*onventional Prompt Global Strike*: *A Fresh Perspective* (Arlington, VA: National Institute Press, June 2012), 30–32, www.nipp.org/Publication/Downloads/Downloads%202012/CPGS_REPORT%20for%20web.pdf.

5 See, for example, the comments by Congressman Michael Turner (then Chairman of the Subcommittee on Strategic Forces of the House Armed Services Committee) in U.S. House of Representatives Armed Services Committee, Strategic Forces Subcommittee, *Nuclear Weapons Modernization in Russia and China: Understanding Impacts to the United States*, HASC no. 112–78, 112th Cong., 1st sess., October 14, 2011, 3–4, www.gpo.gov/fdsys/pkg/CHRG-112hhrg71449/pdf/CHRG-112hhrg71449.pdf.

6 The hearings on *Nuclear Weapons Modernization in Russia and China: Understanding Impacts to the United States* are a case in point. Turner asked one of the witnesses, Richard Fisher (a senior fellow at the International Assessment and Strategy Center), to explain why Chinese nuclear modernization was a problem for the United States. Fisher pointed to the possibility that rising Chinese nuclear-weapon numbers "would undermine in a very significant way our ability to deter Chinese aggression." However, even if this argument is correct (and it is certainly debatable), it does not really address the question; increasing arsenal size is a quite separate issue from designing new warheads (modernization). Fisher also made other arguments, such as the potential for modernized conventional Chinese air defenses to defeat U.S. nuclear-armed aircraft, that are also entirely unrelated to Chinese nuclear modernization efforts.

7 See, for example, Amy Chang and John Dotson, *Indigenous Weapons Development in China's Military Modernization*, U.S.-China Economic and Security Review Commission Staff Research Report (U.S.-China Economic and Security Review Commission, April 5, 2012), section 3, http://origin.www.uscc.gov/sites/default/files/Research/China-Indigenous-Military-Developments-Final-Draft-03-April2012.pdf.

8 Michael S. Chase and Andrew S. Erickson, "The Conventional Missile Capabilities of China's Second Artillery Force: Cornerstone of Deterrence and Warfighting," *Asian Security* 8, no. 2 (2012): 127. For a discussion of Chinese doctrine for anti-ship ballistic missile operations see Andrew S. Erickson and David D. Yang, "Using the Land to Control the Sea? Chinese Analysts Consider the Antiship Ballistic Missile," *Naval War College Review* 62, no. 4 (Autumn 2009): 60–63, www.usnwc.edu/getattachment/f5cd3bb5-a1d1-497d-ab70-257b9502d13e/Using-the-Land-to-Control-the-Sea--Chinese-Analyst.aspx.

9 Mark Stokes, *China's Evolving Conventional Strategic Strike Capability: The Anti-Ship Ballistic Missile Challenge to U.S. Maritime Operations in the Western Pacific and Beyond* (Project 2049 Institute, September 14, 2009), 9, http://project2049.net/documents/chinese_anti_ship_ballistic_missile_asbm.pdf.

10 Office of the Secretary of Defense, U.S. Department of Defense, *Military Power of the People's Republic of China 2008*, Annual Report to Congress, 2, www.defense.gov/pubs/pdfs/china_military_report_08.pdf. For an example of an earlier reference see Office of Naval Intelligence, U.S. Navy, "Seapower Questions on the Chinese Submarine Force," December 20, 2006: 2–3, www.fas.org/nuke/guide/china/ONI2006.pdf. For a more detailed timeline see Andrew Erickson and Gabe Collins, *China Deploys World's First Long-Range, Land-Based 'Carrier Killer': DF-21D Anti-Ship Ballistic Missile (ASBM) Reaches 'Initial Operational Capability'* (IOC), China SignPost, December 26, 2010, 8–10, www.chinasignpost.com/wp-content/uploads/2010/12/China_SignPost_14_ASBM_IOC_2010-12-26.pdf.

11 Quoted in Erickson and Collins, *China Deploys World's First Long-Range, Land-Based 'Carrier Killer,'* 1.

12 Zhang Han and Huang Jingjing, "New Missile 'Ready by 2015,'" *Global Times*, February 18, 2011, http://english.peopledaily.com.cn/90001/90776/90786/7292006.html.

13 Hu Yinan, Li Xiaokun and Cui Haipei, "Official Confirms China Building Aircraft Carrier," *China Daily*, July 12, 2011, www.chinadaily.com.cn/china/2011-07/12/content_12881089.htm. Chen went on to add that "it is a high-tech weapon and we face many difficulties in getting funding, advanced technologies and high-quality personnel, which are all underlying reasons why it is hard to develop this."

14 Robert Johnson, "China Successfully Tests 'Carrier Killer' Missile in the Gobi Desert [REPORT]," *Business Insider*, January 25, 2013, www.businessinsider.com/chinas-carrier-killer-missile-test-proves-df-21d-lives-up-to-name-2013-1.

15 See, for example, the comments by Roger Cliff in Harry Kazianis, "Did China Test Its "Carrier-Killer?" *Diplomat*, January 24, 2013, http://thediplomat.com/flashpoints-blog/2013/01/24/did-china-test-its-carrier-killer.

16 Stokes, *China's Evolving Conventional Strategic Strike Capability*, 14–19.

17 Defense Writers Group, transcript of briefing with David J. Dorsett, January 5, 2011, 4, www.airforcemag.com/DWG/Documents/2011/January%202011/010511dorsett.pdf.

18 One question for further study is whether, in a process similar to the technological opportunism that partly drove the CPGS program in the United States, China developed an interest in longer-range land-attack weapons because it could build them.

19 One nongovernmental estimate is that the PLA has acquired between 15 and 40 DF-21Cs. Hans M. Kristensen and Robert S. Norris, "Chinese Nuclear Forces, 2011," *Bulletin of the Atomic Scientists* 67, no. 6 (November/December 2011): 83.

