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Conventional Counterforce Strike: An Option for Damage Limitation in Conflicts with Nuclear-Armed Adversaries?

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China and some other nuclear-armed countries have become concerned about the development and deployment of U.S. conventional global strike systems that may permit damage limitation operations against the nuclear forces of adversaries. This article argues that a counterforce strike is more likely to target tactical nuclear forces than intercontinental ballistic missiles and provides an analysis of the probability that U.S. conventional strikes might destroy China's theater nuclear forces which include DF-3A, DF-4, DF-21, DF-31 missiles, Type 094 nuclear submarines, and nuclear-capable H-6 bombers. The results indicate that China's strategy of building robust underground facilities may effectively protect its nuclear forces from preemptive strikes making it unlikely that a U.S. conventional strike could destroy a meaningful part of China's theater nuclear forces. This study also assesses the potential capabilities of future conventional prompt global strike systems, points out problems with the strategy of damage limitation, and proposes that the United States consider improving strategic stability in its relationship with China rather than threatening a preemptive strike.

The United States has become increasingly interested in pursuing development of conventional weapons for targeting time-sensitive targets or targets that are hardened and deeply buried and against potential adversaries' nuclear forces. The Obama administration's 2010 Nuclear Posture Review Report states that "[non-nuclear prompt global strike] capabilities may be particularly valuable for the defeat of time-urgent regional threats."[1] The concept of

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conventional prompt global strike, for example, is indicative of such interests and efforts.[2] The report on conventional strike produced by the Defense Science Board explicitly includes the scenario of using conventional strike to preempt perceived nuclear missile attack from a regional power.[3] A National Research Council report suggests keeping the option of using conventional prompt global strike weapons against Russia's and China's "critical targets" on the table. It claims that the risks associated with such conventional strike are "sufficiently low and manageable," and "they do not constitute a reason to forgo acquiring the capability."[4]

If achievable, a conventional counterforce capability will provide the United States the option to eliminate a perceived imminent nuclear threat without having to risk the cost of initiating a nuclear war. Conventional weapons, it is argued, will permit the United States to "conduct a counterforce strike without crossing the nuclear threshold, and without killing millions."[5] A conventional counterforce strategy has problems, however. The most prominent of which is that the pursuit of conventional counterforce capability might raise concerns about survivability of nuclear forces and encourage countries to maintain large nuclear arsenals. For years, Russia has been concerned its nuclear deterrence could be undermined under the scenario of conventional counterforce strike.[6]

Conflicting views about conventional global strike weapons have already troubled the movement for deep nuclear reductions. After the United States and Russia concluded the New START Treaty in April 2010, it was pointed out that further reductions beyond the New START level would not be achievable until China joins the two previous nuclear superpowers in a multilateral nuclear disarmament process.[7] China's participation in discussions about nuclear disarmament probably will not happen if its concern about U.S. conventional counterforce capability cannot be adequately addressed.

This article assesses the potential of conventional global strike weapons and their impact on China's nuclear weapons capabilities, looking in particular at the vulnerability of China's theater nuclear forces, perhaps a more realistic concern than the potential of U.S. use of precision-guided bombs to eliminate China's intercontinental ballistic missiles (ICBM).[8]

It is widely believed that the only scenario under which the use of nuclear weapons might be considered between the United States and China is an escalation of a conventional conflict over Taiwan. From the U.S. perspective, if China faces a catastrophic defeat using conventional weapons in a regional conflict over Taiwan, China might want to use nuclear weapons to reverse the situation on the battlefield. Under such circumstances, if the United States believes the use of nuclear weapons by China against U.S. military assets near Taiwan is imminent and unavoidable, the United States might be forced to preemptively destroy China's nuclear forces that are most likely to be used against them in order to limit the potential damage to U.S. military capabilities. Or, if China had already launched a nuclear attack against U.S. military assets near Taiwan, the United States would want to quickly destroy the rest of China's nuclear forces to prevent further offensive strikes. In either case, the target of U.S. counterforce strikes are theater nuclear forces as China is not likely to use its ICBMs under these circumstances.

Official Chinese documents do not include the category "theater nuclear forces." This term is used here to describe those Chinese nuclear weapons that cannot reach the continental United States, such as China's medium or intermediate range nuclear missiles (MRBM and IRBM, respectively), nuclear-capable bombers, and possibly ballistic missile nuclear submarines.[9] These theater nuclear weapons pose real threats to U.S. military assets in the Asia-Pacific. China's ICBMs, including a handful of silo-based DF-5 missiles and newly introduced land-mobile DF-31A missiles, are generally reserved for retaliatory strikes against continental U.S. targets in an all-out nuclear war.

A summary of China's current theater nuclear weapons is provided in Table 1. U.S. conventional precision-guided weapon systems are summarized in Tables 2 and 3.

Table 1: China's theater nuclear forces[1]

Type/Chinese designation (US designation)	No. deployed	Year first deployed	Range (km)	Warhead loading	No. of warheads
Land-based missiles	*99*				*99*
DF-3A (CSS-2)	12	1971	3100	1 × 3.3 Mt	12
DF-4 (CSS-3)	12	1980	5500	1 × 3.3 Mt	12
DF-21 (CSS-5)	60	1991	2100[2]	1 × 200–300 kt	60
DF-31 (CSS-10 Mod 1)[3]	∼15	2006	>7200	1 × . .	15
SLBMs	(*36*)				(*36*)
JL-1 (CSS-N-3)	(12)	1986	>1770	1 × 200–300 kt	(12)
JL-2 (CSS-NX-14)[4]	(24)	(2010)	>7200	1 × . .	(24)
Aircraft	>*20*				(*40*)
H-6 (B-6)	20	1965	3100	1 × bomb	(20)

[1]Adapted from Stockholm International Peace Research Institute, *SIPRI yearbook 2010: Armaments, disarmaments and international security* (Oxford: Oxford University Press, 2010). ". ." = not available or not applicable; () = uncertain figure; SLBM = submarine-launched ballistic missile.

[2]The DF-21A missile (CSS-5 Mod 2) variant is believed to have a range of up to 2500 km.

[3]The DF-31 missile is classified as a theater system because China defines DF-31 as a long-range ballistic missile, not an intercontinental ballistic missile. Its range is likely to be too short to reach the continental United States. It is believed to be primarily used for regional targeting, not targeted primarily at the continental United States. Also, the DF-31 missile is generally regarded as a replacement for the older DF-4 missile, which only has a regional role.

[4]It is difficult to categorize the JL-2 SLBM. Some sources believe this missile is capable of reaching the continental United States, even when launched from waters close to China. On the other hand, the missile can also be used to target nearer targets such as Guam or used in a hypothetical regional conflict over the Taiwan Strait. Ultimately, it depends on whether or not the United States would perceive the JL-2 missile as a threat in a theater battlefield over Taiwan.

Table 2: Existing and near-future U.S. conventional precision munitions delivery systems[1]

Delivery systems	Potential number of delivery systems (by 2015)
B-2	16
Los Angeles-class submarine (SSN-688)	7
Providence-class submarine (SSN-719)	31
Virginia-class submarine (SSN-774)	10–12
Ohio-class ballistic missile submarine	4
B-52H	44
Total	*112–114*

[1]Yevgeny Miasnikov, "The Counterforce Potential of Precision-Guided Munitions," in *Nuclear Proliferation: New Technologies, Weapons, Treaties*, edited by Alexei Arbatov and Vladimir Dvorkin (Moscow: Carnegie Moscow Center, 2009); Robert S. Norris and Hans M. Kristensen, "U.S. Nuclear Forces, 2010," *Bulletin of the Atomic Scientists* (May/June): 57.

