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Tracking Chinese Strategic Mobile Missiles

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This paper analyzes the maneuverability, capabilities, and survivability of Chinese DF-31 mobile missiles and the ability of a proposed U.S. Space Radar system to persistently track them. The author posits possible defense strategies for the Chinese military and concludes that the survivability of the mobile DF-31's is not guaranteed during a nuclear attack given the huge U.S. strategic arsenal, but also questions the ability of the proposed U.S. Space Radar system to persistently track the DF-31's if the Chinese military engages in relatively simple countermeasures. Neither China nor the United States can be completely confident of a strategic advantage. The two countries need strategic dialogues to improve relations on this topic.

INTRODUCTION

Relations between China and the United States are complicated. On one hand, the two countries are developing tremendous trade, cultural and educational exchanges and are cooperating on important global affairs. However, there are disputes and suspicions over several issues including Taiwan and complex relations persist in many fields, including security. China and the United States cooperate on nuclear nonproliferation and antiterrorism but their interests conflict on space weaponization, missile defense, mobile missile and antimobile missile developments.

China is developing strategic mobile missiles whereas the United States is simultaneously developing the capability to target mobile missiles. These efforts are counterproductive and may destabilize security relations between the two countries unless efforts are made to clarify the motivations and objectives

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for these actions. This article evaluates the potential capabilities of Chinese strategic mobile missiles and U.S. antimobile technology. The article examines the security implications of the mobility and antimobility game and makes policy recommendations to increase stability between China and the United States.

Unlike Soviet–U.S. relations during the Cold War, issues surrounding strategic weapons have played a marginal role in longstanding and deeply rooted Sino–U.S. relations. However, this does not suggest that strategic weapons should be ignored. The significance of nuclear weapons could increase during a crisis. The Taiwan problem is widely believed to be a fuse that could lead to serious military confrontation, even military conflict, between China and the United States.[1] It is strategically important to maintain peace in the Taiwan Strait to avoid military confrontation between China and the United States. Recently there has been effort and progress toward this end. However, the risk of military confrontation between China and the United States cannot be completely ruled out. Consideration should be given to reducing the destabilizing role of strategic weapons should a confrontation arise.

Strategic weapons are, in principle, psychological rather than employable weapons. Compared to a deliberate use of nuclear weapons, a more realistic danger results from strategic miscalculations and misinterpretations. Decisionmakers may be tempted to use strategic threats to push for specific political outcomes. A dangerous situation results when decisionmakers believe that an escalating nuclear competition favors their side, making it difficult to seek compromise during a military confrontation. The quest for a unilateral victory will prevent each side from making compromises necessary to resolve a crisis.

Individuals in the United States, mainland China, and Taiwan are seeking to expand their freedom of action and believe that enhancing their respective strategic position serves this purpose. For example, former Taiwanese leader Lee Tenghui expects that U.S. nuclear weapons targeted at China will deter China's military action in response to a declaration of independence.[2] Some Taiwanese want more freedom to begin separation and believe that U.S. nuclear weapons will promote that cause. Policymakers understand that if the Taiwanese authority ever formally declared independence, China might launch a military attack against Taiwan. They are concerned that the U.S. commitment to defend Taiwan against such an attack would not be credible. They hope that U.S. superiority in strategic forces would deter a conventional action on China's part. Conversely, some people in mainland China, specifically General Zhu Chengdu, believe that Chinese nuclear weapons will deter U.S. involvement during a conflict in the Taiwan Strait.[3] The Chinese want the freedom to launch military actions in response to any Taiwanese move toward independence. General Zhu worries that China's inferior conventional forces could be defeated by the United States in a conflict in the Taiwan Strait and expects that China's strategic weapons will play an extended role toward deterrence. As Leonard S. Spector noted,[4] "Many U.S. analysts, both inside and outside the administration of U.S. President George W. Bush, are hoping that America's proposed missile defenses, by blunting China's ability to attack the U.S. homeland, will provide Washington greater freedom of action to respond if Beijing uses force in an attempt to absorb Taiwan." These analysts do not want the U.S.'s freedom to be constrained by the deterrent effects of Chinese nuclear weapons. Missile defense and antimobile missile warfare are approaches that could negate the deterrent effects of Chinese nuclear weapons.[5]

Although there has been no formal negotiation between China and the United States on the subject of missile defense, intensive debates among security experts in the past[6] have made this issue transparent to the public and decisionmakers of both countries. The debates on the technical capabilities and constraints of missile defense and their countermeasures have served to educate decisionmakers and the public in China and the United States. Continuation of serious dialogue among security experts in the two countries may prevent strategic miscalculations and misperceptions and could therefore contribute to bilateral stability.

The competition between Chinese development of strategic mobile missiles and U.S. efforts to develop antimobile capability may be another important factor shaping strategic calculations in both countries. The public and the decisionmakers in both countries need to correctly understand the technical capabilities and feasibilities of these technological developments so they will neither base policy on unrealistic expectations, nor overreact to developments on the other side.

This article examines how this competition might unfold in the next ten to fifteen years and discusses the security implications of such competition. The Chinese believe that development of strategic mobile missile technology is necessary to ensure the survivability of its strategic force. It is not publicly known how, and to what extent, mobility would contribute to China's security and survivability. This article assesses the survivability of Chinese mobile missiles under nuclear attack based on publicly available information and analyzes the overall security costs and benefits of different methods to improve stealth mobility.

Survivability of Chinese mobile missiles depends not only on the military capabilities of China but also on those of the United States. The U.S. capabilities are divided into strike capability and intelligence gathering capacity. The United States has a large strategic nuclear force but it is unknown whether or not the United States would be able to detect and track Chinese strategic mobile missiles. If the United States believes that it can successfully track all the Chinese strategic mobile missiles it could gain confidence that it could supress Chinese nuclear retaliation. One emphasis of this article is to analyze the tracking capability provided by U.S. space-based radars that may be deployed in the next ten years.

ROLES OF CHINESE STRATEGIC MOBILE MISSILES

The United States pays close attention to nuclear developments in China. There are many different assessments in the United States about China's nuclear modernization and its security implications. These assessments are of concern to the United States.[7] It is believed that the main effort in Chinese nuclear modernization is to develop and deploy solid fuel, road-mobile DF-31 missiles,[8] and that the mobility of the new DF-31-class missiles will enable these systems to operate over a larger area, making them more difficult to locate and neutralize.[9] Some experts[10, 11] believe that Chinese nuclear modernization will allow China increased ability to achieve a credible minimal deterrence. Credible minimal deterrence means that both China and its rivals have some level of certainty that a number of Chinese nuclear weapons are able to survive a first strike and can be used for retaliation. China's strategy for fixed-based strategic missiles is to create uncertainty regarding the number of deployed missiles. If the United States knows the number and locations of these missiles, it would have confidence in its ability to destroy them. However, because China does not disclose the number of these missiles, it is difficult for the United States to rule out some errors in its estimate. The deterrent effects of the Chinese nuclear weapons stems from this uncertainty. China, in return, does not know how accurately the United States estimates the numbers and locations of Chinese nuclear missiles and therefore cannot estimate the size of a retaliatory strike. This article examines whether the deployment of strategic mobile missiles would increase the deterrent effect of Chinese nuclear forces.

It is more accurate to refer to the Chinese nuclear strategy as counter nuclear coercion rather than minimal nuclear deterrence.[12] The main difference between the strategies of counter nuclear coercion and nuclear deterrence results from the assessments of the likelihood of a first nuclear attack from other countries. Nuclear deterrence theory assumes that the probability of a nuclear attack from the enemy is high if the attacker ever becomes confident of complete success, so an operational retaliatory nuclear force must be maintained at all times to dissuade the enemy from striking. Counter coercion strategy believes that nuclear coercion, the use of the threatening influence of nuclear weapons, is what must be countered, and its main goal is to prove to adversaries that the threat of using nuclear weapons is credible. A recent article by two American scholars, Lieber and Press, argues that the United States has had the capability to wipe out China's long-range nuclear retaliatory capability and that this capability could give U.S. leaders' coercive leverage in any future high-stakes crisis[13] and suggests that the United States could use nuclear coercion if China loses its retaliatory capability.