20 Zhang and Huang, "New Missile 'Ready by 2015.'"

21 Office of the Secretary of Defense, Military and Security Developments Involving the People's Republic of China 2013, 42. In its 2010 and 2011 reports, the Department of Defense stated that "as detailed elsewhere in this report, China's ballistic missile force is acquiring conventional

medium-range and intermediate-range ballistic missiles." Confusingly, however, the only intermediate-range ballistic missiles discussed elsewhere in these reports were nuclear armed. Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of Chin*a 2011, Annual Report to Congress, 33, www.defense.gov/pubs/pdfs/2011_cmpr_final.pdf. Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2010, Annual Report to Congress, 33, www.defense.gov/pubs/pdfs/2010_cmpr_final.pdf. The 2012 report was silent on the issue.

22 See, for example, Duncan Lennox, *Jane's Strategic Weapon Systems*, 55th issue (Coulsdon: IHS Global, July 2011), 27–28; "China's Anti-Ship Ballistic Missile Program: Checkmate for Taiwan?" Taiwan Link, June 17, 2009, http://thetaiwanlink.blogspot.com/2009/06/chinas-anti-ship-ballistic-missile_17.html. Individual Chinese analysts have also advocated for the development of such weapons. For examples see Chase and Erickson, "The Conventional Missile Capabilities of China's Second Artillery Force," n. 108.

23 Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, 42.

24 Second Artillery Corps, People's Liberation Army, *The Science of Second Artillery Campaigns* [in Chinese] (Beijing: PLA Press, 2004), 318. (The page numbers refer to the original Chinese text.) Many experts on China regard this document as authoritative. For a more skeptical view see Larry M. Wortzel, "China's Nuclear 'Leakage,'" *Diplomat*, August 7, 2012, http://thediplomat.com/china-power/chinas-nuclear-leakage.

25 Peng Guangqian and Yao Youzhi, eds. *The Science of Military Strategy* (Beijing: Military Sciencen-Publishing House, 2005), 219. The 2005 edition is an official translation of the 2001 Chinese-language version.

26 Peng and Yao, The Science of Military Strategy, 219. See also Chase and Erickson, "The Conventional Missile Capabilities of China's Second Artillery Force," 117. Compare this statement with Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*, February 2004, 2-2, which states that "throughout the Cold War, *strategic* was virtually synonymous with *nuclear*. This is no longer so. While we could previously execute some military operations only with nuclear weapons, we can now execute many of these with highly precise conventional weaponry." Italics in original.

27 Stokes, *China's Evolving Conventional Strategic Strike Capability*, 32–34. One important difference between Chinese and U.S. approaches to boost-glide technology is that the Chinese sources Stokes identified focus on boost-glide weapons with "phugoid" trajectories in which the reentry vehicle "skips" on the atmosphere (much like a stone can skim the surface of a pond). By contrast, the U.S. CPGS program is currently focused on using a depressed-trajectory missile to launch a reentry vehicle into "level" flight with no skipping.

28 Ibid., 2.

29 The only document Stokes identifies that specifically mentions the existence of an overarching plan is an anonymous blog entry. Ibid., n 26. On p. iii, Stokes states that KKTT, the author of the blog entry, is the "screen name of anonymous Chinese blogger" (albeit a relatively well regarded one).

30 Erickson and Collins, *China Deploys World's First Long-Range, Land-Based 'Carrier Killer*,' 7–8; Stokes, *China's Evolving Conventional Strategic Strike Capability*, 9; Erickson and Yang, "Using the Land to Control the Sea?" 55.

31 Stokes, *China's Evolving Conventional Strategic Strike Capability*, 23–25.

32 Inertial navigation, by itself, is insufficiently accurate for this purpose.

33 For a discussion of other possible solutions see Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Time Critical Conventional Strike From Strategic Standoff*, March 2009, 26–28, www.acq.osd.mil/dsb/reports/ADA498403.pdf.

34 Vladimir Putin, "Being Strong: National Security Guarantees for Russia," *Rossiyskaya Gazeta*, February 19, 2012, translation available from http://rt.com/politics/official-word/strong-putin-military-russia-711.

35 Ibid.

36 *The Military Doctrine of the Russian Federation*, February 5, 2010, para. 22, translation available from http://carnegieendowment.org/files/2010russia_military_doctrine.pdf.

37 "Russia to Resume Hypersonic Missile Activities."

38 "Hyperactivity: Russia Reveals Mega-Merger for Hypersonic Weapons Production," *Russia Today*, September 19, 2012, http://rt.com/politics/russia-launch-holding-weapons-489.

39 "Putin Signs 'DARPA' Future Research Fund Bill," RIA Novosti, October 17, 2012, http://en.rian.ru/military_news/20121017/176692006.html.

40 "'Predator' on the Prowl: Multi-Billion DARPA Rival Set Up in Russia," *Russia Today*, July 5, 2012, http://rt.com/news/darpa-rogozin-army-future-technologies-529.

41 "India and Russia to Develop Hypersonic Cruise Missile," RIA Novosti, March 30, 2012, http://en.rian.ru/world/20120330/172478672.html.

42 The BrahMos is a derivative of the Russian 3M55/SS-N-26 cruise missile. Lennox, *Jane's Strategic Weapon Systems*, 67–69.

43 "India and Russia to Develop Hypersonic Cruise Missile."

44 "Testing of India-Russia Hypersonic Cruise Missile May Come in 2017," Global Security Newswire, June 29, 2012, www.nti.org/gsn/article/testing-india-russia-hypersonic-cruise-missile-may-come-2017.