SURVIVABILITY OF CHINA'S THEATER NUCLEAR WEAPONS UNDER U.S. CONVENTIONAL PRECISION-GUIDED STRIKES

In general, China's theater nuclear forces can be grouped into four categories: 1) land-based missiles with limited mobility; 2) land-based missiles with high mobility; 3) nuclear ballistic missile submarines; and 4) nuclear-capable aircraft. This section examines the survivability of each category in a total destruction scenario. The complete destruction of a nuclear weapon system is different from "functional defeat," which refers to causing sufficient damage to a weapon system or associated facilities so that the system is unable to function effectively. The issue of functional defeat is discussed in the following section.

Land-Based Missiles with Limited Mobility

DF-3A

DF-3A is the oldest nuclear missile in China's theater forces and is undergoing retirement. It is road-mobile and uses liquid fuel.[10] It has a range of 3,100 km and can be launched from either a permanent launch pad or a portable stand.[11] In one suspected but unidentified photograph, a DF-3A launch pad and storage garage can be observed in a relatively clear and easy-to-locate area. The suspected missile garage is an above-ground building next to a launch pad that can accommodate up to two DF-3A missiles.[12] If this is a real DF-3A missile storage and launch facility, it seems vulnerable against a potential conventional precision-guided attack. The storage garage does

Table 3: Main precision-guided weapons in the U.S. inventory[1]

Type	Weight (kg)	Penetrating munitions[2]	Range (km)	Guidance systems	CEP (m)	Delivery systems
			Guided air bombs			
MOP (Massive Ordnance Penetrator)	13600	9000 kg Warhead		INS,[3] GPS		B-52, B-2
GBU-15	1125	BLU-109	8–25	Teleguidance system, INS, GPS	~3	F-15E
GBU-31 (JDAM)	1070	BLU-109	25	INS, GPS	<6	B-1, B-2, B-52, F-14, F-15E, F-16, F-22, F/A-18
GBU-32 (JDAM)	450	BLU-110	25	INS, GPS	<6	
GBU-38 (JDAM)	225	BLU-111	25	INS, GPS	<6	
GBU-28	2115	BLU-122, BLU-113	5–40	Laser, GPS	<10	B-2, F-15E
GBU-27	1070	BLU-116, BLU-109	5–40	Laser, GPS	<10	F-15E, F-16
GBU-24	1070	BLU-116, BLU-109	5–40	Laser, GPS	<10	F/A-18, F-14
GBU-10 (EGBU-10)	1070	BLU-109	3–25	Laser, GPS	<10	B-52, F-14, F-15E, F-16, F/A-18
AGM-154B (JSOW)	450	BLU-108	<130	INS, GPS		
			Guided missiles			
AGM-130	1300	BLU-109	>65	INS, GPS, Teleguided	<3	F-15E
SLAM-ER	230	WDU-40?B	<280	INS, GPS, Teleguided	~2.5	
JASSM	450		>320	INS, GPS		
JASSM-ER	450		>800	INS, GPS		
			Long-rang cruise missiles			
TLAM (Tomahawk Land Attack Missile)	340	WDU-43/B	1600	INS, GPS, Terrain Contour Matching	~5	
Tact Tomahawk	450	WDU-43/B	1600	INS, GPS, Terrain Contour Matching	~5	
CALCM (Conventional Air Launched Cruise Missile)	1430	AUP	>1000	INS, GPS	~2.5	

[1]Yevgeny Miasnikov, "The Counterforce Potential of Precision-Guided Munitions," in *Nuclear Proliferation: New Technologies, Weapons, Treaties*, edited by Alexei Arbatov and Vladimir Dvorkin (Moscow: Carnegie Moscow Center, 2009).

[2]In this and following tables, "penetrating munitions" refers to the warhead, the part of the device that explodes after penetrating into the ground. In comparison, a "weapon" includes penetrating munitions, guidance and control unit, computer package, and other components.

[3]Inertial Navigation System.

appear to be heavily reinforced, and most of the precision-guided weapons in Table 3 should be able to penetrate and destroy the building. If the missile is on the launch pad, it would be even more vulnerable than in the garage, because the missile body is usually not protected by armor or external covers. Therefore, if DF-3A missiles are deployed in above-ground facilities that are not particularly hardened, they seem very unlikely to survive conventional precision attacks as long as the facilities are identified by the adversary.

However, it is more likely that most DF-3A missiles are deployed in more secure facilities. As Kristensen, Norris, and McKinzie point out, China has a large number of underground facilities, and "placing important assets underground in some form seems to be a common element of China's military planning."[13] Since the "Third Line Project" between 1964 and the mid- to late-1970s, China has built a large number of underground facilities in remote and mostly mountainous regions, in order to protect its most important military and industrial assets. In the late 1970s, China made another decision to construct the "Great Wall Project" which is aimed at building highly secure underground facilities for China's nuclear forces.[14] Kristensen, Norris, and McKinzie point out that, "a rule of thumb seems to be that if the base is near a mountain, then there likely will be some form of underground facility." This conclusion describes China's bomber and fighter bases, but broadly speaking, China places particular emphasis on using underground facilities to protect its nuclear forces. The "Great Wall Project" illustrates this strategy.

The "Great Wall Project" is reported to be an underground web of tunnels built in mountainous areas in China for the purpose of protecting missiles of the Second Artillery, which has the responsibility for all Chinese nuclear missiles. Beginning in the late 1970s and early 1980s, the construction of the project (or some part of the project) was reportedly completed in the 1990s. In 1995, a press report from *Jiefangjun Bao* (People's Liberation Army Daily) noted that after more than 10 years' construction by tens of thousands of Second Artillery engineer troops, a major national defense project had successfully finished. This is believed to be the first time that the "Great Wall Project" was openly reported.[15] In 2008, more than 10 years later, an official TV program "Junshi Jishi" (Military Documentary) broadcasted a documentary which revealed that an engineering unit of the Second Artillery successfully built new underground missile bastions in Kunlun Mountains in 2006 and 2007. This was widely interpreted by foreign analysts as a message that the "Great Wall Project" has been extended to the Qinghai-Tibet Plateau, and that strategic missiles have been deployed to that region.[16] Therefore, it is likely that the "Great Wall Project" does not refer to specific projects, but to a series of relatively new underground facilities built to conceal and protect missiles and other strategic assets of the Second Artillery.[17] For example, it is believed that somewhere in Northern China, there are more than 5,000 kilometers (km) of underground tunnels built into the mountains, or "Great Walls."[18]

It is likely that a significant number of DF-3A missiles are deployed in these underground "Great Walls." DF-3As are suspected to be deployed in at least four missile bases across six provinces.[19] Some of these missiles, such as those deployed in Qinghai and Liaoning provinces, are most likely targeting India and Russia.[20] Since this article considers a hypothetical U.S. preemptive attack against China's nuclear forces, it will focus on those nuclear forces whose combat radii are long enough to cover the Taiwan Strait. In the case of DF-3A missiles, at least three provinces that are suspected to have DF-3A missiles are close enough to the Taiwan Strait: Shandong, Anhui, and Yunnan.[21] All three provinces have mountains that are suitable for building underground facilities. Anhui Province, for example, is reported to have a missile base located at Huangshan which is a huge and extensive mountain made of granite over 1,200 km^2.[22]

In order to protect missiles from preemptive strikes, these underground facilities are reportedly built inside mountain bodies that are made of hard rock such as granite. The tunnels are usually located as deep as hundreds of meters under the surface.[23] Physical and functional characteristics, such as the size of different missile vehicles, were taken into account when designing the specific shape, size, and internal structure of the tunnels.[24] Based on official images of the "Great Wall Project," the underground tunnels have sufficient room for land-mobile and locomotive missile vehicles to travel freely (see Figure 1). Some sections of the tunnels are large enough to allow two locomotives or one locomotive and one land-mobile missile vehicle to travel side by side. The following analysis, therefore, assesses the robustness of these underground facilities against a hypothetical conventional precision-guided strike.