Survivability of a nuclear strike is as important to counter coercion strategy as to nuclear deterrence. According to nuclear deterrence theory, if a country understands that a nuclear attack against China would cause some retaliation from the surviving nuclear weapons of China, it would choose not to strike. Survivability plays a similar role in the counter coercion strategy. If China can show that some of its nuclear weapons can survive a preemptive attack, the threat of using nuclear weapons against China would no longer be convincing and it is therefore no longer an effective strategy for other countries to use nuclear weapons as a coercive tool against China.

To assure minimal deterrence a country requires a continuous operational force that can launch nuclear retaliation after suffering an attack. The counter coercion strategy emphasizes the importance of demonstrating survivability in a crisis rather than putting the nuclear force on constant alert. The present analysis is based on the counter coercion nuclear strategy of China.

The growing U.S. intelligence capability is weakening Chinese efforts to maintain quantitative ambiguity about its fixed-based strategic missiles. The deterrent effects of Chinese fixed-based strategic missiles are declining. Eventually, the United States could develop confidence that it has perfectly estimated the Chinese fixed-based strategic missiles if no new ones were added. To compensate for this declining deterrent ability, China can deploy strategic mobile missiles. An important question is whether or not mobile missiles would enable China to increase the deterrent effects of its nuclear force to a higher level. If some Chinese strategic mobile missiles survived a first strike while the remainder of the mobile missiles saturates the remaining incoming warheads, the Chinese nuclear force would constitute an effective deterrent. The next section tries to understand how mobility contributes to survivability by focusing on the DF-31 missile.

THE DF-31 MISSILE

The author's assessment on the survivability of the Chinese strategic mobile missiles using the DF-31 as illustrative case is based on the following assumptions. First, China does not now and will not have in the next ten or fifteen years an effective early warning system against incoming missile attacks. Second, the size of the Chinese strategic mobile force will be at the same level as its fixed-based nuclear force, which is about twenty.

MODELING THE DF-31

There are various descriptions about the specifications of DF-31 (sometimes referred as CSS-9), a Chinese road-mobile missile (see Table 1).

The data in Table 1 are inconsistent with each other and incomplete, so an estimation is needed regarding the specifications of the DF-31 missile and its Transporter-Erector-Launcher (TEL). In publicly available pictures, the DF-31 TEL is an 8-axle semi-trailer towing vehicle.

Table 1: Specifications of DF-31.

Source	Length (m)	Diameter (m)	Mass (kg)	Range (km)	RV mass (kg)
FAS[i]	10.0+	2.0	20,000+	8,000	700
DoE[ii]				7,250+	
Jane's[iii]	16.0	2.0	42,000	8000	800–1200
CDT[iv]	13.0	2.25	42,000	8000	1050–1750
NWPU[v]	13.4	2.2	17,000	8,000	700

[i]Federation of American Scientists, "DF-31," http://www.fas.org/nuke/guide/china/icbm/df-31.htm (12 March 2007).
[ii]Office of the Secretary of Defense, "Annual Report to Congress, The Military Power of the People's Republic of China 2005," http://www.dod.mil/news/Jul2005/d20050719china.pdf (12 March 2007), p. 45 (12 March 2007).
[iii]"Land-Based Ballistic Missiles: CSS-9 (DF-31)" http://www.aeronautics.ru/archive/wmd/ballistic/ballistic/css9-01.htm. This is a Venik's Aviation webpage but it indicates the source is Jane's Strategic Weapon Systems. (1 February 2007).
[iv]Chinese Defense Today, "DF-31 Intercontinental Ballistic Missile," http://www.sinodefence.com/strategic/missile/df31.asp, (12 March 2007).
[v]Information website of the Second Artillery Students at Northwestern Polytechnical University, "Weapons and Equipments," http://www.nwpu.edu.cn/departments/pla/shtml/st003.html (12 March 2007).

The width of the DF-31 TEL vehicle is used to scale all other pertinent sizes relative to the DF-31 pictures published on the Internet.[14] Chinese regulations set a width of 2.5 meters (m) as a standard for semi-trailer towing vehicles.[15,16] Therefore it is assumed that the width of DF-31 TEL is 2.5 m. Based on this, relevant sizes are scaled as follows: the missile has a length of 14.3 m (among which, 13.2 m is its solid part) and a diameter of 1.8 m; the canister has a length of 15.4 m and a diameter of 2.2 m; and the TEL vehicle has a width of 2.5 m, a length of 18 m and a height of 3.1 m.

The Trident I (C-4) missile is used as a benchmark to scale the mass of DF-31. The DF-31 has a diameter of 1.8 m and a length of 13.2 m for its solid mass whereas the Trident I (C-4) missile has a length of 10.39 m, a diameter of 1.88 m, and a launch mass of 29,500 kg. Its range is 7,400 km,[17] which is about the same as that of DF-31. Assuming that the launch mass is proportional to the volume of the solid mass of the missiles, the launch mass of the DF-31 is then scaled to 34,400 kg [29,500$\times$ (13.2 $\times$ 1.82)/(10.39 $\times$ 1.882)].

Next the mass of the DF-31 TEL vehicle is estimated. A semi-trailer towing vehicle, CZ4260HF294, with the same size as a DF-31 towing vehicle is 9,120 kg[18] and a semi-trailer, ZCZ9402TJZP, which is somewhat longer than that of DF-31's trailer, weighs 7.8 tons.[19] It is assumed that the DF-31 TEL vehicle has a mass of 16,900 kg (9,120 kg + 7,800 kg).

The DF-31 missile canister has a total area of 114 m^2 [2 $\times$ 3.14 $\times$ (2.2/2)2 + 3.14 $\times$ 2.2 $\times$ 15.4]. Assuming that the canister has a thickness of 0.005 m and is made of steel with density of 7,800 kg/m^3, the canister shell has a volume of 0.57 m^3 and a mass of 4,400 kg. The total mass of the DF-31 TEL including the missile and the canister is 55,700 kg. The specifications of the DF-31 system are summarized in Table 2.

Table 2: Specifications of the DF-31.

Parts	Parameters	Data
Missile	Length	14.3 m
	Diameter	1.8 m
	Launch mass	34,400 kg
Canister	Diameter	2.2 m
	Length	15.4 m
	Mass	4,400 kg
TEL vehicle	Width	2.5 m
	Length	18 m
	Height	3.1 m
	Mass	16,900 kg
Total	Mass	55,700 kg

The specifications of the DF-31 TEL suggest that the missile can move on existing standard roads in China rather than only on roads specially built for heavy missiles. Chinese road regulations[20] set standards for semi-trailer towing vehicle as: 2.5 m width, 16 m length and 550 k Newton weight. A 550 k Newton weight corresponds to a mass of 56,100 kg. It seems that the width and mass of DF-31 TEL system meets the standards and that the length is slightly over the standard. Another government document[21] defines a length larger than 18 m as "over limit" and prohibits such vehicles on the roads. A length of 18 m seems to be tolerable moving on standard roads. The sizes and weight of DF-31 TELs derived from the earlier analysis are about the upper limits in the Chinese road regulations whereas the range of DF-31 is near the lower limit of typical Intercontinental Ballistic Missiles (ICBM). This suggests that China could have intentionally reduced the size and mass of the DF-31 missile to allow it to move on standard roads. The DF-31 missile may be downsized at the sacrifice of the yield of its warhead and its range. If this is the case, it suggests that China values survivability more than explosive yield and missile range.