45 "Deputy PM Repeats Call for Hypersonic Bomber," RIA Novosti, August 27, 2012, http://en.rian.ru/military_news/20120827/175461736.html. Because the development of a long-range hypersonic bomber is such a daunting prospect, there has been some speculation that these comments referred not to the aircraft but to the missiles with which it would be armed. However, Rogozin was entirely clear that the bomber itself should be hypersonic—though this clarity does not make the goal any more feasible. Separately, *Izvestia* reported in January 2013 that Russia intended to test a hypersonic missile during 2013. No further details are available. "Russia Carries Out Mock Missile Firing," Global Security Newswire, January 17, 2013, www.nti.org/gsn/article/russia-carries-out-missile-firing-simulation.

46 Russia has successfully developed at least one short-range weapon—the anti-radar and anti-ship Kh-15 Kickback missile—that is reported to be capable of reaching hypersonic speeds. Lennox, *Jane's Strategic Weapon Systems*, 137. However, this weapon is propelled by a solid-rocket motor that cannot sustain aerodynamic flight over long ranges.

47 Alexander S. Roudakov, Vyacheslav L. Semenov, and John W. Hicks, *Recent Flight Test Results of the Joint CIAM-NASA Mach 6.5 Scramjet Flight Program*, NASA/TP-1998-206548 (Edwards, CA.: NASA, April 1998), www1.nasa.gov/centers/dryden/pdf/88580main_H-2243.pdf.

48 Norman Freidman, *The Naval Institute Guide to World Naval Weapon Systems 1997-1998* (Annapolis, MD: U.S. Naval Institute, 1997), 234 and 238.

49 Other programs, which are often cited in discussions of Russia's ambitions for hypersonic technology, appear much less relevant. The Kh-80 Meteorit program to develop a supersonic cruise missile with a range of thousands of kilometers is often mentioned. Although accounts of this program are confused and contradictory, this missile was most likely powered by a jet engine, which would not be capable of enabling hypersonic flight. Moreover, the one point on which all sources agree is that this missile had a simply dire testing record. See, for example, Friedman, *The Naval Institute Guide to World Naval Weapon Systems*, 238; "3M-25 Meteorit-A (Kh-80, AS-X-19 'Koala') and GELA (Kh-90)," *Jane's Air-Launched Weapons* (IHS Global, October 23, 2012).

50 "Russia to Develop Precision Conventional ICBM Option," RIA Novosti, December, 14 2012, http://en.rian.ru/military_news/20121214/178154441.html. The potential for the new missile to carry a maneuvering warhead had been noted long before Karakayev's announcement. See, for example, Pavel

Podvig, "Would Russia Build a New MIRVed ICBM?" *Russian Strategic Nuclear Forces*, December 10, 2010, http://russianforces.org/blog/2010/12/would_russia_build_a_new_mirve.shtml.

51 Nikolai Sokov, "Military Exercises in Russia: Naval Deterrence Failures Compensated by Strategic Rocket Success," *CNS Research Story*, James Martin Center for Nonproliferation Studies, February 24, 2004, http://cns.miis.edu/stories/040224.htm.

52 Ibid.

53 Nikolai Sokov, "The Future Shape of Russia's ICBM Force Clarified," *CNS Research Story*, James Martin Center for Nonproliferation Studies, November 9, 2005, http://cns.miis.edu/stories/051109.htm; Sokov, "Military Exercises in Russia."

54 Pavel Podvig, "New Warhead Tested in a UR-100NUTTH/SS-19 Launch," *Russian Strategic Nuclear Forces*, December 27, 2011, http://russianforces.org/blog/2011/12/new_warhead_tested_in_a_ur-100.shtml. See also Pavel Podvig, "Object 370, Project 4202 and Construction in Dombarovskiy," *Russian Strategic Nuclear Forces*, February 6, 2013, http://russianforces.org/blog/2013/02/object_370_project_4202_and_co.shtml.

55 In fact, even the name of the maneuvering reentry vehicle is uncertain. It is sometimes called Igla. However, this may be incorrect since Igla is the name of a man-portable air defense system.

56 This has been confirmed by U.S. officials involved in New START negotiations.

57 For a useful, if slightly dated review, see "A Conversation With Dr. Mark Lewis United States Air Force Chief Scientist," *AIAA HyTASP Newsletter* 1, no. 1 (April 2008): 5–17, https://info.aiaa.org/tac/pc/HYTAPC/Newsletter/April_2008_HyTASP_Newsletter.pdf. Since this review was published the British-designed SABRE propulsion system (which burns oxygen condensed from the atmosphere in a rocket engine) has made a number of headlines. See, for example, Jonathan Amos, "Skylon Spaceplane Engine Concept Achieves Key Milestone," BBC News, November 28, 2012, www.bbc.co.uk/news/science-environment-20510112.

58 In this regard, the German SHEFEX (Sharp Edge Flight EXperiment) program, which involves testing a series of progressively more sophisticated hypersonic gliders, is particularly interesting. See DLR, "Shefex," www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10548//year-all.

59 James M. Acton, "Bombs Away? Being Realistic About Deep Nuclear Reductions," *Washington Quarterly* 35, no. 2 (Spring 2012): 47, http://csis.org/files/publication/twq12springacton.pdf.

60 Lennox, *Jane's Strategic Weapon Systems*, 58.

61 Notably, longer-range Agni missile variants are reportedly equipped with terminal guidance systems that use both radar and GPS. Lennox, *Jane's Strategic Weapon Systems*, 58.

62 Ibid., 128.

63 Compare, for example, ibid. to Richard Fisher Jr., "Pakistan's Long Range Ballistic Missiles: A View From IDEAS," International Assessment and Strategy Center, November 1, 2004, www.strategycenter.net/printVersion/print_pub.asp?pubID=47.