In an earth-penetrating weapon, whether it is nuclear or conventional, the warhead hits the surface of the ground at a very high speed, penetrates into the ground, and explodes. The powerful shock wave will crush tunnels within a certain range. The depth of penetration to a large extent is determined by the speed of the warhead. However, as the speed increases, the weapon material would no longer survive the severe ground impact stresses and would destroy itself before it can explode as designed. At present, the maximum impact speed for the hardest steel is about 1km/s. Under such constraint, the maximum penetration depth into reinforced concrete is roughly about four times the length of the penetrator.[25] For typical conventional earth penetrators in the current U.S. arsenal, such as BLU-109 and BLU-116, their length is about 2.4 m,[26] meaning their maximum penetration capability is about 9.6 m into reinforced concrete.[27] Accordingly, it is reasonable to assume that 10 m is approximately the maximum depth that a typical conventional precision-guided weapon can penetrate into reinforced concrete. After penetration and detonation, the range of destruction is largely proportional to the cube root of the force of the explosion.[28]

(a)

(b)

(c)

Figure 1: Images of the "Great Wall Project" from the television documentary "Junshi Jishi" produced by CCTV-7 (Military Channel of China Central Television). In Figure 1a, the English translation is, "Caves in the mountain for Second Artillery Missile Brigades" (top) and "Suddenly, an order came" (bottom).

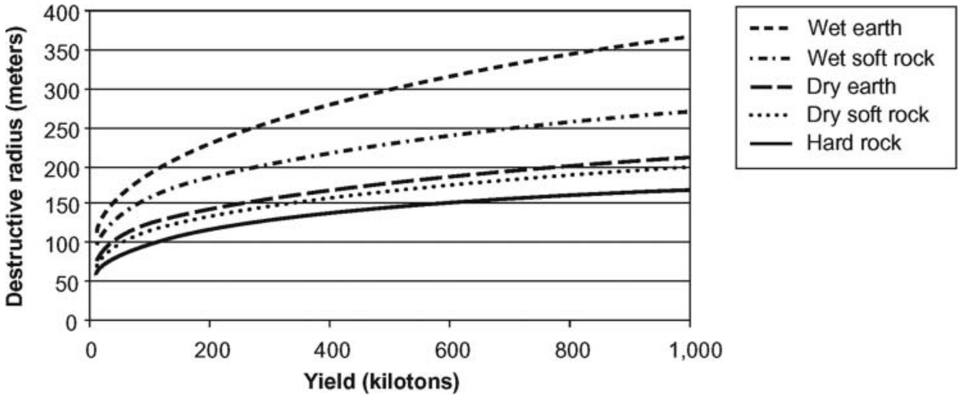

Figure 2: Range of destruction by blast of nuclear weapons detonated in less than 5 meters. (Source: Michael A. Levi, *Fire in the Hole: Nuclear and Non-nuclear Options for Counterproliferation*, Carnegie Endowment for International Peace, (2004), 13).

Figure 2 shows the relationship between weapon yield and the range of destruction.[29] As for the range of destruction, a widely used assumption is that any underground facility that is within the crater created by the explosion or in the crushed rock zone would be destroyed.[30] Even if a facility is hardened, there is little chance that it will survive if it is within the crater or in the crushed rock zone. There is certainly a possibility that a facility will still be destroyed if it is located beyond the crushed rock zone, for example, in the plastic zone.[31] Therefore, the assumption about the range of destruction is conservative, which makes the results of the analysis even more robust.

The detonation depth in Figure 2 is set as 5 m, different from the 10 m maximum penetration depth of a conventional weapon. This difference does not impact the analysis in a meaningful way because when detonation depth exceeds 1.5 m, further increases in detonation depth do not significantly improve the destructive capability of an explosion.[32] According to Figure 2, yields of approximately 10 kt (kiloton) are required in order to destroy facilities buried in granite (hard rock) 60 m below the detonation point. As noted above, the range of destruction is proportional to the yield of the warhead, and this permits an estimate for the approximate depth of destruction by conventional precision-guided weapons (see Table 4).

As shown in Table 4, a typical conventional precision-guided weapon in the current U.S. inventory has a destruction range of no more than 25 m in granite. Even the powerful Massive Ordnance Penetrator (MOP), still in development, has a destruction range of about 35 m. It seems unlikely, even under extreme circumstances (for example when a number of these weapons were to be delivered repeatedly with very high precision on a single target), that there is any chance for conventional weapons to destroy targets buried hundreds of

Table 4: Approximate destruction ranges for conventional precision-guided weapons in granite

Weapon warhead/ Penetrating munitions	Explosive weight (kg)	Yield (kg, TNT equivalent)[1]	Range of destruction (m, distance from detonation point)
BLU-109	243	365	~14
BLU-116	243 or less[2]	365 or less	<14
BLU-113	N.A.	304[3]	~14
SLAM-ER (AGM-84H)	230	345	~14
JASSM (AGM-158A)	450	675	~18
TLAM	450 or less[4]	675 or less	<18
CALCM (AGM-86C/D)	N.A.	1,300[5]	~22
MOP (Massive Ordnance Penetrator)	3,500	5,250	~36

[1]The advanced explosives that BLU-109 carries are reported to have about 18 percent and perhaps up to 50 percent more explosive power relative to TNT. See, Keir A Lieber, and Daryl G Press, "The Nukes We Need: Preserving the American Deterrent (Technical Appendix)," <http://www.dartmouth.edu/~dpress/docs/Press_FA-2009-Appendix-12-post.pdf>. To be conservative, this study assumes that advanced explosives are used for all conventional precision-guided weapons and are 50 percent more powerful than TNT.

[2]"Blu-116 Advanced Unitary Penetrator (Aup)," <http://www.globalsecurity.org/military/systems/munitions/blu-116.htm>.

[3]"Blu-113/B, a/B Penetrator Warhead," <http://www.globalsecurity.org/military/systems/munitions/blu-113.htm>.

[4]"Tomahawk Land Attack Missile." Raytheon Company, <http://www.raytheon.com/capabilities/products/stellent/groups/public/documents/content/cms01_055764.pdf>.