SURVIVABILITY AND MOBILITY MODES

When the United States developed its mobile ICBMs, there were debates about MX (Missile Experimental) missile basing.[22] China also faces choices of mobility modes. Discussed in the last section, the DF-31 is designed for mobility on standard roads.[23] In principle, there are two modes of mobility that China could employ to increase the survivability of the DF-31. The first mode is to disperse the DF-31 TELs to reduce the efficiency of the volley of the attacker.[24] Because China does not have a full-scale early warning system, the TELs would need to be sent out when China believes that a crisis has reached a dangerous point. The movement of a TEL creates uncertainty in its location during the flight of incoming missiles and the attacker would need to launch a volley of several warheads to cover the area of uncertainty. The question is whether the United

States has enough warheads to cover multiple areas of uncertainty. The next section estimates how many warheads the United States would need to destroy one DF-31 if its original position is known.

The second mobility mode is to periodically relocate DF-31 TELs in peace time and hide them at new sites to elude monitoring of by potential attackers. The details of this mode will be explained and the problems of intelligence will be examined.

DISPERSAL UNDER ATTACK

This section assesses the survivability of the DF-31 in the first mobility mode under an assumption that the U.S. can locate DF-31 TELs before it launches an attack. The U.S. Submarine-Launch-Ballistic-Missile (SLBM) is used as an example. Today, the United States deploys 1,632 W76 warheads on its SLBMs, which represent approximately 80% of total SLBM inventory, each with a nominal yield of 100 kilotons TNT equivalent. The United States also deploys 384 W88 warheads on its nuclear missile submarines and 1,050 warheads on its ICBMs, with a higher 455 kiloton TNT equivalent. Not all of the U.S. submarines are in the Pacific Ocean. However, the United States has in the last few years transferred three from the Atlantic to the Pacific Ocean. Nine of fourteen U.S. nuclear-armed submarines are in the Pacific Ocean, and more could be moved in the future.[25]

To analyze the survivability of the Chinese mobile missiles under the first mobility mode, this article makes several conservative assumptions in favor of China. Even with such conservative assumptions, it would appear that the United States has the capability to destroy all twenty DF-31-like mobile missiles if their locations at the start of the war were known. The real U.S. strike capability may be greater given the conservative assumptions.

First, a U.S. SLBM has a flight time of 14 minutes for a range of 4,000 kilometers. Because the DF-31 has a marginal range to reach the U.S. continental territory, China cannot launch retaliation from deep inside the country. If the United States moves its submarines closer than 4,000 kilometers to the targets, the flight time is one or two minutes shorter, which would increase the efficiency of the U.S. attack. Therefore, an assumption of a flight time of 14 minutes is in favor of China. Secondly, DF-31 TELs would start their movements when China believes that a crisis has developed to a dangerous level and the movements would be continuous during the crisis. Therefore, the DF-31 TELs have only 14 minutes in motion. If DF-31 TELs start to move after the U.S. SLBMs are launched or stop while in motion, it would increase the efficiency of the U.S. attack. This assumption is also in favor of China. Third, the DF-31 TELs move in areas where the road density is at the national average or higher. Because Chinese strategic missiles do not carry nuclear warheads, it is possible to drive these missiles on roads in populated areas. For safety reasons, the DF-31 TELs may be chosen to move in sparsely populated areas where the road density is much lower. The United States needs even fewer warheads to destroy one TEL on roads in unpopulated area, another assumption in favor of China.

According to recent statistics, China has 1.6798 million kilometers of standard roads[26] within a territory of ten million square kilometers. The average road density is 0.17 km/km^2. Assuming that the DF-31 is moving at a speed of v km/hr, it can move for a distance of $R = 0.23v$ in 14 minutes (0.23 hours). When the incoming warheads arrive, the DF-31 TEL is within a circle having an area πR^2. The incoming warheads need to cover only the roads utilized for a DF-31. The total length of the road in the circle is $0.17\pi R^2$. A warhead can destroy a DF-31 TEL in a range of $2r$ on a road. According to U.S. nuclear war plan, a 100 kiloton warhead has a lethal radius r of 2.875 km when attacking a typical road mobile missile.[27] So the number of incoming warheads needed to cover the whole length is

$$n = \frac{0.17\pi R^2}{2r} = \frac{0.17 \times 3.14 \times 0.23^2 v^2}{2 \times 2.875} = 0.0049v^2$$

When the road density increases, the number of warheads needed also increases but has an upper limit. For a very dense road network, the incoming warheads need to cover the whole area of πR^2. Each warhead covers an area of about $2r^2$ for overlap. The upper limit of warheads needed for a high road density is

$$\frac{\pi R^2}{2r^2} = \frac{3.14 \times 0.23^2 v^2}{2 \times 2.875^2} = 0.01v^2$$

According to Chinese road regulations, the speed limit is 20 km/h on a level IV road (the lowest level of standard road) in uneven areas and is 40 km/h in flat areas. The maximum design speed of most semi-trailer towing vehicles is 90 km/h.[28] One can calculate the number of SLBM warheads needed in various cases (see Table 3).

From Table 3, if the TEL is moving at a speed of 20 km/h, only two warheads are needed to destroy a DF-31 TEL moving on a Level IV road in uneven areas and only four are needed if the road network is very dense. If the speed of the DF-31 TEL is raised to 40 km/h, 8 to 16 warheads are needed to destroy one DF-31 TEL depending on the road density. If the speed is raised to

Table 3: Warheads needed to destroy one DF-31.

	Current road density $n = 0.17\ \pi R^2/2r = 0.0049\ v^2$	**High road density** $n = \pi R^2/2r^2 = 0.01\ v^2$
$v = 20$ km/h	2	4
$v = 40$ km/h	8	16
$v = 90$ km/h	40	80

90 km/h, which is technically challenging for road-mobile missiles, about 40 to 80 warheads are needed to destroy one DF-31 TEL. Raising the speed of a DF-31 is an effective strategy to reduce the efficiency of the attack. However, this is still not sufficient to insure that a certain number of DF-31 missiles will survive a first U.S. strike considering the large U.S. nuclear arsenal. If China does not build special roads for its mobile missiles, these missiles will move on standard roads and 2 to 16 nuclear warheads are needed to destroy one mobile missile. Assuming that China will deploy 20 DF-31-like strategic mobile missiles, several hundreds of SLBM warheads have a strong chance of destroying all 20 Chinese mobile missiles if they are located. The United States can certainly afford several hundred warheads in a first strike. Even when the exchange rate is raised to 80:1 by dramatically increasing the speed of DF-31 TELs and the road density, the 1,632 W76 warheads currently in U.S. deployment are still enough to destroy the 20 DF-31 TELs. As mentioned previously, the United States also has some 384 W88 warheads on its SLBM and 1,050 warheads on its ICBMs. The large U.S. strategic nuclear force does not allow for survivability of the 20 Chinese strategic mobile missiles if these missiles are detected and located. Dispersing the Chinese strategic mobile missiles may reduce the efficiency of attack, but the United States can afford the inefficiency. The conclusion is that two dozen DF-31-like strategic mobile missiles cannot saturate a U.S. first strike, that is, no one missile can credibly survive the strike, assuming that they can all be found. The belief that missile mobility alone enables China to build a credible minimum deterrence is incorrect. To increase the chance of survivability, it appears that the DF-31 TELs need to elude U.S. intelligence so they are not targeted by U.S. nuclear weapons.