CHAPTER 5

1 Personal communication, senior Bush administration official, April 2013.

2 For a summary of Congressional actions on the Conventional Trident Modification see Amy F. Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues*, CRS Report for Congress, R41464 (Washington, DC: Congressional Research Service, February 13, 2012), 21–24 (the latest version of this report is available from www.fas.org/sgp/crs/nuke/R41464.pdf). For a summary of Congressional concerns see M. Elaine Bunn and Vincent A. Manzo, *Conventional Prompt Global Strike: Strategic Asset or Unusable Liability?* Strategic Forum 263 (Institute for National Security Studies, National Defense University, February 2011), 14–15, http://csis.org/files/media/csis/pubs/110201_manzo_sf_263.pdf.

3 Not only is there a lack of evidence, but the few relevant historical examples provide fodder for both sides of the debate. Keith Payne, Thomas Scheber, Mark Schneider, David Trachtenberg, and Kurt Guthe, *Conventional Prompt Global Strike: A Fresh Perspective* (Arlington, VA: National Institute Press, June 2012), 47–48, www.nipp.org/Publication/Downloads/Downloads%202012/CPGS_REPORT%20for%20web.pdf, cite the Soviet/Russian responses to two false warnings of a U.S. missile launch (in 1983 and 1995) as evidence that Russia would be likely to react cautiously to indications of a possible nuclear attack. However, critics of CPGS could equally well argue that the very fact these incidents occurred at all is worrying and demonstrates the potential for unforeseen chain of events to raise the risk of an accidental nuclear launch.

4 For insightful discussions on this question see Keith Payne et al., *Conventional Prompt Global Strike*, 22–29 and 38–48; Bunn and Manzo, *Conventional Prompt Global Strike*, 14–17; Joshua Pollack, "Evaluating Conventional Prompt Global Strike," *Bulletin of the Atomic Scientists* 65, no. 1 (January/February 2009): 18–19, http://bos.sagepub.com/content/65/1/13.full.pdf+html; and Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strik*e: *Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 71–77, www.nap.edu/catalog.php?record_id=12061.

5 White House, *Report on Conventional Prompt Global Strike in Response to Condition 6 of the Resolution of Advice and Consent to Ratification of the New START Treaty*, February 2, 2011, 9–10.

6 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 75.

7 Mark A. Stokes, *China's Nuclear Warhead Storage and Handling System* (Project 2049 Institute, March 12, 2010), 12, http://project2049.net/documents/chinas_nuclear_warhead_storage_and_handling_system.pdf.

8 China's recent White Paper on defense repeated a long-standing formulation that "if China comes under a nuclear threat, the nuclear missile force will act upon the orders of the [Central Military Commission], go into a higher level of readiness, and get ready for a nuclear counterattack to deter the enemy from using nuclear weapons against China." Information Office of the State Council, People's Republic of China, *The Diversified Employment of China's Armed Forces*, April 16, 2013, sec. 3, official translation available from www.china.org.cn/government/whitepaper/2013-04/16/content_28556880.htm.

9 China's JL-2 SLBM is expected to enter service in 2013, creating the possibility that its Jin-class SSBNs (ballistic missile submarines) will start to conduct regular patrols. Office of the Secretary of Defense, U.S. Department of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, Annual Report to Congress, 31, www.defense.gov/pubs/2013_China_Report_FINAL.pdf. This could have mixed implications for warhead ambiguity. On the one hand, assuming these missiles are mated with warheads, it is conceivable they could give China the capability to launch a rapid nuclear response on warning of an attack, although China might not adopt launch procedures that allowed such a response. UK SSBNs, for example, are on "several days' 'notice to fire.'" *The Future of the United Kingdom's Nuclear Deterrent*, Cm 6994 (December 2006), 13, www.gov.uk/government/uploads/system/uploads/attachment_data/file/27378/DefenceWhitePaper2006_Cm6994.pdf. On the other hand, by enhancing the survivability of China's nuclear forces, regular SSBN patrols could help ease Chinese concerns about the survivability of its nuclear forces and thus help mitigate the risk of warhead ambiguity (especially since missile-delivered nuclear warheads could not hold SSBNs at risk).

10 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 73.

11 Ibid., 11–12.

12 Ibid., 74.

13 Payne et al., *Conventional Prompt Global Strike*, 46–48.

14 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 75.