[5]Yevgeny Miasnikov. "The Counterforce Potential of Precision-Guided Munitions." In *Nuclear Proliferation: New Technologies, Weapons, Treaties*, edited by Alexei Arbatov and Vladimir Dvorkin (Moscow: Carnegie Moscow Center, 2009).

meters underground in granite, the reported depth of typical "Great Wall Project" tunnels.[33]

According to Figure 2, as the required destruction range increases, the required yield increases at a much more rapid rate. A yield of at least 1,000 kt is required to have a destruction range of about 180 m.[34] This seems to support both the expert estimate that "a single large yield nuclear warhead is unable to destroy the facilities by a direct hit" and the statement in a China Defense News report that "the facilities can only be destroyed under a repeated strike at the same point by a number of nuclear penetrators of hundreds of kilotons yield."[35]

In addition, even if China's tunnels are not built in granite, but simply under wet earth, they do not seem vulnerable to conventional precision-guided strikes. Figure 2 also shows the destruction range of weapons detonated in softer materials. It is clear that even in wet earth, conventional weapons with yields at the level of 0.1–1.0 kt can reach a depth no more than 70 m underground. The maximum destruction range for the most powerful MOP weapon with a yield of 3.5 kt seems no more than 90 m. In other words, even if China's tunnels are covered simply by hundreds of meters of wet earth, not by granite as is reported, they seem relatively safe from repeated strikes by conventional precision-guided weapons.

Moreover, as tunnels go deep into mountain bodies, there is no way to identify the exact locations of the tunnels. For large and complex tunnel webs such as the "Great Wall Project," which has a reported length of more than 5,000 km, the entire underground network of tunnels can cover an extensive area, making it essentially impossible to employ a barrage strategy of destroying the entire area with the conventional precision-guided weapons (or even nuclear weapons, in this case) in the current U.S. inventory.

DF-4

The DF-4 missile, developed in the late 1960s, has a range of about 5,500 km. It shares many of the physical features of the DF-3A. It uses liquid fuel and is land-mobile and can be towed by other vehicles to a pre-designated launch pad. Although there may have been a silo version of DF-4, the only current operational mode is the land-mobile rollout-to-launch version.[36]

Some early satellite images published by Google showed a number of above-ground DF-4 missile garages. The garages were located next to launch pads and seemed vulnerable to a preemptive conventional strike.[37] This, however, may not be an adequate indication of how DF-4 missiles are deployed today. First of all, the above-ground missile garages identified in previous images may not be permanent facilities. Secondly, the "Great Wall Project" may have been extended to regions where DF-4 missiles are deployed. The 2008 official release about the engineering units of the Second Artillery specifically mentions that new underground missile bastions had been recently built on the Qinghai-Tibet Plateau where some foreign analysts believe DF-4 missiles are deployed.[38] In addition to Qinghai Province, Henan Province is also suspected of having DF-4 missile bases.[39] Henan Province is where Taihang Mountain and Qinling Mountain intersect, and should have plenty of places appropriate for building underground facilities.[40] It is reasonable to assume that, like DF-3A missiles, a certain proportion of existing DF-4 stockpiles are deployed in "Great Wall Project" style underground facilities. As discussed previously, it is highly unlikely that conventional precision-guided weapons would be able to neutralize these DF-4 missiles.

Land-Based Missiles with High Mobility

DF-21

The DF-21 is a relatively new solid-fueled medium-range ballistic missile which is believed to be replacing China's old DF-3A missiles. The DF-21 is more accurate than its predecessor, has a higher degree of mobility and is attached to a transporter-erector-launcher (TEL). The missile itself is contained within and protected by a launch canister and needs fewer additional logistical vehicles than DF-3A and DF-4. As a result, DF-21 seems less vulnerable and more adaptable to various battlefield environments. For the same reasons, the United States might perceive DF-21 as a more serious security threat, and it is likely that DF-21 missiles would receive high priority for targeting in a hypothetical U.S. preemptive strike against China's theater nuclear forces.

China is suspected to have about 60 nuclear-armed DF-21 missiles. It is reasonable to assume that in peacetime China may keep a significant number of DF-21 missiles in secure facilities and send a number of missiles out for patrols. Based upon analysis in previous sections, DF-21 missiles that are kept in "Great Wall Project" style underground facilities are safe from any conventional precision-guided strike. The following section will address the DF-21 missile's survivability against a conventional attack when the missile is on a patrol mission.

Survivability of the DF-21

In an explosion, the destruction radius is proportional to the third root of the weapon yield, known as the *scale law*:[41]

$$d_W = d_o\, W^{1/3} \tag{1}$$

Where d_o is the distance from which a given peak overpressure is felt by a detonation of 1 kg of TNT; d_W is the distance from which the same peak overpressure will be felt by a detonation of a warhead whose yield is W. To estimate the lethal radii of conventional precision-guided weapons against the DF-21, the maximum level of overpressure that a vehicle like DF-21 TEL can withstand must be determined. This analysis assumes that the robustness of China's ballistic missile TEL is similar to U.S. missiles.[42] That means if a maximum overpressure of approximately 210 kPa (or, 30 psi) is imposed upon heavy transport vehicles like DF-21 TELs they will be "severely damaged."

Based on data from explosive tests, d_o is about 2 m for a 1 kg TNT detonation.[43] Putting that into Eq. (1), the lethal radius (LR) of any conventional warhead can be determined as long as its yield is known. Under such circumstances, the probability that a given warhead will be delivered within the lethal radius can be calculated using the following equation:[44]

$$\text{SSPK} = 1 - 0.5^{(\text{LR}/\text{CEP})2} \quad (2)$$

Where SSPK is the so-called "single shot probability of kill"; CEP is a measure of a weapon's accuracy and it stands for "circular error probable." Equation (2) assumes that the actual detonation points about the aim point are described by the circular normal distribution, which implies that random errors are the primary physical errors in a fire control system.[45] In practice, nonetheless, all weapon systems, including unguided bombs, have both random and systemic errors.[46] For precision-guided weapons, systematic errors are also present, no matter whether the guidance system has an Inertial Navigation System (INS), Global Positioning System (GPS), laser, or a combination of systems. However, details about systemic errors in the guidance systems are classified and open-source data does not provide enough information for an in-depth analysis. Therefore, it is assumed in this calculation that impact points of precision-guided weapons have a random distribution centered at the target.

If multiple weapons are used to strike the same target, the overall chance of destroying the target is then determined by:

$$P(n) = 1 - (1 - \text{SSPK})^n \quad (3)$$

Where P(n) is the overall chance of destroying the target, and n is the number of weapons that are used in the strike.[47]

If a DF-21 missile vehicle is moving, the conventional precision-guided weapons need to receive real-time updates about the location of the moving target. If communication/data transfer is not jammed by China and if the weapons' design accuracy can be achieved, the probability of destroying the vehicle is shown in Table 5.