An article[29] published in a Chinese Communist Party magazine for political education in 2004 described the progress the Second Artillery has made in the past years. It explains the training of the Second Artillery with regard to mobility. However, there is no evidence that the DF-31 has been operationally deployed. This article might be referring to the DF-21, an intermediate range mobile missile[30] when it talks about the transition from a fixed-base to a mobile-base. The DF-31 will follow the operation pattern of DF-21 missiles. China may have deployed some model TELs of the DF-31 (vehicles carrying decoy payloads) for exercise because some pictures show DF-31 patrols in fields.[31]

Another article on Xinhua News Agency's website describes details of an exercise of patrol and retaliation of the Chinese strategic nuclear force.[32] According to this article, the surviving missile TELs began their patrol after absorbing nuclear attacks; the missiles carried nuclear warheads and the warheads were put on the missiles on the fifth day in bad weather after the patrol began; the missile was simulated to be launched on the eighth day. Currently, the TELs use multispectrum camouflage webs to distort the infrared signals.[33] According to another article,[34] the preparation for a launch started at 9:58 am and launched at 10:25 am in a military exercise. Based on this, preparation takes about a half an hour.

These articles provide many details about the mobility strategy of Chinese strategic mobile missiles. The strategy is to elude tracking during patrol of these missiles. One problem is the timing of the patrol. According to the Xinhua article, the patrol begins after a nuclear attack. The author does not believe this is a good time to begin the patrol for two reasons. First, it is too late to patrol after suffering an attack. The missiles are either destroyed in the attack or do not need to go to a new place to launch retaliatory strikes. Second, the road situation and the weather may not be favorable for patrol after a nuclear strike. The author suggests a different timing strategy for patrol, to occasionally relocate a few strategic mobile missiles and hide them in new places. These missiles do not deploy nuclear warheads. The warheads are kept in a safe place and are sent to the missile sites by small and safe vehicles to be deployed when needed. This avoids most problems associated with nuclear safety and security. China can always choose the best time (for example, cloudy weather) and best route (to avoid the sights from U.S. satellites) to relocate its strategic mobile missiles. According to China's nuclear strategy of counter-coercion, China does not need to relocate its mobile missiles frequently. What it needs is to demonstrate that it could elude the U.S. tracking of its strategic mobile missiles by relocating them. As the missiles move in peacetime, the concern of sending misleading nuclear signals is minor.

As stated previously in the discussion on the role of strategic mobile missiles, the location of an operational Chinese strategic missile could be revealed by exposing it to U.S. intelligence gathering during maintenance, for example, via optical sensors on satellites, human intelligence or communications monitoring. For mobile strategic missiles, China can relocate them and hide them again. So the key question is whether or not the United States can track the Chinese strategic mobile missiles all the time when they are moving. If the United States can continuously track the mobile missiles from old to new sites, the patrol would not increase survivability. If these mobile missiles have a high chance to elude the U.S. tracking from space, they could be survivable.

TRACKING CHINESE MOBILE MISSILES BY U.S. SPACE RADAR

It is a U.S. strategic goal to develop a capability for attacking mobile ballistic missiles. The U.S. Nuclear Posture Review (NPR) 2002[35] proposes developing a capability consisting of long-range precision strike weapons and real-time intelligence systems capable of attacking mobile targets including mobile ballistic missiles.

Long-range weapons can be divided into two categories: nuclear and non-nuclear. ICBMs and SLBMs are two main long-range nuclear weapons. The

United States has deployed ICBMs and SLBMs for several decades and these weapons, in principle, are able to attack mobile targets if the targets are located, although the costs may be high. The question is whether or not conventional weapons are able to attack mobile targets from long distances. As conventional weapons have a much smaller lethal radius, they must be very precise to hit the target.

To attack mobile or re-locatable targets, real-time intelligence systems are also required as an adjunct to weapons in order to locate and track mobile targets.

For many years, the United States has employed satellite-based optical and infrared sensors that observe ground targets with a resolution of sub-meters. The optical and infrared observation capabilities from space have been applied in recent warfare and proved to be strategically important. However, the detection of optical and infrared signals is not always possible. Darkness precludes the use of optical signals and heavy clouds can shield both optical and infrared signals. To ensure persistent monitoring all-weather systems are needed. One idea is to detect the targets on the ground by satellite based radar. Radar can penetrate clouds and rain, and space radar is an ideal alternative. The main question is whether space radar can provide persistent tracking. This study uses the DF-31 as the example and assumes that it can move on standard roads at 20 km/h (5.6 m/s), the limit set by the Chinese government for transportation vehicles on level IV roads in uneven areas.[36] In the first mobility mode analyzed in the previous section, the survivability of DF-31 increases when its speed increases. In that analysis the author examined the DF-31 TELs at speeds of 20 km/h and higher to see if a higher speed helps China saturate a U.S. preemptive strike. In the mode analyzed next, higher speeds of DF-31 TELs make them more visible to space radar when the radar monitors moving ground targets. Therefore the author examines a case in which the DF-31 TELs are at low speed (20 km/h).

Research in the United States has explored the roles of using space radar to track Chinese mobile missiles.[37] Space radar detects targets on the ground or in the air by sending radar waves to targets and picking up reflected signals. To reach the same level of resolution, the size of the radar antenna needs to be much larger than the size of the telescope that picks up infrared and optical signals as the radar wavelength (e.g., several centimeters for X-band) is much larger than optical and infrared signals (10^{-4} to 10^{-5} centimeters). Satellites in space cannot carry large radar antenna to achieve such a high resolution. An alternative is to pick up a reflected radar wave at different positions when the satellite is traveling and piece the picture together from coherent signals. Radar working in this mode is called a Synthetic Aperture Radar (SAR). Space-based SAR is good for taking pictures of nearly stationary targets, for example, mapping the terrain. To highlight moving targets, the Doppler effects of radar waves are utilized. If a beam of a radar wave is projected to a moving target with radial speed (speed in the direction of the radar beam), the frequency of the radar wave reflected from the moving target changes slightly. A larger radial speed creates larger frequency shift. Space radar can pick up only the signals from moving targets whose frequency is slightly different from that from stationary targets. This mode of detection is called Ground Moving Target Indicator (GMTI) or Surface Moving Target Indicator (SMTI). When space radar is operated in SMTI mode, all stationary objects in the field become dark and only moving targets with appropriate radial speed are bright. Space radar in SMTI mode is the primary available tool to monitor mobile targets and therefore is the main candidate for tracking Chinese strategic mobile missiles. This analysis will focus mainly on space radar in SMTI mode.

SAR and SMTI were originally carried by airplanes. In recent years the United States began to work on space-based radar that has SAR and SMTI functions.[38] In 1998, the Discoverer II program was created by the U.S. to develop space radar capability[39] as a joint technology demonstration program between the U.S. Air Force, Defense Advanced Research Projects Agency (DARPA), and the National Reconnaissance Office (NRO). It was intended to develop prototype SMTI/SAR satellites. The objective was to deploy 24 satellites and achieve greater than 90% access to areas of interest at 30 to 40 degrees latitude.[40] The satellites would orbit at 770 kilometers with a 54 degree inclination, and each satellite radar would have a nadir hole of 70 degrees elevation or 20 degrees from vertical.[41] Radar is blind in its nadir hole because the radar cross-section of the ground becomes large and saturates the radar system. The satellite constellation was expected to be operational during fiscal year 2008.[42] The average cost for one satellite was estimated at $100 million and the 20-year life-cycle cost of a large operational system was expected to be less than $10 billion.[43,44] A desired attribute of the system was its ability to track critical mobile targets from "birth-to-death."[45] In SMTI mode, the Discoverer II system would have a detectable speed between 1.3 and 58 knots and the nadir hole is believed to be 70 degrees elevation or 20 degrees from vertical.[46,47] The space radar monitors a target point frame by frame with a reasonable time interval by scanning the areas of interest. As long as a moving vehicle is cued by space optical/infrared sensors or identified as a critical target by radar, the radar would begin its track in SMTI mode. "Off-road tracks are predicted based on the estimated velocity, and on-road tracks are predicted based on the estimated speed but constrained to roads. When tracks pass through intersections, predicted tracks are placed on each of the links emerging from the intersection."[48] If the target vanishes, the system would identify the location at the moment of disappearance as a hide.[49]