15 Ibid.
16 See, for example, Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China* 2013, 29–32 as well as versions of this report from earlier years.
17 Pavel Podvig, "Russia and the Prompt Global Strike Plan," *PONARS Policy Memo* 417, December 2006, 2, http://csis.org/files/media/csis/pubs/pm_0417.pdf.
18 Ibid., 2. For the classic discussion of complexity and tight coupling and their role in nuclear accidents see Scott D. Sagan, *The Limits of Safety: Organizations, Accidents and Nuclear Weapons* (Princeton, NJ: Princeton University Press, 1993), 32–36.
19 Bruce M. Sugden, "Speed Kills: Analyzing the Deployment of Conventional Ballistic Missiles," *International Security* 34, no. 1 (Summer 2009): 143. Sugden supports the CPGS concept but also views warhead ambiguity as a potential problem.
20 Theodore A. Postol, "An Evaluation of the Capabilities and Limitations of Non-Nuclear-Armed Trident Ballistic Missiles," presentation, October 5–6, 2006, 21–43, www.aaas.org/cstsp/files/GlobalStrikeSystemOverviewBriefing_October5-6,2006_October3,2006-01.pdf.
21 Pollack, "Evaluating Conventional Prompt Global Strike," 19. Italics in the original.
22 See, for example, Payne et al., *Conventional Prompt Global Strike*, 38–48. Given the report appears to argue for CPGS strikes against China as part of a campaign to disable Beijing's anti-access/area-denial capabilities (p. 8), its failure to evaluate the warhead ambiguity problem in relation to strikes on China is unfortunate.
23 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 216–18.
24 See, for example, Payne et al., *Conventional Prompt Global Strike*, 22–29; White House, *Report on Conventional Prompt Global Strike in Response to Condition 6 of the Resolution of Advice and Consent to Ratification of the New START Treaty*, 9–11.
25 Interviews with Chinese experts, Beijing, February 2012.
26 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 73.
27 Office of the Assistant Secretary of Defense (Public Affairs), U.S. Department of Defense, transcript of briefing with Robert Gates and James Cartwright, September 17, 2009, www.defense.gov/transcripts/transcript.aspx?transcriptid=4479.
28 Yevgeny Miasnikov, "Precision-Guided Conventional Weapons" in *Nuclear Reset: Arms Reduction and Nonproliferation*, eds. Alexei Arbatov and Vladimir Dvorkin, trans. ed. Natalia Bubnova, (Moscow: Carnegie Moscow Center, 2012), 437, http://carnegieendowment.org/files/nuclear_reset_Book2012_web.pdf. The Minotaur IV Lite launch vehicle, used for Hypersonic Technology Vehicle-2 flight tests, is a retired MX/Peacekeeper ICBM. The first two stages of the Strategic Target System booster, used for Advanced Hypersonic Weapon flight tests, come from retired Polaris A3 missiles.
29 The 2011 White House report on CPGS states that the "[t]he [Conventional Strike Missile] *could* use a commercial booster." White House, *Report on Conventional Prompt Global Strike in Response to Condition 6 of the Resolution of Advice and Consent to Ratification of the New START Treaty*, 10. Italics mine.
30 Payne et al., *Conventional Prompt Global Strike*, 26–28.
31 Ibid., 43, claims that Russia has some "over-the-horizon missile radars." However, according to Podvig (who was the source of most of the information about Russian early warning in this report), no Russian over-the-horizon radars are part of its missile early-warning system; they are for coastal defense. The Soviet Union did try to use over-the-horizon radars for missile early-warning, but discovered they could not detect individual reentry vehicles and had only limited utility against a large-scale first strike. Personal communication, Pavel Podvig (April 2013).
32 Bunn and Manzo, *Conventional Prompt Global Strike*, 17. Italics in original.

33 See chapter 2, note 39.
34 See his remarks as quoted in Elaine M. Grossman, "U.S. Navy Brass: No Technical Fixes to Avoid Ambiguous Missile Launches," Global Security Newswire, March 16, 2012, www.nti.org/gsn/article/us-navy-brass-no-technical-fixes-avoid-ambiguous-ballistic-missile-launches.
35 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 72.
36 For a reference to warhead ambiguity by President Vladimir Putin see Vladimir Putin, Address to the Russian Federal Assembly, Moscow, May 10, 2006, official translation available from http://archive.kremlin.ru/eng/speeches/2006/05/10/1823_type70029type82912_105566.shtml. See also Sergei Lavrov, "New START Treaty in the Global Security Matrix: The Political Dimension," *Mezhdunarodnaya Zhizn* 7 (July 2010), official translation available from www.mid.ru/brp_4.nsf/e78a48070f128a7b43256999005bcbb3/25909cfe1bbd1c6ec325777500339245?OpenDocument.
37 Miasnikov, "Precision-Guided Conventional Weapons," 432.
38 Vladimir Dvorkin, "Reducing Russia's Reliance on Nuclear Weapons in Security Policies," in *Engaging China and Russia on Nuclear Disarmament*, eds. Cristina Hansell and William C. Potter, Occasional Paper 15, (Monterey, CA: James Martin Center for Nonproliferation Studies, Monterey Institute of International Studies, 2009), 100, http://cns.miis.edu/opapers/op15/op15.pdf.
39 For a discussion of this program see Jim Nichol, *Russian Military Reform and Defense Policy*, CRS Report for Congress, R42006 (Congressional Research Service, August 24, 2011), 12–13, www.fas.org/sgp/crs/row/R42006.pdf. The State Armaments Program for 2011–2020 calls for the procurement of 56 divisions of S-400 air defense systems and 10 divisions of S-500 systems. Vladimir Shabanov, "Major Army Modernization Program to Cost Russia Over 20 Trillion," *Pravda*, March 1, 2011, http://english.pravda.ru/business/finance/01-03-2011/117052-russian_army-0.
40 *The Military Doctrine of the Russian Federation*, February 5, 2010, para. 27.f, translation available from http://carnegieendowment.org/files/2010russia_military_doctrine.pdf.
41 Alexei Arbatov, Vladimir Dvorkin, and Sergey Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament: Ballistic Missile Defense, High-Precision Conventional Weapons, Space Arms* (Moscow: IMEMO RAN, 2010), 26, www.nuclearsecurityproject.org/uploads/publications/NON_NUCLEARFACTORSOFNUCLEARDISARMAMENT_062210.pdf.
42 Miasnikov, "Precision-Guided Conventional Weapons," 432–33.
43 Yao Yunzhu, "China Will Not Change Its Nuclear Policy," *China-U.S. Focus*, April 22, 2013, www.chinausfocus.com/peace-security/china-will-not-change-its-no-first-use-policy.
44 Rong Yu and Peng Guangqian, "Nuclear No-First-Use Revisited," *China Security* 5, no. 1 (Winter 2009): 85, http://mercury.ethz.ch/serviceengine/Files/ISN/97889/ichaptersection_singledocument/3ee6fe17-087c-40e4-ab61-9ddfb1e917fa/en/Rong_Peng.pdf.
45 For an analysis written by a Chinese expert that discusses, in great detail, the potential threat posed by a variety of cruise missiles, gravity bombs and potential CPGS systems see Tong Zhao, "Conventional Counterforce Strike: An Option for Damage Limitation in Conflicts With Nuclear-Armed Adversaries?" *Science and Global Security* 19, no. 3 (2011): 195–222, http://scienceandglobalsecurity.org/archive/sgs19tongzhao.pdf.
46 Second Artillery Corps, People's Liberation Army, *The Science of Second Artillery Campaigns* [in Chinese] (Beijing: PLA Press, 2004), 356.
47 Ibid., 357.
48 Ibid., 364.
49 Lora Saalman, *China and the U.S. Nuclear Posture Review*, Carnegie Paper (Beijing: Carnegie-Tsinghua Center for Global Policy, February 2011), 8–9, http://carnegieendowment.org/files/china_posture_review.pdf. By contrast, two other American analysts, Elbridge Colby and Abraham Denmark, report that, during a series of interviews two years later, "there was very little discussion of the conventional prompt global strike as a potential threat to China's strategic deterrent." Elbridge A. Colby, Abraham M. Denmark, John K. Warden et al., *Nuclear Weapons and U.S.-China Relations:*