The results in Table 5 indicate that most of the conventional precision-guided weapons in the current U.S. inventory have a more than 70% chance of destroying a DF-21 missile vehicle by a single shot.[48] If the United States uses

Table 5: Probability of destruction by conventional precision-guided weapons against a DF-21 missile vehicle

Weapon warhead/ penetrating munitions	Yield (kg, TNT equivalent)[1]	Guidance system	CEP (m)	LR (m)	SSPK	P(2)	P(3)
BLU-109	365	INS, GPS	<6	~14	0.980	0.999	0.999
BLU-116	365 or less	Laser, GPS	<10	~14	0.757	0.941	0.986
BLU-113	304[2]	Laser, GPS	<10	~13	0.715	0.918	0.977
SLAM-ER (AGM-84H)	345	INS, GPS, Teleguided	~2.5	~14	1.000	1.000	1.000
JASSM (AGM-158A)	675	INS, GPS	2.4[3]	~18	1.000	1.000	1.000
TLAM	675 or less	INS, GPS, Automatic self-guided warhead	~5	~18	0.999	0.999	1.000
CALCM (AGM-86C/D)	1,300[4]	INS, GPS	~2.5	~22	1.000	1.000	1.000
MOP (Massive Ordnance Penetrator)	5,250	INS, GPS	<5[5]	~35	1.000	1.000	1.000

[1]The advanced explosives of the BLU-109 are reported to have about 18 percent and perhaps up to 50 percent increased explosive power relative to TNT. Keir A. Lieber and Daryl G. Press, "The Nukes We Need: Preserving the American Deterrent (Technical Appendix)," <http://www.dartmouth.edu/~dpress/docs/Press_FA-2009-Appendix-12-post.pdf>. In order to provide conservative estimates, this study assumes that advanced explosives are used for all conventional precision-guided weapons, and these explosives are 50 percent more powerful than TNT.

[2]"Blu-113/B, a/B Penetrator Warhead,"<http://www.globalsecurity.org/military/systems/munitions/blu-113.htm>.

[3]"Lockheed Martin Agm-158 Jassm," <http://www.designation-systems.net/dusrm/m-158.html>.

[4]Yevgeny Miasnikov, "The Counterforce Potential of Precision-Guided Munitions," in *Nuclear Proliferation: New Technologies, Weapons, Treaties*, edited by Alexei Arbatov and Vladimir Dvorkin (Moscow: Carnegie Moscow Center, 2009).

[5]"Gbu-57 Massive Ordnance Penetrator (Mop),"< http://airpower.callihan.cc/post/10-gbu57.aspx>.

up to three weapons to target one Chinese missile vehicle, the probability of causing "severe damage" would approach 100%.

It is important to note that these results are based on two assumptions: first, a GPS signal is present, which helps the warhead to identify its own location during the flight; and second, the warhead can receive real-time updates about the coordinates of a moving target, which is usually achieved through radio communication with a satellite or other sources of intelligence. In practice, however, China probably would try to block or jam GPS and other radio signals in areas where nuclear missile vehicles patrol; especially at a time of crisis when an adversary might contemplate a preemptive strike. In order to take this into account, the following analysis will assess the survivability of DF-21 missile vehicles when real-time communication is not available for U.S. precision-guided munitions during the final phase of their reentry.

For GBU-32/BLU-109, if the GPS signal is effectively jammed and the weapon can only use its INS, its accuracy decreases significantly from about 5 m to more than 30 m.[49] Accordingly, this study assumes that without GPS guidance most precision-guided weapons' CEP will increase as much as fivefold, if not more. Under such conditions, their destruction probability is shown in Table 6.

The results in Table 6 show that if the GPS signal is effectively jammed, the single-shot destruction probability will decrease significantly. More weapons will be required to achieve a relatively high overall destruction probability. However, for some precision-guided munitions, even as many as six weapons do not seem enough to guarantee a destruction of the target.

Moreover, if the target is moving and the radio signal (including GPS signal) to the precision-guided weapon is jammed during its final phase of flight, the weapon would be unable to receive the new coordinates of the target or to identify its own location.[50] Assuming that the communication signal is jammed during the last 30 seconds of the flight and the target is moving at a normal velocity of 30 miles per hour, the missile vehicle could travel as far as 400 m during the half minute. Under this scenario, the United States might consider using a barrage strategy to strike the entire area with a radius of 400 m. It may be essentially impossible to effectively cover the entire area, however, even if a large number of weapons are used, since when the GPS signal is jammed, the accuracy of most conventional precision-guided weapons drops so dramatically that their lethal radius becomes smaller than CEP. Therefore, reliable radio communication (including GPS signal) seems critical for conventional precision-guided weapons to have a chance to hold China's DF-21 missiles at risk.

DF-31

The DF-31 is China's first solid-fueled road mobile long-range ballistic missile. The analysis in the previous section about the DF-21's survivability

Table 6: Probability of destruction by conventional precision-guided weapons (without GPS guidance) against a stationary DF-21 missile vehicle

Weapon warhead/ Penetrating munitions	Guidance system	CEP (m)	LR (m)	SSPK	P(2)	P(3)	P(4)	P(5)	P(6)
BLU-109	INS	~30	~14	0.146	0.270	0.376	0.467	0.545	0.611
BLU-116	Laser	~ 50	~14	0.055	0.107	0.156	0.203	0.247	0.288
BLU-113	Laser	~50	~13	0.049	0.095	0.140	0.182	0.222	0.260
SLAM-ER (AGM-84H)	INS, Teleguided	~12.5	~14	0.582	0.825	0.927	0.970	0.987	0.995
JASSM (AGM-158A)	INS	~12	~18	0.773	0.948	0.988	0.997	0.999	1.000
TLAM	INS, Terrain Contour Matching	~25	~18	0.289	0.495	0.641	0.745	0.819	0.871
CALCM (AGM-86C/D)	INS	~12.5	~22	0.879	0.985	0.998	1.000	1.000	1.000
MOP (Massive Ordnance Penetrator)	INS	~25	~35	0.738	0.931	0.982	0.995	0.999	1.000

against U.S. conventional strikes applies to the DF-31. Both DF-21 and DF-31 missiles are loaded on TELs and they share many operational features. However, the DF-31 is larger than the DF-21 and this may make it less survivable than DF-21 for at least two reasons.

First, it is uncertain whether China's underground tunnels are spacious enough to accommodate DF-31 TELs. According to the open literature, the DF-31 TEL vehicle is about 2.5 m wide, 18 m long, and 3.1 m high.[51] As Figure 1 shows, the "Great Wall Project" tunnels may be wide and high enough for DF-31 TEL vehicle to drive in, but it could be difficult for the vehicle to make turns and move around in the tunnels. There seem to be no technical limitations against building more spacious tunnels for the DF-31, however. If that is the case, DF-31 vehicles that are protected by underground tunnels will be highly survivable against U.S. conventional strikes.

If some DF-31 missiles are sent on patrol, they may be susceptible to conventional precision-guided strikes if the radio signal is not jammed, similar to the case for the DF-21. The fact that the DF-31 vehicle is notably larger and more cumbersome than the DF-21 means that it might be easier to locate and be tracked by U.S. surveillance and reconnaissance systems such as space radars. If China's military engages in relatively simple countermeasures, however, it appears the United States is not likely to be capable of persistently tracking DF-31s.[52]

Nuclear Ballistic Missile Submarines

Compared to land-based nuclear forces, China's nuclear ballistic missile submarines pose a lesser threat to a forward-deployed U.S. military force.[53] China's single Xia-class nuclear submarine (Type 092) is relatively old and no longer considered fully operational.[54] The operational status of the more advanced Jin-class submarines (Type 094) and the JL-2 submarine-launched ballistic missiles has not been confirmed yet, though it is believed that China now has at least two Jin-class submarines (see Table 1). More importantly, it is uncertain whether the Jin-class is primarily targeted at the continental United States or it is deployed with a regional role in the Asia-Pacific area. Regardless, the United States may perceive China's nuclear submarines as a concern and might target them.

