Mobile Targets From Under the Sea

An MIT Security Studies Program Conference

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Executive Summary by Owen Cote

This report is in part a summary and in part a reaction to a conference held in December 1999 by the MIT Security Studies Program. The conference looked broadly at two questions. Why mobile targets? Why from under the sea? Operation Allied Force demonstrated some important facts about our current military posture, and particularly about our strike warfare capabilities, that hint at answers to these two questions. First, Integrated Global Positioning System (GPS) and Inertial Navigation System (INS) guidance will soon "solve" the fixed target problem. What does this mean? If the U.S. military is vigilant and aggressive in developing and protecting GPS/INS, it will be able to guide weapons of any range, precisely, night or day, cloudy or clear, to any point on the surface of the earth. When the target being attacked is fixed at the point the weapon is aimed at, it will simply be a matter of assigning the right payload to assure that the target will be within that weapon's lethal radius.

Second, the mobile target problem is far from being solved. One definition of the mobile target problem is those circumstances in which the attacker cannot be certain his target will be at the point of its most recent detection when the weapon he aims at it arrives. In this category of targets lies the bulk of an opponent's military forces, which remain still for much of the time, but which move enough to make them mobile by this definition. During Allied Force, Serbian army and police forces engaging in ethnic cleansing operations faced little opposition from allied air forces, even though the latter enjoyed complete air supremacy by most definitions of that term.

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This was a shock to some for whom Desert Storm had validated the long-claimed but rarely-achieved ability of air power to attack and defeat an opposing army in the field.

Part of the explanation is that Serbian ground-based air defenses, another part of the mobile target set, were able to survive the war reasonably intact. Though they bought their survival essentially through self-suppression, and therefore failed to shoot down more than a few allied aircraft, these defenses had two significant effects. They limited allied aircraft to medium altitude operations, which contributed to the ineffectiveness of those aircraft against mobile targets, and they forced allied planners throughout the war to continue the expensive practice of providing strike aircraft with the full panoply of defense suppression assets, which reduced the strike capability of a force whose overall size was limited by access to ramp space at in-theater airfields, but whose operational tempo was limited by shortages in key defense suppression assets.

Third, a definition of the mobile target problem that treats them as time urgent fixed targets strongly implies a solution that will emphasize a significant reduction in the time it takes a weapon to arrive on target once it is detected. There are a variety of measures that could have this effect, but one that is likely to be an element of the solution in many cases is greatly reduced time-of-flight weapons. Time of flight is broadly dependent on range, both for the obvious reason that range divided by speed equals time, and because weapon designers are usually forced to trade off range and speed. For example, when one looks at the volume available in a VLS tube, per pound of payload, one generally gets more speed and less range from a rocket, and more range and less speed from a cruise missile. Thus, one consequence of a greater emphasis on reduced time-of-flight weapons will be a greater reliance on tactical ballistic missiles (TBMs) instead of cruise missiles, which in turn will pull the launch platforms for those weapons closer to their targets.

Fourth, other pressures will be driving launch platforms away from their targets. These pressures can be plotted along two axes, the technical and the political, and the near and the far term. For example, in the near term, political constraints on the U.S. military designed to limit its own casualties in conflicts over less than vital interests like Allied Force will increasingly drive it toward the use of weapons that allow greater standoff distances for its manned launch platforms. Political factors may also constrain the U.S. military's access to bases from which to operate those platforms. In the longer term, assuming the potential for conflicts over more vital interests with a more equal opponent, purely military factors may return to dominate as they did during the Cold War, but probably with the same broad effect. On these battlefields, direct fire engagements will be rare because they will be so lethal to both sides, and fixed bases near the theater of combat will be extremely vulnerable to physical attack by TBMs and cruise missiles.

Fifth, the mobile target problem therefore presents both challenges and opportunities to the Navy. It is a new problem where the potential demand for naval forces greatly exceeds the current supply. Therefore, it is also one of those mission areas within which each of the Navy's major platform communities can and should search aggressively for profitable niches in which its strengths are most relevant. For example, the submarine force, whose stealth and endurance give it essentially unrestricted access to the littoral waters from which power must be projected from the sea, waters in which other naval platforms can ot deploy covertly in advance of conflict, and in which they may not be able to safely operate early in a conflict, may find a niche as a TBM shooter against high value, time urgent targets. But filling this niche will depend on new weapons, new sensors, and new sensor-to-shooter or sensor-to-weapon communication networks that do not exist today. This report helps explain why efforts by the Navy and by the submarine force to develop these new systems, if successful, will result in dramatic innovations in the U.S. military's precision strike capabilities that will be relevant to the demands of the future security environment.