A Way Forward (Washington, DC: Center for Strategic and International Studies, March 2013), 39, http://csis.org/files/publication/130307_Colby_USChinaNuclear_Web.pdf.

50 A. I. Antonov, remarks, NATO-Russia Council Meeting, 2007 (now available from http://web.archive.org/web/20080704102317/http://www.nato-russia-council.info/htm/EN/news_33.shtml).

51 Yao, "China Will Not Change Its Nuclear Policy." See also M. Taylor Fravel and Evan S. Medeiros, "China's Search for Assured Retaliation: The Evolution of Chinese Nuclear Strategy and Force Structure," *International Security* 35, no. 2 (Fall 2010): 83; the comments by Fan Jishe, quoted in Saalman, *China and the U.S. Nuclear Posture Review*, 23.

52 Saalman, *China and the U.S. Nuclear Posture Review*, 22–23.

53 Alexei Arbatov, *Gambit or Endgame? The New State of Arms Control*, Carnegie Paper (Moscow: Carnegie Moscow Center, March 2011), 21, www.carnegieendowment.org/files/gambit_endgame.pdf.

54 Arbatov, Dvorkin, and Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament*, 34.

55 Arbatov, *Gambit or Endgame?*, 20. He goes on to add that "Ohio-class submarines [some of which have been converted to carry cruise missiles] are designed to stay on patrol for long periods of time and to remain undetectable even to sophisticated anti-submarine warfare systems, and heavy bombers are capable of penetrating advanced air defenses. Rogue states and terrorists possess neither anti-submarine warfare nor serious air-defense systems" (pp. 21–22).

56 Yao, "China Will Not Change Its Nuclear Policy." Quoted material can be found in *National Defense Authorization Act for Fiscal Year 2013*, Public Law 112-239, 112th Cong. (January 2, 2013), sec. 1045, para.(a).(1), www.gpo.gov/fdsys/pkg/PLAW-112publ239/pdf/PLAW-112publ239.pdf.

57 See, for example, U.S. House of Representatives Armed Services Committee, *National Defense Authorization Act for Fiscal Year 2008 and Oversight of Previously Authorized Programs: Budget Request from the U.S. Strategic Command, Northern Command, Transportation Command, and Southern Command*, HASC no. 110-40, 110th Cong., 1st sess., March 21, 2007, 5–6, www.gpo.gov/fdsys/pkg/CHRG-110hhrg37320/pdf/CHRG-110hhrg37320.pdf.

58 Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, *Report of the Defense Science Board Task Force on Future Strategic Strike Skills*, February 2004, 2-4, www.acq.osd.mil/dsb/reports/ADA421606.pdf. Chinese and Russian fears are probably further exacerbated when similar statements are made by nongovernmental analysts who, at various points in their careers, also served within the U.S. government. See, for example, Keith B. Payne, *The Fallacies of Cold War Deterrence and a New Direction* (Lexington, KY: University of Kentucky Press, 2001), 181.

59 U.S. Department of Defense, *Nuclear Posture Review Report*, 2010, 34.

60 Ibid., 28–29.

61 Arbatov, *Gambit or Endgame?* 14–15 and 21–22.

62 Fravel and Medeiros, "China's Search for Assured Retaliation," 75–85. James Schlesinger, who served as secretary of defense under Presidents Richard Nixon and Gerald Ford, made a similarpoint during Senate hearings on New START when he said that "in dealing with the major powers, China and Russia, we must be careful, I think, not to convey to them that we are threatening their retaliatory capability. . . . It's not because we would not like to have an impenetrable defense, as President Reagan had hoped for. It's just beyond our capability. They can always beat us with the offensive capabilities." U.S. Senate Foreign Relations Committee, *The New START Treaty*, S. HRG. 111-738, 111th Cong., 2nd sess., May 18, 2010, 25, www.gpo.gov/fdsys/pkg/CHRG-111shrg62467/pdf/CHRG-111shrg62467.pdf.

63 Colby, Denmark, Warden et al., *Nuclear Weapons and U.S.-China Relations*, 12–13.

64 For a summary of this debate see ibid., 30–32. Among Chinese sources, see, in particular, Rong and Peng, "Nuclear No-First-Use Revisited," 85.

65 Yao, "China Will Not Change Its Nuclear Policy."

66 U.S. Department of Defense, *Nuclear Posture Review Report*, 2010, 27 and 30.

67 For statements by senior Russian officials see, for example, "Russia Rejects Independent Nuke Curbs," Global Security Newswire, September 7, 2012, www.nti.org/gsn/article/russia-rejects-

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69 U.S. Department of Defense, *Nuclear Posture Review Report*, 2010, 29.

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72 Second Artillery Corps, *The Science of Second Artillery Campaigns*, 294.