Western analysis of China's submarine forces indicates that submarine bases are more difficult to conceal and protect than land-based underground facilities: U.S.-based independent analysts have identified underground facilities with sea entrances at some of China's submarine bases.[55] This suggests China's nuclear submarines are usually hidden in underground facilities and move in or out of these submerged tunnels through sea entrances. These tunnels may be relatively short in length and may not extend deep into the shore, which means the distance between the top of the tunnel and the ground surface may not exceed tens of meters. If the submerged tunnels are built in hard rock, Table 4 suggests most U.S. conventional weapons would face difficulty penetrating the rock and reaching the tunnels. Some of the most powerful weapons such as the MOP, however, have a maximum range of destruction of about 30 m in hard rock, which might be capable of destroying these underground tunnels.[56]

It is hard to assess how confident Beijing is about its nuclear submarines or how much confidence Washington has about its capability to track and hold at risk China's submarines.[57] But, at a time of crisis, the United States may not be confident about whether the submarines are in or out of the underground facilities, because the submarines may be able to leave the facility secretly through the submerged sea entrances. When the submarines are at sea, their survivability may depend on being deployed in waters close to China where they are protected by China's airplanes and surface ships and are less susceptible to attacks by America's advanced anti-submarine platforms. These uncertainties create problems for decision-makers who want to consider conventional counterforce strike against China's nuclear submarines during crises.

Nuclear-Capable Aircraft

China is believed to possess a small number of nuclear-capable H-6 intermediate-range bombers, which are seen as becoming increasingly obsolete. The H-6 has a very limited flight range (compared with modern bombers of the United States, for example) and is susceptible to advanced air defense systems. If not on alert, H-6 bombers can be very vulnerable to U.S. conventional precision strikes —the bombers do not appear to be protected by underground tunnels or other hardened facilities.[58] Both the aircraft and the runways could be destroyed by conventional weapons without much difficulty. The nuclear gravity bombs that are assigned to the bombers may be more difficult to destroy, however, since they are believed to be stored in separate facilities close to the airbases. Many of China's airbases are close to mountains where underground facilities have been identified. If the nuclear bombs are stored in these underground facilities, they might not be vulnerable to any conventional precision-guided strike. However, in a preemptive strike aimed at damage limitation, the existence of nuclear gravity bombs might not be much of a concern, as long as the bombers that are used to deliver them can be destroyed.

Functional Defeat

Functional defeat of China's theater nuclear forces may serve to meet the U.S. objective of damage limitation, and at the same time requires fewer and less powerful munitions. This section will discuss the capability of the United States to conduct a functional defeat operation against China's theater nuclear forces. China's nuclear-capable bombers are not discussed here since they seem quite vulnerable to U.S. conventional strikes, making the issue of functional defeat largely irrelevant for these weapons systems.

As for China's nuclear ballistic missile submarines, functional defeat of submarine bases might be easier to achieve than complete destruction. China's underground submarine facilities are mostly built by digging into hills that are next to the shoreline, protected by the rock or earth above.[59] However, the sea entrances to these tunnels seem less protected and the front-end of the tunnels that are close to the entrances may be relatively vulnerable. By striking the entrances, it might be possible to block submarines inside the tunnels without having to destroy the tunnels and the submarines inside.[60]

However, it is unknown if the United States can reliably identify whether China's submarines are at port in underground tunnels or at sea, since these tunnels have submerged sea entrances and submarines may be able to move in and out without exposing themselves. As long as the submarines remain in waters close to China's mainland, they may be safe from U.S. attack submarines and other anti-submarine warfare capabilities.

A functional defeat strategy also may be more practical against China's land-based theater nuclear forces. As analyzed above, a significant number of China's land-mobile nuclear missiles seem to be deployed in hardened and deeply buried underground tunnels. Although the tunnels are extremely robust and cannot be compromised by conventional strikes, their entrances may be vulnerable. If all the entrances to tunnels are destroyed by conventional precision-guided weapons, the nuclear missiles would be trapped in the tunnels until the debris is cleared and the entrances re-opened, which could take a long time. Beijing seems to have already taken this scenario into consideration when designing and building its underground "Great Walls." A press release specifically mentioned that countermeasures have been taken to diminish the possibility that all entrances can be destroyed in a conflict.[61] Apparently, a large number of entrances have been built at various locations in the tunnel network so that even if some of the entrances are blocked there will still be a number of entrances left intact. Many dummy targets have been created around the facilities to increase the difficulty of identifying and destroying all the real entrances.

The efficacy of functional defeat operations can be seriously undermined both by the adversary's countermeasures and the need for highly accurate intelligence. Recent history suggests that it is very difficult to successfully identify important weapons of mass destruction (WMD) facilities. The most frequently quoted examples are the 1991 Persian Gulf War and the 2003 Iraq War. On the first occasion, a significant proportion of Iraq's WMD facilities were not identified and therefore left intact during the U.S. massive conventional bombing campaign. In the second case, a large number of suspected WMD facilities were later found to be either misidentified or inactive.[62]

As for striking China's DF-21 missile vehicles on patrol, it is difficult to clearly distinguish between "complete destruction" and "functional defeat." As analyzed in previous sections, a moderate number of conventional precision-guided weapons (with the assistance of GPS guidance) would be sufficient to "severely damage" the missile vehicles by overturning the vehicle and crushing the missile canister to the extent that the missile could no longer be launched.[63] A functional defeat strategy, therefore, is not of particular significance for attacking moving missile vehicles.

FUTURE U.S. CONVENTIONAL PROMPT GLOBAL STRIKE CAPABILITY

Besides existing weapon systems, the United States has a range of near- to mid-term plans for future conventional prompt global strike systems. This section assesses the potential capability of future conventional global strike systems against China's theater nuclear forces. A brief summary of proposed conventional prompt global strike systems is provided in Table 7.

In theory, the capability of conventional weapons can be improved in three ways: increased accuracy, a shortened response time, and greater explosive power. The last approach, increasing the explosive power, generally requires a larger yield, which translates into bigger warheads carrying more explosives. However, Table 7 indicates that this may not be the approach that the United States plans to take. Most of the proposed near- to mid-term weapon delivery systems do not have a significantly greater payload capacity than existing systems such as the B-2A bomber which has a throw weight capacity of roughly 20,000 kg.[64]

The planned systems suggest a goal of significant improvements in terms both of responsiveness and accuracy. Better responsiveness is achieved by putting reentry vehicles on high-speed delivery systems such as ballistic missiles and space operational vehicles. The reentry vehicle can be delivered to targets in no more than two hours or even in matters of tens of minutes, depending on the specific delivery systems. Increased reentry velocity puts limits on strike accuracy, however. The higher the velocity at which the reentry vehicle travels, the more difficult it becomes for the vehicle to make necessary adjustments and to maneuver before it hits the ground. Also, when the vehicle travels at speeds higher than 4.6 km/s, it will be surrounded by a cloud of plasma which can block the GPS signal and significantly undermine the weapon's accuracy.[65] Slowing down the reentry vehicle after it enters the atmosphere, therefore, might be a solution.[66] The idea to put reentry vehicles on a glider, for example, is proposed as a way to reduce reentry speed. As shown in Table 7, the accuracy of future weapon systems is about 3 m.[67]

According to Table 5, the lethal radius of a conventional weapon with a yield of about 365 kg TNT is 14.3 m, when used to strike China's DF-21 missile