The U.S. Congress was not satisfied with the Discoverer II program[50] and ended it in 2000 because of uncertainty in costs and schedule. A new space-based radar program was set up to continue the effort of space radar capability.[51] The new program is led by the Secretary of Defense to the Air Force. Its objective is "to field, beginning in 2008, a space-borne capability for theater commanders to track moving targets."[52] The total schedule seems to be more relaxed than its predecessor. The goal of the program is still to provide global (except the 2 pole areas above 65 degrees north and south latitude), all weather, day/night, persistent access of areas of interest with SMTI and imaging. The system could be a combination of Low Earth Orbit (LEO) satellites at a nominal altitude of 1,000 km and Medium Earth Orbit (MEO) at a nominal altitude of 10,000 km. A LEO constellation requires 21 satellites to provide persistent global access and the orbits have a 53 degree inclination. The SMTI requirement is to track a target with 10-decibel (10 m^2) radar cross-section at 2,800 km.[53] Use of radar on MEO satellites is much more improbable and is not a focus of this discussion.

The space based radar program was criticized for a lack of information regarding its feasibility.[54] In 2005, the Space Based Radar name was changed to Space Radar and the new program is a joint DoD and intelligence community program. The first operational satellite of the system is currently planned to be fielded in 2015.[55,56] Besides the schedule, there has been very little information released about any proposed changes to the technical features of the system.

This analysis assumes that during the period between 2015–2020, the United States will deploy a LEO constellation of 21 satellites for space radar reconnaissance. Space radar in SMTI mode has a maximum detectable range of 2,800 km for targets with radar cross-section of 10 m^2 and a minimum detectable speed of 1.3 knots (2.4km/h or 0.67m/s).

The period of a satellite at 1,000 km is 6,300 seconds (1.75 hours) and the speed of the satellite is 6,687 m/s. When a radar system looks at a target at its maximum detection range (2,800 km), the grazing angle is 9.5 degrees and the core angle between the nadir point and the target point measured at the earth's center is 22 degrees. The footprint of the radar has a view angle of 44 degrees from the earth's center. To have 100% viewing access to a point of interest, 8 (360/44) satellites are needed. Three groups of eight satellites are required to cover the area below 65 degrees north and south latitude. A constellation of 21 satellites have blind slots between two sequential satellites. See Davis[57] for a good discussion of satellite coverage. Radar could monitor a point of interest for 770 seconds (13 minutes or 0.21 hours).

Based on this information about the future U.S. space radar system, this article examines how capable the U.S. space radar system is in tracking the Chinese strategic mobile missiles. The next section analyzes three factors that complicate the tracking task, sight block, small radial speed, and radar stealth. In the analysis it is assumed that China chooses to move the DF-31 TELs during peacetime rather during a crisis. If the DF-31 TELs move in bad weather the U.S. optical and infrared sensors will be unable to detect this movement.

SIGHT BLOCK

Space radar operated in SMTI mode has a nadir hole of 70 degrees elevation or 20 degrees from vertical. The diameter of the hole is approximately 560 km (2×770 km $\times$ tan (20)). The radar cannot detect the target in the nadir hole, and it is difficult for a missile TEL to intentionally locate inside a nadir hole because it takes only about one minute for a space radar satellite to pass a distance of 560 km. However, because some natural or man-made objects may block the sight of a satellite at low elevations, the nadir hole could add blind intervals, although these intervals may not be continuous.

According to current design, space radar requires a grazing angle of 9.5 degrees to detect ground targets before it hands over the tracking task to another radar. However, many natural and man-made obstacles prevent space radar from seeing some ground targets when the radar has a low elevation angle of sight. For a missile TEL moving on regular roads, trees, buildings, and hills on either side of the road could block radar signals.

The chance for space radar to see a missile TEL can be measured by the minimum elevation angle θ, below which the space radar's sight is blocked by obstacles on at least one side of the road as shown in Figure 1. Because China is likely to know at least approximately the orbit of the satellites, the TEL will know which side of the road to hide on. A large θ will result in increased probability that the radar will not be able to detect the missile TEL. If θ equals 9.5 degrees, it means that space radar will be able to continuously detect the TEL except when it passes through the nadir hole. If θ is close to 70 degrees (the elevation of the nadir hole), it will be very difficult for radar to detect the TEL. A θ between 9.5 and 70 degrees allows the space radar to see the TEL but its track of a point of interest is not continuous during its monitoring period.

In Figure 1, the sight of the space radar is blocked by the shelter and it cannot detect the TEL in the shadow behind the shelter. In the following calculation, AB is the width of the truck (2.5 m),[58] AE is the height of the TEL (3.1 m), DC is the height of the shelter, and BC is the distance of the shelter to the TEL. Therefore:

$$\tan(\theta) = \frac{AE}{OA} = \frac{DC - AE}{AB + BC} = \frac{DC - 3.1}{2.5 + BC}$$

In Figure 2, buildings on a side of the road are used to illustrate and assess the effects of sight block. A photo of this scenario is also available on the Internet.[59]

This study assumes that the buildings are three stories high and their height is approximately 10 m. It also assumes that a DF-31 TEL is located 3 m from the buildings (1.5 m walkway and 1.5 m bikeway) while moving on this road. One can then derive the minimum detectable elevation angle θ as 51 degrees. The angular speed of elevation angle θ is smaller at lower elevations, and therefore it takes more time for the satellite to move up one degree before

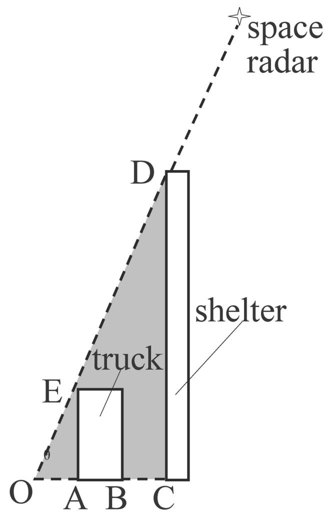

Figure 1: Blocked sight of space radar.

the 51 degree level than after. When the TEL is in the nadir hole as the elevation of the satellite moves up to 70 degrees, the visible interval is between 51 and 70 degrees. Therefore a space radar has roughly less than a one fourth chance [(70–51)/ (90–9.5) = 24%] to detect the TEL if it moves on the road

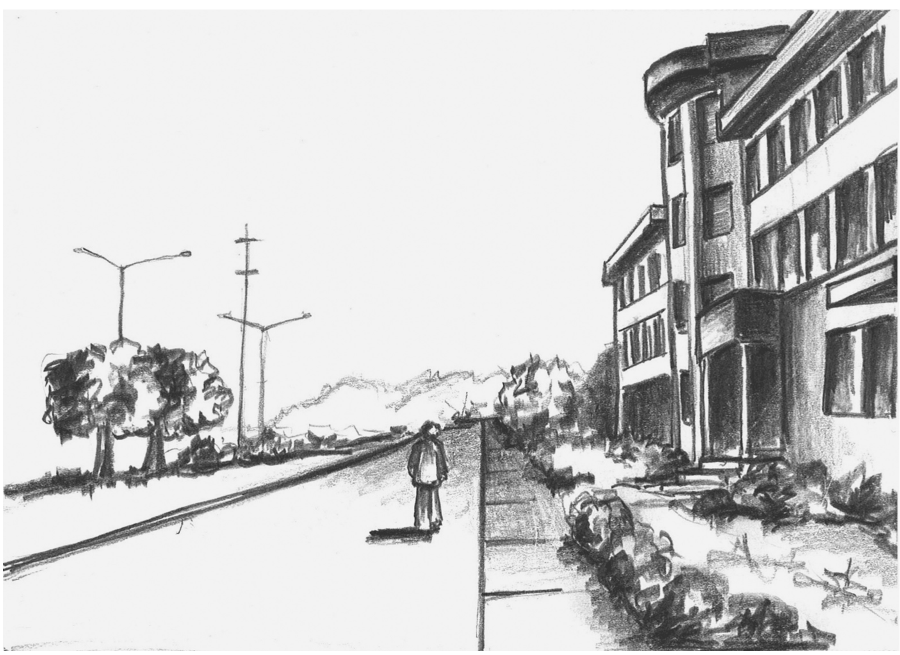

Figure 2: An example of buildings contributing to sight block.