73 Putin, "Being Strong."

74 Rogov, Esin, Zolotarev, and Yarynich, "Sood'ba Stratyegichyeskih Vooroozhyeniy Poslye Pragi." The 2010 version of Russia's Military Doctrine was widely perceived to have slightly raised—not lowered—the nuclear threshold relative to the previous iteration, which was published in 2000. Rogov et al. are presumably, therefore, comparing the 2010 doctrine to either the 1993 version (which did assign a smaller role for nuclear weapons) or to Soviet policy toward the end of the Cold War (which included a no-first-use pledge). For a comparison of the 2010 doctrine to its predecessors see Nikolai Sokov, "The New, 2010 Russian Military Doctrine: The Nuclear Angle," CNS *Feature Story*, James Martin Center for Nonproliferation Studies, February 5, 2010, http://cns.miis.edu/stories/100205_russian_nuclear_doctrine.htm.

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76 U.S. Department of Defense, *Quadrennial Defense Review Report*, February 2010, 32, www.defense.gov/qdr/images/QDR_as_of_12Feb10_1000.pdf. The most detailed publicly available discussion is Air-Sea Battle Office, "Air-Sea Battle: Service Collaboration to Address Anti-Access & Area Denial Challenges," May 2013, http://navylive.dodlive.mil/files/2013/06/ASB-ConceptImplementation-Summary-May-2013.pdf. A "point of departure" written by analysts at a think tank closely connected to the Pentagon is Jan van Tol, with Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, DC: Center for Strategic and Budgetary Assessments, 2010), www.csbaonline.org/wp-content/uploads/2010/05/2010.05.18-AirSea-Battle.pdf.

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83 Jaganath Sankaran, "Debating Space Security: Capabilities and Vulnerabilities" (PhD thesis, University of Maryland, 2012): 78–93, http://cissm.umd.edu/papers/files/sankaran_debating_space_securitycapbilities_and_vulnerabilities.pdf.

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87 Payne et al., *Conventional Prompt Global Strike*, 9–12.

88 Michael S. Gerson, "Conventional Deterrence in the Second Nuclear Age," *Parameters* XXXIX (Autumn 2009): 36–39, http://strategicstudiesinstitute.army.mil/pubs/parameters/Articles/09autumn/gerson.pdf.

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93 Committee on Conventional Prompt Global Strike Capability et al., *U.S. Conventional Prompt Global Strike*, 81.

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Kamphausen, eds., *Chinese Lessons from Other Peoples' Wars* (Carlisle, PA: Strategic Studies Institute, U.S. Army War College, 2011), www.strategicstudiesinstitute.army.mil/pdffiles/PUB1090.pdf.

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102 The United States and Russia already have extensive experience of such inspections under three bilateral arms control agreements (the Intermediate Nuclear Forces Treaty, START, and New START).

103 See, for example, the comments by Rose Gottemoeller, acting U.S. under secretary of state for arms control and international security, at 31 mins., 45 secs. during the panel discussion on *Prague 2.0? Deterrence, Disarmament, and Nonproliferation in Obama's Second Term* (Carnegie International Nuclear Policy Conference, Washington, DC, April 8, 2013), 77 min., 35 sec.; http://carnegieendowment.org/2013/04/08/prague-2.0-deterrence-disarmament-and-nonproliferation-in-obama-s-second-term/fv9q.

104 Miasnikov, "Precision-Guided Conventional Weapons," 451; James M. Acton, "The Dragon Dance: U.S.-China Security Cooperation," in *Global Ten: Challenges and Opportunities for the President in 2013*, ed. Jessica T. Matthews, (Washington, DC: Carnegie Endowment for International Peace, 2012), 123–25, http://carnegieendowment.org/files/global_ten.pdf; James M. Acton, ed., *Beyond Treaties: Immediate Steps to Reduce Nuclear Dangers*, Policy Outlook (Washington, DC: Carnegie Endowment for International Peace, October 2012), http://carnegieendowment.org/files/beyond_treaties.pdf; Arbatov, Dvorkin, and Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament*, 36–38; Dennis M. Gormley, *The Path to Deep Nuclear Reductions: Dealing With American Conventional Superiority*, Proliferation Papers 29 (Paris: Ifri, 2009), 38–44, www.ifri.org/downloads/pp29gormley1.pdf.

105 For details of the most recent agreement see Organization for Security and Cooperation in Europe, *Vienna Document 2011: On Confidence- and Security-Building Measures*, November 30, 2011, sec. I, www.osce.org/fsc/86597.

106 For a similar idea applied to ballistic missile defense see Steven Pifer, "The United States Should Make Annual Declarations to Russia of Its Missile Defense Plans," in *Beyond Treaties*, ed. Acton, 3.

107 Arbatov, Dvorkin, and Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament*, 37.

108 Acton, "The Dragon Dance," 123–25.

109 New START, Article IV.11.

110 Eugene Miasnikov, "Russia and the United States Should Agree to Apply New START's Basing Restrictions and Data Exchanges to Heavy Bombers, Such as the B-1B, That Are No Longer Accountable Under the Treaty," in *Beyond Treaties*, ed. Acton, 6–7.

111 Arbatov, Dvorkin, and Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament*, 36.

112 This phrase is used, for example, in Madeleine Albright with Bill Woodward, *Madam Secretary* (New York: Miramax Books, 2003), 256.

113 Arbatov, Dvorkin, and Oznobishchev, *Non-Nuclear Factors of Nuclear Disarmament*, 37.

114 For the latest iteration see Organization for Security and Co-operation in Europe, *Vienna Document 2011*, section VI.

115 Shirley A. Kan, *U.S.-China Military Contacts: Issues for Congress*, CRS Report for Congress, RL32496 (Congressional Research Service, April 17, 2013), 19–22, www.fas.org/sgp/crs/natsec/RL32496.pdf.

116 Miasnikov, "Precision-Guided Conventional Weapons," 444.

117 James M. Acton and Elbridge Colby, "The U.S. and Russian National Academies Should Conduct a Joint Study Into Whether Conventional Cruise Missiles Pose a Realistic Threat to Silos," in *Beyond Treaties*, ed. Acton, 5.