Table 7: Summary of proposed conventional prompt global strike systems[1]

Weapon systems	Launch vehicles	Combat range (nm, nautical mile)	Munitions payload capacity (lb)	Accuracy (meter)	Earliest Initial Operational Capability (IOC)
Conventional Trident Modification (CTM)	Trident: D5	>4,000	>1,000	3–5	2011
Submarine-Launched Global Strike Missile (SLGSM)	2-stage rocket booster	3,000	2,000	3–5	2014–2015
Conventional Strike Missile (CSM)	Minotaur II and III	>6,000	2,000	3–5	2016–2020
Hypersonic Cruise Missile	Launched on land, from aircraft, or from ships	2,000–3,000	1,000–2,000	3–5	2020–2024
Space operations vehicle	Trans-atmospheric vehicle	Global coverage	1,000	~3	Later than 2020
Space-based launch platform	Rockets	Global coverage	>2,000	~3	Later than 2020

[1]National Research Council, *U.S. Conventional Prompt Global Strike: Issues for 2008 and Beyond* (Washington, D.C: National Academies Press, 2008); T.C. Shull, *Conventional Prompt Global Strike: Valuable Military Option or Threat to Global Stability* (Monterey, California: Naval Postgraduate School, 2005); William L. Spacy II, "Does the United States Need Space-Based Weapons," Master's Thesis, School of Advanced Airpower Studies, Air University, Maxwell Air Force Base, Alabama, (1998); Matt Bille and Rusty Lorenz, "Requirements for a Conventional Prompt Global Strike Capability," National Defense Industries Association, Missile and Rockets Symposium and Exhibition, (2001); Amy F. Woolf, "Conventional Warheads for Long-Range Ballistic Missiles: Background and Issues for Congress," Congressional Research Service, CRS Report for Congress, RL33067, (2008); Bruce M. Sugden, "Speed Kills: Analyzing the Deployment of Conventional Ballistic Missiles," *International Security*, 34 (2009): 1, 113–46.

Table 8: Destruction probabilities of a conventional weapon with different levels of accuracy

Weapon yield (kg, TNT equivalent)	LR (m)	CEP (m)	SSPK	P(2)	P(3)
365	∼14	10	0.758	0.941	0.986
365	∼14	3	1.000	1.000	1.000

vehicle on patrol. Applying Eqs. (1), (2), and (3) shows how different levels of accuracy will affect the destruction probability of the same conventional weapon (see Table 8).

Table 8 implies that as many as three weapons with yields of 365 kg TNT are needed to destroy an unsheltered Chinese DF-21 missile vehicle, whereas only one weapon is necessary if the accuracy of the weapon can be increased from 10 m to 3 m. Therefore, future advanced conventional global strike weapons will be much more capable of destroying China's unsheltered missile TELs. However, it is important to note that most of these advanced precision-guided weapons rely heavily on satellite guidance, especially during the final phase of their flight. If the radio signal is jammed, their accuracy level is likely to decline considerably, making it more difficult and less certain for them to strike China's missile vehicles, particularly if the target is moving.

As for striking China's underground facilities, planned conventional global strike weapons do not seem to have a higher chance of success compared with existing weapons. Accuracy is not much of a concern for striking China's underground facilities, because no matter how accurate the weapons are, if they cannot penetrate deeply enough into the ground they will not put the tunnels at significant risk. Also, China's underground tunnels usually stretch extensively into a wide area and precision-guided weapons are of little use in dealing with large-area targets.

In terms of penetrating capacity and explosive power, planned weapons may not be significantly superior to existing weapons. First of all, penetrating capacity will increase as the speed at which the weapon hits the ground (impact speed) increases. However, when the speed reaches 3 km/s, the depth of penetration will be primarily a function of the square root of the density ratio of the weapon material to the target material and is no longer affected by increasing the impact speed.[68] In addition, high impact speed poses a challenge to the weapon material. The currently demonstrated maximum impact speed at which the hardest material can survive is about 1,000 m/s,[69] so the current available technology does not allow an impact speed as high as 3,000 m/s. However, in order to understand the potential of future weapon systems, this article assumes that future technology will produce new materials that are hard enough to withstand an impact speed of 3 km/s, and calculates how deep the weapon can penetrate into hard rock such as granite under such an assumption.[70]

According to the Young (Sandia) penetration equations, when impact velocity $V \geq 200$ fps (feet per second), the depth of penetration (D) into rock is determined by the following equation:[71]

$$D = 0.00178\,S\,N\,(W/A)^{0.7}\,(V - 100) \quad (4)$$

Where S is penetrability of target (dimensionless) and is determined by features of the target material; N is nose performance coefficient (dimensionless) which describes the shape and configuration of the nose of reentry vehicle; W is weight of penetrator; and A is cross sectional area. Therefore, Eq. (4) shows that holding all the other features of the target and the penetrator constant, the depth of penetration (D) has a linear relationship with impact speed (V).

Analysis in previous sections has shown that the maximum penetration capacity for existing penetrators is about 10 m into hard rock or reinforced concrete. Therefore, if the maximum survivable impact speed for weapon materials can increase from currently 1,000 m/s to about 3,000 m/s in the future, the maximum depth of penetration for future penetrators will be about three times the penetration depth of existing penetrators. In other words, penetration depth of future weapon systems will not be more than 30 m into hard rock.

Although new weapons may penetrate deeper into the ground, their range of destruction (the distance between detonation point and the deepest position where the explosion can reach and cause a certain level of damage) will probably not increase substantially. Because the range of destruction is proportional to the cube root of the force of the explosion, and the limited payload of new weapon delivery systems do not seem adequate to deliver conventional weapons that are of very high yields, the overall depth of impact (depth of penetration plus the range of destruction) will not increase substantially, and new conventional weapons may not have the potential to threaten China's underground facilities. A significant proportion of China's theater nuclear forces including DF-3A, DF-4, and DF-21 may continue to be protected by the "Great Wall Project" and may be highly survivable against advanced conventional weapons in the near- to long-term future.

CONCLUSION

Conventional counterforce preemptive strike scenarios have been proposed by U.S. analysts and policy makers to justify and advocate for the development of conventional global strike capabilities. China sees these systems as a threat to the survivability of its nuclear forces. If the United States were to consider a first strike against China for the purpose of damage limitation, it would likely be to target China's theater nuclear forces. The analysis presented here suggests that China's theater nuclear forces, which include DF-3A, DF-4, DF-21, and DF-31 missiles, Type 094 nuclear submarines, and nuclear-capable H-6 bombers, would mostly survive strikes by current U.S. conventional precision-guided weapons. The bombers are by far the most vulnerable. China's strategy to build robust underground facilities for its missiles and submarines, in particular, seems effective in protecting its nuclear forces from threats of preemptive strikes.

An assessment of the potential of planned U.S. conventional strike systems shows that these systems may not add significantly to existing U.S. conventional preemptive strike capabilities against China. Even if the proposed global strike systems are successfully developed and fully deployed, China's theater nuclear forces likely will remain highly survivable against U.S. conventional attack.

This analysis is conservative in that it does not take into consideration a number of factors that could further undercut the efficacy of conventional strikes against China's theater nuclear forces. For example, this study does not take into account the possible decoys that China has created to increase the targeting uncertainty for any attacker, or the extent to which China's early warning, air defense, and missile defense capabilities may blunt a conventional strike. In the mid- to long-term future, China is improving its air defense capability and may improve its currently limited early warning capability so as to have time to deploy emergency protective measures for its nuclear forces to make them more survivable.