Figure 3: A road with uneven hills on both sides.

referenced in Figure 2. The space radar has even less of a chance to detect a TEL if it moves in populated areas where high buildings increase the shielding of roads.

The article also analyzes a road containing uneven areas, as shown in Figure 3. A photograph of this scenario can be viewed on the Internet.[60]

The hills on one or both sides of the road can block the sight of the radar. The minimum detectable elevation angle θ depends on the topography and can be simply estimated as the incline of the hillside close to the road. In this picture, the incline of the hillside is approximately 45 degrees, which can be expressed as the minimum detectable elevation angle θ. In this example, the space radar has slightly more than a one in four chance of detecting the TEL moving on the road.

Figure 4 describes a scenario where trees line both sides of a road. Assuming the space radar operates at X-band, it cannot detect a TEL through the trees. Because many trees have an expanded crown, they provide almost complete shielding with a narrow gap to the sky.

In this case, the space radar has almost no chance of detecting the TEL. China is now planting many trees for environmental reasons, which may also contribute to shielding missile TELs from U.S.-based radar.

Figure 4: Trees line both sides of the road.

The Chinese can elect to move TELs on roads with shelters that are high and close to the road, reducing the chance for space radar to detect the TEL. In the three cases already described, the space radar has equal or less than a one in four chance of detecting the missile TEL. A single satellite monitors a specific point for approximately 13 minutes before another satellite picks up the target. This means that space radar may not be able to detect a TEL moving on a shielded road for a significant fraction of the 13 minutes and the TEL has a greater chance to elude tracking from space radar.

SMALL RADIAL SPEED

A target becomes invisible to space radar in SMTI mode if its radial speed is smaller than the minimum detectable speed of the radar. A TEL moving very slowly or stopping is undetectable to space radar in SMTI mode. In this situation, it looks like the vanished target remains stationary. It would be possible to verify the TEL's position by switching to regular SAR mode and taking a still picture. However, a fast moving target can also create very small radial speed to space radar and therefore become invisible if its moving direction is perpendicular to the sight of the space radar. One cannot assume that the vanished target stays stationary in this situation.

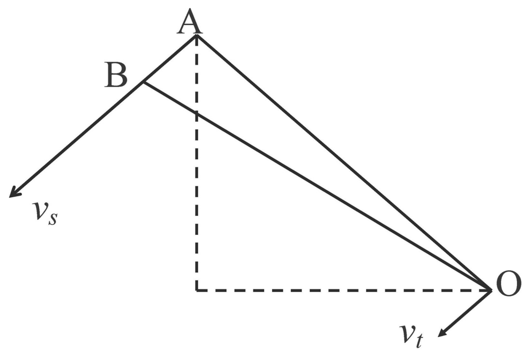

Figure 5: Parallel movements of TEL and radar.

The designed minimum detectable radial speed of the space radar is 1.3 knots (2.4 km/h or 0.67 m/s). A TEL moving at 20 km per hour requires an inclination smaller than 0.12 radian (7 degrees) to the perpendicular direction in order to be undetectable to radar. Because the satellite is in perpetual motion, a perpendicular geometry can be changed and the duration of invisibility may be limited. The article estimates how long invisibility can be maintained if the TEL does not change its moving direction for the duration of invisibility.

In Figure 5, the TEL is at O and its movement can be ignored because its speed ($vt = 20$ km/h $= 5.6$ m/s) is much smaller than the speed of the satellite ($vs = 6700$ m/s); the velocities of the TEL and the satellite are parallel when the satellite is at point A; the velocity of the TEL is perpendicular to the TEL's sight to the space radar (OA) when it is at A; the satellite moves from A to B in time t; and at point B, the TEL's radial speed reaches the minimum detectable speed ($vm = 0.67$m/s). Therefore

$$AB = \frac{v_m}{v_t} BO$$

$$t = \frac{v_m}{v_s v_t} BO = \frac{0.67}{6700 \times 5.6} BO$$

BO is between 1,000 and 2,800 km, so t is about 18–50 seconds. In 18–50 seconds, the TEL moves for a distance of about 100–280 meters. The duration of invisibility is twice that of t, approximately 36–100 seconds and the TEL can move for 200–560 meters if it does not change its direction.

As shown, if the TEL does not change direction, it can become invisible to the radar for tens of seconds because of the low radial speed of the TEL. During this time, the TEL can move hundreds of meters. After the TEL becomes visible again, the radar may not be able to identify which target is the one it tracked.

Almost every time a TEL makes a turn, there is a point at which the TEL's velocity is perpendicular to its sight to the satellite and is parallel to the velocity of the satellite as shown in Figure 6.

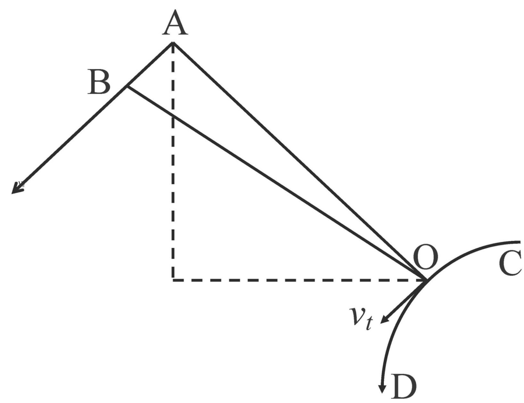

Figure 6: A TEL making a turn.

In Figure 6, a TEL makes a turn from C to D. O is a point during the turn. At point O, the TEL's velocity is perpendicular to its sight to the satellite. The TEL is invisible to the radar around point O. Invisibility is created almost every time the TEL makes a turn and the track by radar is interrupted. The radar may pick up the target TEL later when it is visible to the radar if there are no other vehicles around. However, if the TEL turns at a busy intersection, the radar cannot identify the TEL amidst a group of vehicles after a temporary blinding.

If a TEL patrol route and timing is chosen carefully to keep its direction perpendicular to its sight to the satellite at all times, it can be invisible to the radar until a successor satellite appears after 770 seconds. During the 770 seconds, the TEL can move up to 4.3 km without detection by the radar, and the space radar loses track of the TEL. To implement this strategy, the trajectories of the space radar satellites must be accurately predicted. These predictions may not be reliable as the satellites may deviate from their inertial trajectories by slightly adjusting velocity. This evasion strategy depends on China's capability to track objects in space and is likely to improve in coming years, and although it is not currently reliable, could become a concern for the United States in the future.