The body of the following report is divided into three main sections and a conclusion. The first section looks at the United State's future security environment and makes some assumptions about the geopolitical and technical trends which will inform it. It divides this look into a near and a far term perspective, with the far term loosely defined as the time it might take for a new peer competitor for the United States to emerge.

The second section takes these assumptions about trends in the near and far term security environment and looks more closely at how they will effect different platforms and methods of conducting strike warfare, particularly against mobile targets. It uses a metric for comparison that contains the five operational hurdles that must be cleared in strike warfare. They are: secure base access and survivability, connectivity, the ability to penetrate defenses, the ability to find and identify targets, and the ability to attack and destroy them. It then asks for each platform whether it will encounter increasing or diminishing returns in its future efforts to clear these hurdles.

The third section demonstrates that submarines are likely to grow in importance in strike warfare, and particularly in strike warfare against mobile targets. This is because their current and enduring strengths will be in great demand in the future security environment, while they will face dramatically increasing returns in their future ability to clear those hurdles where they are now weak. This section also demonstrates that although they may cede some tasks to other platforms, aircraft will retain unique advantages in strike warfare, particularly in their infinite reusability and ability to deliver large payloads. On the other hand, it argues that radical innovation will be needed to combat the diminishing returns on investment aircraft face today in penetrating advanced air defenses, and will face tomorrow in surviving attacks at their bases, especially at land bases within range of an opponent's precision TBMs and cruise missiles.

The report concludes by suggesting that the submarine force begin in the near term to apply the unique advantages of its platform to the task of destroying rather than merely suppressing modern, mobile radar-guided SAMs.

Assumptions About the Future Security Environment

The future security environment will be affected by new geopolitical and technical trends in both the near and the far term. The dominant geopolitical change in the new security environment has been the virtual elimination for military planning purposes of the U.S. continental commitment to the security of Western Europe from attack by the Warsaw Pact. The dominant technical change in the new security environment has been the continued if not accelerating advance in the performance of sensors, weapons, and communication links; all broadly driven by the underlying logarithmic advance in the speed and processing power of microelectronic information processors. These and other subsidiary changes in the external security environment mutually interact in many ways, but with two general consequences; one which the United States is already experiencing today, and one which it is likely to face in the coming decades.

The near term consequence is that the U.S. military will find itself fighting in conflicts where the political stakes for the United States are dramatically lower than those of its adversaries, and where pre-arranged military alliances are either absent or not directly relevant. In these conflicts, the opponent will be unable to contest American military superiority in direct, force-on-force engagements, but will seek instead to attack the political will of its leaders by deploying its more limited military capabilities against those points where it will be most able to cause American military casualties.

In general, these points of vulnerability will vary according to the degree to which American military forces present the opponent large, fixed, surface targets such as air bases or ports close to the theater of battle; to the degree that they must use non-stealthy, manned platforms to penetrate ground, sea, and air battlefields protected by modern defensive weapons; and to the degree that the opponent is able to focus its more limited exploitation of modern military technology at those points of maximum American weakness or exposure. Under no circumstances will the resulting vulnerabilities be decisive in a traditional military sense: the

goal for an opponent will be to use these vulnerabilities to drive up the political costs of an engagement, ideally in such a fashion as to deter the engagement altogether.

In the more distant term, the battlefields for which the U.S. military needs to prepare are obviously less well defined, but a longer term perspective does force consideration of the potential reemergence of one or even several so-called "peer competitors," or put in other terms, the reemergence of a bipolar or multipolar balance of power to replace what some are already calling today's unipolar moment.[1] Should such a power or powers emerge, the issue of preserving a Eurasian balance of power would return as the main focus of U.S. military planning, but it is more likely than not that this focus will be on political fault lines with a maritime rather than a continental aspect. This is because the collapse of the former Soviet Union and the reunification of Germany have fundamentally altered the balance of power along Eurasia's major land boundaries, making it unlikely in the extreme that a renewed continental commitment of American ground and air forces on the scale which obtained during the Cold War will be necessary.[2]

Instead, strategically significant imbalances in the Eurasian balance of power are most likely should China continue to grow in power and ambition, intensifying the already existing triangular competition for security and prestige between China, Japan, and India, and threatening the many wealthy medium powers in the long littoral extending between Korea and the Persian Gulf. Should an imbalance of power threaten to develop as a result, the United States might once again need to commit a major element of its military forces to restore the balance. That commitment would be conditioned by two factors: the borders in need of protection will bisect seas rather than rolling plains, and the opponent will be sufficiently advanced to exploit modern military technology much more widely and deeply than today's opponents. This will result in a return to more traditional military planning, in which both sides have the highest national interests at stake and are willing to suffer substantial military losses in their pursuit, and in which

victory will be determined by the result of relatively unlimited force-on-force struggles for control of the sea and the land alongside it, between opponents wielding the most advanced weapons available.