Another serious problem with the U.S. strategy of damage limitation is uncertainty in intelligence. Under the current Chinese strategy of hiding nuclear forces underground, it is not very likely that the United States will be able to detect or deter China when it puts its nuclear forces on alert during a crisis. The United States would not be able to tell the alert status of Chinese underground nuclear missiles and China's nuclear submarines may be able to leave ports unnoticed through submerged sea entrances. China's nuclear-capable bombers would be visible if they are put on alert, but bombers are also the least reliable leg of its nuclear forces. It also would be very difficult for the United States reliably to detect all of China's theater nuclear weapons before a possible conventional preemptive strike, and to accurately assess the outcome of such an attack. This suggests a U.S. conventional counterforce strike against China is practically unachievable with high confidence.

A limited U.S. conventional strike may have the unintended effect of accelerating escalation instead of preventing or controlling escalation. It is possible that the U.S. may see China's emergency measures for post-attack disaster relief and recovery, or its actions to disperse its surviving nuclear forces as preparations for retaliation and may believe it has no option but to launch further attacks to preempt such an anticipated retaliation.

The U.S. should consider strategies of damage limitation other than using conventional preemptive strikes against China's theater nuclear forces. To reduce the risks posed by U.S. conventional counter-force plans, the U.S could firstly consider taking off the table the option of nuclear or conventional preemptive strike against China's nuclear forces. Secondly, the U.S. could engage China in discussions about the balance of military power in the Asia-Pacific region and regional strategic stability. This could include efforts to reinforce existing military-to-military communication mechanisms.

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9. Chinese Type 094 nuclear submarine(s), if deployed within the First Island Chain and in waters close to China, their missiles may not be able to reach the continental United States and may only be capable of striking shorter-range regional targets.

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27. This is a conservative assessment which probably overestimates the penetrating capability of these weapons. In practice, even if the weapon material does not wear out during penetration, the munitions might not withstand the very high deceleration and could be destroyed or malfunction. This conservative estimation reinforces the results of the analysis which proves the limits of conventional earth-penetrators.

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31. *Ibid*.

32. Robert W. Nelson, *op. cit.*, Figure 1.

33. Current technology does not offer such pinpoint accuracy even for precision-guided weapons.

34. Robert W. Nelson, *op. cit.*, Figure 3.

35. Jingjing Wang, *op. cit*.

36. Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, *op. cit*.

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38. Bates Gill, James Mulvenon, and Mark Stokes, *op. cit*.; Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, *op. cit*.

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40. Both Qinling and Taihang Mountain are made of rock. Qinling Mountain, in particular, is made of granite, and seems ideal for building underground facilities. For example, the suspected Chinese nuclear warheads central storage facility is located in Qinling Mountain (although this facility is close to but not exactly in Henan Province). See Mark A. Stokes, "China's Nuclear Warhead Storage and Handling System," Project 2049 Institute (2010).

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46. Department of Defense, *Department of Defense Handbook, Fire Control Systems - General MIL-HDBK-799* (Department of Defense: Washington, D.C. 1996).

47. It is assumed that U.S. conventional weapons are 100% reliable. In other words the probability that the weapon might not function properly is not taken into consideration. First, the probability of malfunction is generally very low; and second, there is no open source estimate for the probability of malfunction. This assumption produces conservative results and if the weapon reliability is less than 100%, the case is strengthened.

48. Note that this is a conservative assessment about the survivability of DF-21 missile vehicle. A number of factors may reduce the chances of a conventional weapon destroying a missile vehicle. For example, the relative position between the explosion and the target vehicle also matters. In this article, the maximum overpressure that the target vehicle can withstand is based on the scenario of the target vehicle being sideways to the explosion. If the explosion is in front of the vehicle, the maximum overpressure the vehicle can withstand would be higher, which makes the lethal radium shorter than what is shown in Table 5. In general, if these additional factors are taken into consideration, they would further strengthen the case made in this article.

49. Keir A. Lieber and Daryl G. Press, *op. cit*.

50. It is assumed that the weapon relies on radio signals to receive the coordinates of a moving target. It is possible that a weapon can be equipped with advanced sensors that can independently detect and identify a moving target and therefore does not need a GPS signal to know the coordinates of the target. It is difficult, however, to assess how well such sensors may work, due to the scarcity of publicly available sources of information.

51. Li Bin, "Tracking Chinese Strategic Mobile Missiles." *Science and Global Security*, 15 (2007): 1–30.

52. *Ibid*.

53. This is not to say that China intends to use their nuclear ballistic missile submarines against military targets—some may argue that they are primarily used as a force of reprisal in counter-value strikes. This article takes Chinese nuclear submarines into account because from American perspectives, Chinese nuclear submarines may pose a threat to American military assets during crises.

54. Robert S. Norris and Hans M. Kristensen, "Chinese Nuclear Forces," *Bulletin of the Atomic Scientists*, 64 (2008): 3, 42–44, 45.

55. The Nuclear Information Project, "China's Nuclear Missile Submarine Base," <http://www.nukestrat.com/china/subcave.htm>; Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, *op. cit*.

56. This may be an oversimplified discussion about the survivability of Chinese underground submarine facilities. However, little is known about the robustness of these facilities and the ability of conventional weaponry to destroy underground submarine facilities.

57. Wu Riqiang, "Survivability of China's Sea-Based Nuclear Forces," *Science & Global Security*, 19 (2011): 2, 91–120.

58. Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, *op. cit*.

59. Hans M. Kristensen, Robert S. Norris, and Matthew G. McKinzie, *op. cit*.

60. Hans M. Kristensen, "New Chinese Ballistic Missile Submarine Spotted," FAS Strategic Security Blog, <http://www.fas.org/blog/ssp/2007/07/new_chinese_ballistic_missile.php>.

61. Jingjing Wang, *op. cit*.

62. Charles L. Glaser and Steve Fetter, "Counterforce Revisited: Assessing the Nuclear Posture Review's New Missions," *International Security*, 30 (2005): 2, 84–126.

63. Jixiang Wang and Lan Chang, *op. cit*.

64. Bruce M. Sugden, "Speed Kills: Analyzing the Deployment of Conventional Ballistic Missiles," *International Security*, 34 (2009): 1, 113–46.

65. William L. Spacy II, "Does the United States Need Space-Based Weapons?" Master's Thesis, School of Advanced Airpower Studies, Air University, Maxwell Air Force Base, Alabama, (1998).

66. The Common Aero Vehicle, for example, can operate as the reentry vehicle of Conventional Strike Missiles, space operational vehicles, and potentially other future delivery systems.

67. This is a conservative assessment. Although such accuracy was claimed, it might be very difficult to achieve in practice. If this were true, the case made in the article would be strengthened.

68. William L. Spacy II., *op. cit*.

69. Robert W. Nelson, *op. cit.*

70. This is a bold assumption and will likely overestimate the capability of advanced weapons in the future. The analysis will show that even under such bold assumptions, advanced weapons will still be incapable of threatening existing Chinese underground facilities.

71. C. W. Young, "Penetration Equations," Contractor Report, SAND97–2426, Sandia National Laboratory (1997).