118 Acton and Colby, "The U.S. and Russian National Academies Should Conduct a Joint Study Into Whether Conventional Cruise Missiles Pose a Realistic Threat to Silos," 5.

119 For a detailed account see Richard Weitz, "Illusive Visions and Practical Realities: Russia, NATO and Missile Defence," *Survival* 52, no. 4, (August–September 2010): 108–112.
120 Susan Cornwell and Jim Wolf, "U.S. Invites Russia to Measure Missile-Defense Test," Reuters, October 18, 2011, www.reuters.com/article/2011/10/18/us-russia-usa-missiles-idUSTRE79H80D20111018.
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122 For a summary of the attempts to initiate dialogue see Acton, "The Dragon Dance," 119–20.
123 *National Defense Authorization Act for Fiscal Year 2012*, Public Law 112–81, 112th Cong. (December 31, 2011), sec. 1244, www.treasury.gov/resource-center/sanctions/Programs/Documents/ndaa_publaw.pdf.
124 Interestingly, Saalman notes that New START's limits on conventional ballistic missiles were dismissed "as ineffectual, not comprehensive enough, or entirely missed" by Chinese commentators. Saalman, *China and the U.S. Nuclear Posture Review*, 22. It would be important, therefore, for Washington to explain to Beijing the "positive externalities" of any future U.S.-Russian agreement.
125 Protocol to New START, part I, para. 6.
126 U.S. Senate, *Treaty With Russia on Measures for Further Reduction and Limitation of Strategic Offensive Arms* (The New START Treaty), Report, EXEC. REPT. 111-6, 111th Cong., 2nd sess. (October 1, 2010), 51–57, www.foreign.senate.gov/download/?id=4C65B25B-F3E8-4CF6-8660-36E21D639ECC.
127 New START, article V.2.
128 Thomas Moore, "New START and 'New Kinds,'" Arms Control Wonk, February 5, 2013, http://guests.armscontrolwonk.com/archive/3385/new-start-and-new-kinds. A similar provision was also included in START I. See START I, Agreed Statements Annex, statement 2.
129 One obvious difficulty would be agreeing how many conventional ballistic missiles should be attributed to each attack submarine. This could become especially contentious if the United States decided to base conventional ballistic missiles on some submarines but not on others.
130 START I, article V.18.(a).
131 In its preamble, New START acknowledges an "interrelationship between strategic offense arms and strategic defensive arms." Article V.3 also bans the placement of missile interceptors in SLBM or ICBM launchers.
132 U.S. Senate, *Treaty With Russia on Measures for Further Reduction and Limitation of Strategic Offensive Arms*, 114.
133 Ibid.

APPENDIX

1 U.S. Department of the Navy, *Fiscal Year (FY) 2007 Budget Estimates Submission: Research, Development, Test & Evaluation, Navy Budget Activity 4*, February 2006, 814 (PE 0604327N), www.finance.hq.navy.mil/FMB/07pres/RDTEN/RDTEN_BA4_book.pdf.
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3 U.S. Department of the Navy, *Fiscal Year (FY) 2007 Budget Estimates Submission: Weapons Procurement, Navy*, February 2006, 13 (1250-Trident II Modifications), www.finance.hq.navy.mil/FMB/07pres/PROC/WPN_BOOK.PDF.
4 Elaine M. Grossman, "Pentagon Wants Early Start on Conventional Missiles for Subs," InsideDefense.com, January 20, 2006.

5 The linear dimensions of the cross-section of the Virginia-class hull are, on average, a factor of about 0.83 smaller than the equivalent dimensions of the Ohio-class hull. Richard Sharpe, ed., J*ane's Fighting Ships 2000–2001*, 103rd ed. (Coulsdon: Jane's Information Group, 2000), 788 and 792. If the latter can accommodate a missile no longer than 13.4 m (the length of a Trident D5 missile) then the former can probably accommodate a missile that is shorter than 11 m or so.

6 Committee on Conventional Prompt Global Strike Capability, Naval Studies Board, and Division on Engineering and Physical Sciences, National Research Council of the National Academies, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, DC: National Academies Press, 2008), 109, www.nap.edu/catalog.php?record_id=12061.

7 Ibid., 111. The National Research Council was concerned that the "slenderness" (length-to-diameter ratio) of the U.S. Navy's proposed Sea-Launched Global Strike Missile was too great and so conducted this study to explore the trade-offs among shorter, less slender missiles.

8 The launch tubes in the Virginia Payload Module will apparently be able to hold the same number of Tomahawk cruise missiles (seven) as the launch tubes in Ohio-class SSGNs. Ronald O'Rourke, *Navy Virginia (SSN-774) Class Attack Submarine Procurement: Background and Issues for Congress*, CRS Report for Congress, RL32418 (Congressional Research Service, March 1, 2012), 7 (the latest version of this report is available from www.fas.org/sgp/crs/weapons/RL32418.pdf). Given that a slight change in launch tube diameters would necessitate an expensive redesign of cruise missile launch equipment, it is likely that, in fact, they have identical diameters.

9 Detection distances are further shortened because early warning radars are actually tilted slightly upward to avoid the effects of "ground clutter." See, for example, Zia Mian, R. Rajaraman, and M. V. Ramana, "Early Warning in South Asia—Constraints and Implications," *Science and Global Security* 11, nos. 2–3 (2003): 122, www.princeton.edu/sgs/publications/sgs/pdf/11%202-3%20Mian%20 p109-150.pdf. For the U.S. Pave Paws radar, the center of the beam (which is 2° in width) can be oriented to as low as 3° to the horizontal. Missile Defense Agency, *National Missile Defense Deployment: Final Environmental Impact Statement*, July 1, 2000, vol. 4, appendix H, 1-6 , www.mda.mil/global/documents/pdf/env_gmd_eis_append_h.pdf.

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