Strategy and the Near Term Security Environment

In the near term, American military strategy needs to account for the political asymmetries between the United States and its potential opponents, the military asymmetries, and the changed nature if its alliance relationships. Taking these factors into account in anticipating likely conflicts makes clear the importance of minimizing casualties, helps identify where casualties are most likely to be incurred, and demonstrates why allies will be more likely to withhold or limit access to local bases.

Political leaders of strong powers fighting weak powers over less than vital interests constrain their military forces in order to avoid casualties. America's aversion to casualties in post Cold War conflicts has been much discussed. Fear of casualties often measured in the thousands or even tens of thousands dominated the debate over whether to launch a ground war in Desert Storm, a conflict in which American stakes were as high as they are likely to be in any future conflict. In the event, casualties during Desert Storm were orders of magnitude lower than expected, leaving the question of America's tolerance for casualties open for debate.[3] But then the events of early October 1993 in Mogadishu, Somalia seemed to resolve the debate.[4] The death of a small number of Rangers and Delta Force troopers abruptly led the United States to abandon that operation. A growing consensus developed that the United States could be stopped in its tracks with the deaths of a few of its soldiers, leading some to question the viability of its enormous but seemingly unusable military power.

The recent experience in Kosovo certainly does not provide evidence that the United States is not casualty averse. NATO air crews were ordered to remain above 15-20,000 feet

throughout the entire conflict because it was only at that altitude that they remained immune from Serbian air defenses, and, of course, ground forces were foresworn from the outset. This reduced nearly to nil NATO's ability to stop or limit the ethnic cleansing being conducted by Serbian army and police units in Kosovo, and drove NATO political and military leaders to adopt a gradual strategic bombing campaign designed to coerce Serbian compliance which took months to succeed.

The evidence supporting the proposition that America has become casualty averse is overwhelming, but the explanation for this aversion has more to do with the strength of the United States' position in the world, rather than the weakness of its leaders or its people. As Stephen Walt has argued, the United States is the most secure country the world has ever seen:

> "..(which) leads to something of a paradox: Although solving many global problems requires active U.S. involvement, Americans do not see them as vital to their own interests and they are unwilling to expend much effort addressing them…Americans would like to coerce others to do what they want, but they aren't willing to risk much blood or treasure to make sure they do."[5]

In this view, America's aversion to casualties, and the degree to which political leaders will constrain how the military fights in order to reduce their exposure will depend on the stakes the United States has in the conflict. Because of the great overhang of American power in today's security environment, and because of its basic security, few if any conflicts are likely to engage its vital interests, and many conflicts, like Kosovo, will be fought over much lesser interests.

This basic structural paradox sets the bar very high for the U.S. military, because it must win while keeping its exposure to losses extremely low by historical standards. Certainly, the degree of acceptable exposure will vary somewhat, depending on whether a conflict is a major contingency on the Korean peninsula or in the Persian Gulf, or instead, a humanitarian

intervention in Latin America or Central Africa. Yet because there is little prospect of war with a great power, there is little prospect that the U.S. military will be allowed or ordered to fight as great powers have traditionally fought their wars in the 20th century.

The main military consequence of this increasingly apparent reality will be a growing demand for weapons which can stand off at a distance from enemy defenses and avoid direct fire engagements with their targets at short ranges. In many cases, such as in attacks from the air against high profile, fixed targets on the ground, precision weapons have or soon will solve this problem. In other cases, such as in attacks from the air against mobile or hidden targets, the problem of combining effectiveness with essential immunity from attack is far from solved, but it is at least imaginable how to get there. In still other cases, such as in urban counter-insurgency operations by a regular army against local guerillas, it is difficult to even imagine a low casualty, standoff solution in cases where the opponent is highly motivated and his attacker is not.