RADAR STEALTH

If a radar searches a solid angle Ω in time ts, its maximum detection range can be derived from the following equation:[61]

$$P_T A_R = \frac{4\pi\ k_B T_0 F_n L (S/N)_{\min}}{\sigma} \frac{\Omega}{t_s} R_T^4 \tag{1}$$

where PT is the average power of the radar, AR is the area of the antenna of the radar. If the radar cross-section of the target σ is reduced while all other factors

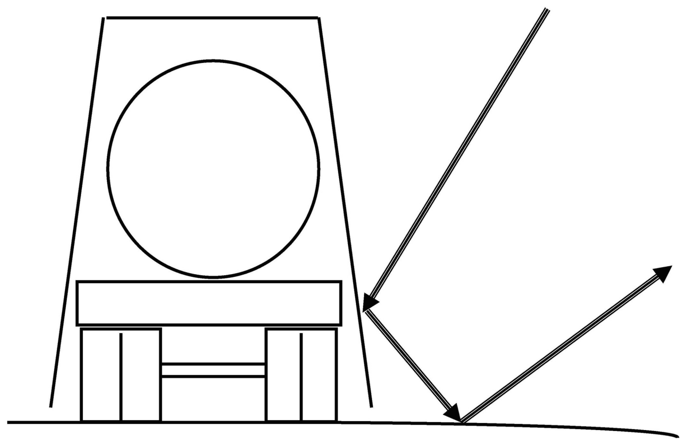

Figure 7: Radar beam projected to one side of the radar stealth cover.

remain the same, the 4th power of the maximum range *RT4* will be reduced proportionally. The current space radar system is expected to have a maximum detection range of 2,800 km for a target with a radar cross-section of 10 dB (10 m^2). Chinese conventional mobile missiles are assumed to have a radar cross-section of 10 dB.[62] 10dB (10 m^2) radar cross-section for a DF-31 TEL is used as a benchmark to estimate how many satellites the United States needs. Two main technologies are used to create radar stealth, coating the target with radar absorbing materials and changing the shape of the surface so fewer radar waves are reflected. The two technologies could certainly apply to the DF-31 TEL if China feels compelled. It is much easier to change the surface shape of a missile TEL than an airplane or warship for radar stealth for two reasons, an airplane needs to maintain its aerodynamic function when its shape is being changed (no such concern exists for a truck) and it does not matter if the radar is immediately overhead because the truck is in the nadir hole in this case. One alternative is to cover the truck with a rectangular cabinet with flat surfaces.

Figure 7 is a sectional view of a DF-31 TEL covered by a simple cabinet. The top of the cover is horizontal whereas the left, right, and back sides are nearly vertical and face slightly up. The radar signals reaching the top of the cover are reflected, and the beams reaching the sides of the cover are reflected downward. As the sides face slightly up, the radar signals reaching the ground surface are not reflected back to the radar.

If space radar is immediately overhead, the reflected signal is strong. However, the TEL at this position is in the nadir hole and is invisible to the radar in SMTI mode. The front of the TEL may not be able to be shielded as completely as the remainder. The TEL may have a larger radar cross-section from a front view than from alternate views. The front part of the truck could be screened with metal for stealth and the driver could still see to drive.

The radar cross-section of the radar stealth cover originates mainly from the edges of the planes from all angles except a few directions perpendicular to these planes. Knott et al. provides tools to estimate the radar cross-section of edges.[63]

If radar detects an edge along its bisector, the radar cross-section of the edge is roughly the square of the edge's length ($l2$). According to Figure 6.19 in Knott,[64] the radar cross-section for an edge between two perpendicular planes is $\alpha\ l2$, where α ranges from 0.20 to 0.79 depending on the polarization. For an edge with a length of 18 m, its radar cross-section ranges from 65 m^2 to 256 m^2 if the radar is on its bisector. A slight deviation from the bisector direction leads to a dramatically reduced radar cross-section. Most of the time, each edge contributes a radar cross-section of about $\lambda 2$ or less. The space radar is at X-band and has a wavelength of a few centimeters. Therefore, the total radar cross-section of the radar stealth cover can be theoretically reduced to about 0.01 m^2 from most directions.

The current requirement for the space radar requires it to detect a target with a radar cross-section of 10 m^2 at 2,800 km. The footprint of each radar has a half-view-angle of 58.5 degrees from the radar; a solid angle of 3.0; a half-view-angle of 22 degrees from the earth's center; and a solid angle of 0.46 from the earth's center. The solid angle of the earth surface covered by 21 satellites at a rate of 96% is approximately

$$0.46 \times 21/96\% = 10.0$$

The geometry of the radar is shown in Figure 8.

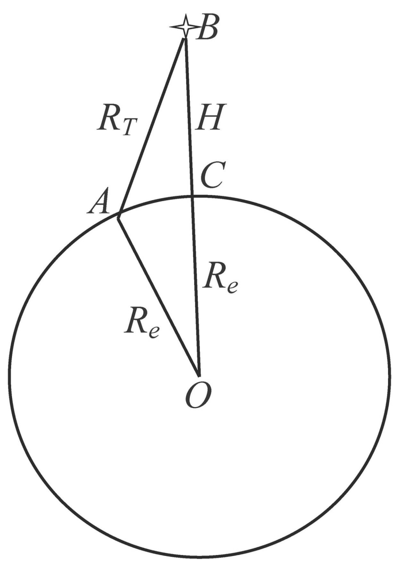

Figure 8: Radar detection geometry.

In Figure 8, the radar is at point B; $BA = RT$ is its maximum detectable range; $OA = OC = Re$ is the radius of the earth (6,370 km); $BC = H$ is the altitude of the radar (1,000 km); $ABC = \theta$ is the half-view-angle of the footprint from the radar; and $AOC = \alpha$ is the half-view-angle of the footprint from the earth's center.

From Equation 1, the following combination is a constant if the radar's specifications, scan time and detection ability do not change:

$$\frac{\Omega R_T^4}{\sigma} = C \tag{2}$$

If the radar cross-section of the DF-31 TEL is reduced, the maximum detection range RT will also be reduced. The half-view-angle of the footprint from the radar θ can be derived by the following equation:

$$\cos\theta = \frac{(H+R_e)^2 + R_T^2 - R_e^2}{2(H+R_e)R_T}$$

$$\Omega = 2\pi(1-\cos\theta) = 2\pi\left[1 - \frac{H^2 + 2HR_e + R_T^2}{2(H+R_e)R_T}\right]$$

Therefore

$$\frac{\Omega R_T^4}{\sigma} = \frac{2\pi}{\sigma}\left[1 - \frac{H^2 + 2HR_e + R_T^2}{2(H+R_e)R_T}\right]R_T^4 = C \tag{3}$$

Based on Equation 3, we calculate how the maximum detection range varies as the radar cross-section of the target (see Table 4). The consequence of a small radar cross-section is a small footprint. The half-view-angle of the footprint from the earth's center α can also be derived by the following equation

$$\cos\alpha = \frac{(H+R_e)^2 + R_e^2 - R_T^2}{2(H+R_e)R_e}$$

The solid angle of the footprint from the earth's center is

$$\Phi = 2\pi(1-\cos\alpha)$$

If a 96% coverage rate is maintained, the number of satellites needed in this case is

$$N = \frac{10.0}{\Phi}$$

Table 4: Number of satellites vs. radar cross-section of targets.

RCS (m^2)	10.0	5.1	2.0	0.85	0.51	0.20	0.057	0.010
R_T (km)	2800	2400	1970	1670	1520	1310	1130	1033
N	21	30	50	80	110	200	500	2139

Based on these equations, Table 4 shows the number of satellites needed as a function of radar cross-section of the target.

From Table 4, the number of satellites needed increases when the radar cross-section of a DF-31 TEL decreases. 2,139 satellites are needed for a 0.01 m^2 radar cross-section for the system to maintain its detection capability. Even if the radar cross-section of a DF-31 cannot reach its theoretical limit, the effort in radar stealth of a DF-31 TEL can still significantly reduce the footprint of the radar and increase the number of satellites needed. For example, 50 satellites are required when the radar cross-section of DF-31 TEL is reduced to 2.0 m^2 and 200 are required when the radar cross-section is reduced to 0.2 m^2. Space radar becomes too costly under these circumstances.

CONCURRENT EVASION STRATEGIES

A DF-31 TEL can take concurrent approaches to elude tracking from space satellites: the TEL can be enclosed with a flat cabinet so it is stealth to radar from most angles; it can move on a road with shelters (trees, buildings, hills) on one or both sides of the road, avoiding detection at low elevation, or it can turn at busy intersections to elude the radar in SMTI mode as shown in Figure 9.

In Figure 9, points A, B, C, D, and E represent the positions of the space radar. Point B has a small elevation angle, so the radar's sight to the TEL is blocked by the trees. When the satellite is at point C, the TEL is in its nadir hole and is invisible to the space radar in SMTI mode. Radar at point D cannot

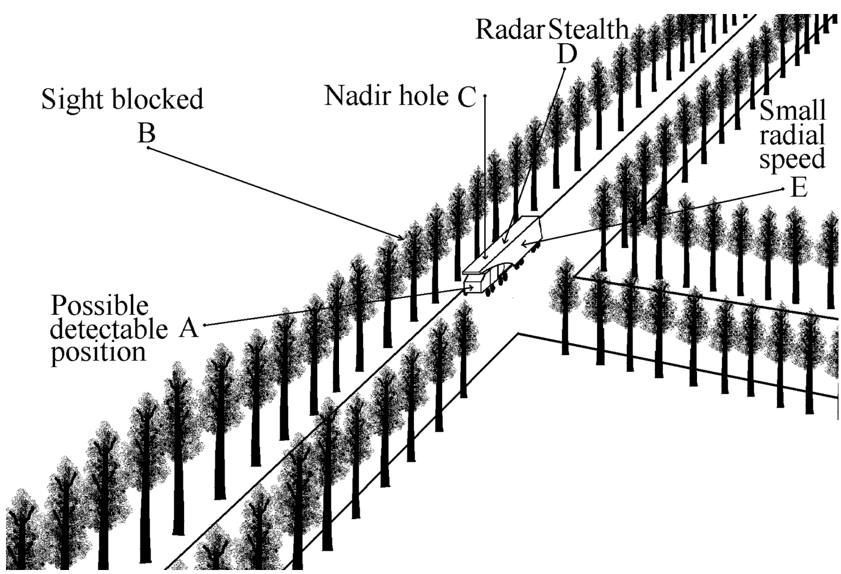

Figure 9: Observations of missile trucks from different angles.

see the stealth TEL because it has a very small radar cross-section at this angle. Space radar in SMTI mode at point E cannot detect the truck as the TEL's movement is nearly perpendicular to the radar creating a very low radial speed. Point A, which is in the front of the truck, is the only good position for radar detection. Radar view from this position could detect a high radial speed; its sight could reach the TEL, and the radar cross-section of the TEL in this direction may not be small. This illustrates that radar in SMTI mode can see a moving TEL only in rare instances. China can add some simple measures to increase the effects of the aforementioned approaches and complicate the task of radar tracking. For example, it could deploy decoys so that the identification of real TELs increases the burden of radar.

Overall, the proposed U.S. space radar system cannot constantly track Chinese strategic mobile missiles "from birth to death" if China takes simple countermeasures. To defeat these countermeasures, the United States needs to make two major efforts. First, to multiply the number of satellites, so several satellites can monitor the same point of interest with the idea that at least one of the satellites would be at a good position to watch the TEL. Second, to significantly raise the power of the radar so it can visualize stealth targets from LEO and even from MEO. These efforts are both expensive and technically challenging. The mobility and anti-mobility competition is not in favor of the United States.

CONCLUSION

The proposed U.S. space radar system, which is expected to be operational after 2015, cannot provide the United States with a new capability to effectively track Chinese strategic mobile missiles after they are deployed. China could relocate these missiles in peacetime and hide them at new sites. It is unreasonable for the United States to build a capability to destroy all Chinese nuclear weapons.[65] At the same time, the mobility of China's strategic missiles cannot bring China's nuclear force to a higher level, the so called credible minimal deterrence, if China limits the number of missiles to several dozen. Therefore, the United States would have little reason to overreact to the development of mobility.

Based on the present analysis, it is not advisable to begin patrol of the Chinese mobile strategic missiles after suffering a nuclear attack, as road conditions and weather may not be favorable for patrol after a nuclear strike. Nor is it advisable to begin the patrol in a crisis for three reasons. First, the weather may not be favorable, the patrol may send unintentional nuclear signals, and this strategy is counter to the Chinese nuclear philosophy, which assumes a low possibility of nuclear attack. China needs to demonstrate a capacity for hiding its strategic missiles by eluding space tracking. China could periodically move its strategic mobile missiles to train its soldiers thus demonstrating this capability in peacetime. Strategies might include timing (cloudy weather) and routes chosen for the patrol to avoid detection. China could increase the TELs radar stealth and send out decoy TELs to train its soldiers. These efforts might provide a high probability that the TELs could elude detection. According to the present analysis, moving the TELs on standard roads rather than roads specially built for heavy missiles is critical for the survivability of the DF-31 missiles. The present modeling suggests that the DF-31 missile may have been downsized at the sacrifice of the yield of its warhead and its range to achieve greater mobility. If this is true, it would suggest that China cares far more for the survivability of its nuclear weapons than for their strike capability and that China's approach to increase the survivability of its missiles is to hide its nuclear weapons rather than to build large numbers to saturate preemptive strikes. These concepts are compatible with China's strategy of counter-coercion.

The United States is making efforts to acquire the capability to track Chinese strategic mobile missiles and may claim some years from now that it has achieved that capability. This would have negative security consequences. First, the huge investment on a space radar system with a declared capability of persistently tracking may provide the illusion that the dissuasive effects of the Chinese nuclear weapons can be neutralized. This may encourage the U.S. decisionmakers to risk unnecessary conflict with China and prevent the two countries from seeking a peaceful solution to a crisis. Second, the U.S. effort in tracking Chinese strategic mobile missiles may worry Chinese decisionmakers. If Chinese decisionmakers believe that they can successfully hide their strategic mobile missiles by relocating them, they will not require their missiles to carry nuclear warheads with them when they are mobile. This can significantly reduce safety and security risks and is in the interests of the United States and China both. On the other hand, if the Chinese decisionmakers were convinced by U.S. declarations that the proposed space radar system could persistently track Chinese strategic mobile missiles, China might be forced to consider putting nuclear warheads on mobile missiles. This would not be in the interests of either side. Bilateral discussions between the two countries are needed to promote a clearer understanding of mutual intentions and capabilities. Because the Bush administration is uncomfortable negotiating with China as a nuclear peer, the discussions could begin at a nongovernmental level and gradually move to the governmental level when mutual understandings are reached.

NOTES AND REFERENCES

1. For example, *US Nuclear Posture Review 2002* indicates that "Immediate contingencies involve well-recognized current dangers. Current examples of immediate contingencies include an Iraqi attack on Israel or its neighbors, a North Korean attack on South Korea, or a military confrontation over the status of Taiwan." See, Nuclear Posture Review [Excerpts], 8 January 2002. http://www.globalsecurity.org/wmd/library/policy/dod/npr.htm (12 March 2007).

2. “Lee Denghui: 48 US Nuclear Submarines targeting Beijing, Shanghai, and the Three Gorges,” *People First Times*, http://www.pfts.com.tw/shownews.asp?id=5005, in Chinese (12 March 2007).

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