The push to provide standoff solutions to battlefield problems will not address all military problems, but it will be ubiquitous as long as asymmetric advantages in new military technology give American forces the ability to standoff, and as long as asymmetric political stakes favor the weaker power in a contest of wills. And just as there are powerful structural reasons for the asymmetry of political will between the United States and its likely opponents in future conflicts, a powerful asymmetry in the ability to exploit modern military technology favoring the United States is also likely to endure.

Lesser powers must focus their investments in modern military forces in only a few areas, and it is those areas which U.S. military forces must either use technology to avoid or overwhelm. Desert Storm was a major contingency in which important American interests were clearly at stake. On the eve of its commencement, the U.S. Senate voted narrowly to support a ground invasion to liberate Kuwait in which thousands of American casualties were expected. Yet the opponent in the case - Iraq - had a defense budget that was less than 5% the size of the

U.S. defense budget. And in the near term, it is extremely difficult to imagine the United States getting into a future conflict with a state whose military capability would match Iraq's capabilities in 1991.

A defense budget of $10-15 a year, which is as much as any so called "rogue state" spends on defense, can by definition buy only a small portion of the capabilities provided by a budget of some $300 billion a year. Public descriptions of the threat posed by these rogue states often mask this reality. This is especially apparent when one looks at the air forces and navies of these states, which cede enormous sanctuaries of control to their opponents compared to the efforts, say, of the former Soviet Union. Thus, the U.S. Navy faces almost no threat to its deep water operations, because smaller states can not even begin to afford long range sea denial assets like nuclear attack submarines. Likewise, the U.S. Air Force is able to quickly gain total control of its own air space and freely penetrate hostile air space from the outset of any conflict because very few states can afford the full range of air assets like Airborne Warning and Control (AWAC) aircraft necessary for a preclusive defense of their air space.

American air and naval forces encounter serious threats only when they close with the enemy, because most states can only afford to defend their coastlines and air space with much shorter range, defensive weapons like antiship cruise missiles and surface-to-air missiles. Yet within their engagement envelopes, both the capability and availability of these weapons are growing faster than are the capabilities of American forces which must suppress them, and it is within the engagement envelopes of such weapons that the most expensive American instruments of rapid power projection face their most serious threats. Therefore, it is the purchase and operational exploitation of weapons like the Russian SAM-10 air defense system or its most modern, submarine-launched, anti-ship missiles where future opponents are likely to focus their efforts. Higher profile but inherently more expensive prestige weapon purchases, such as a

squadron or wing of modern tactical fighters or several major naval surface combatants buy a "shop front" capability which can be quickly destroyed at the outset of a conflict.

It is important that American military strategy adapt itself to this reality. Many of the most important tactical and operational challenges that dominated Cold War military planning and procurement will not exist on future battlefields, while others will remain, in some cases, in more advanced form. A continued focus on the former, especially in a time of more restrained defense spending, will come at the expense of the latter, and this would be dangerous because it is in the latter area where U.S. opponents will be seeking victory.

U.S. alliance relationships, and the access to overseas bases that they provide, will be less formal and more unpredictable than those which obtained during the Cold War. The main Cold War alliance relationships between the United States and NATO and Japan benefited from basic agreement among the parties to each alliance on the threats which justified it, the tools needed to oppose those threats, and the essential equality of national interests and thermonuclear risks at stake for all its members. Though the United States dominated each alliance, it also committed itself to the most binding of security guarantees; the promise to use American nuclear weapons, if necessary, to defend allied territory from attack, whether conventional or nuclear. In return for this commitment, America's allies granted unprecedented access to bases within their territory on which they allowed the United States to station hundreds of thousands of troops. The rights of access and operational activity granted by each host nation were codified in formal status of forces agreements and were therefore predictable and reliable enough to be assumed as a given in Cold War military planning.

Both alliances were a response to the Soviet threat, and both continue after its demise, but neither, with the important exceptions of Japan in a Korean war and Turkey in Iraq, provides access to local bases near or along the long littoral from the Red Sea to the China Sea. There, a better model for alliance relationships of the future is the U.S.-Saudi relationship.

Originally formed early in the Cold War, the relationship grew in importance to both parties after the fall of the Shah appeared to eliminate Iran as a buffer between the Soviet Union and Persian Gulf oil. Yet the United States gained only limited access to Saudi bases in support of its Rapid Deployment Force (RDF), mostly in the form of port visits and pre-positioning of ammunition and other supplies. Iraq's invasion of Kuwait resulted in a decision by the Saudi monarchy to allow U.S. forces unlimited access, but only four days after the invasion began and with Iraqi forces already approaching the Saudi border.[6] After the war, the Saudis allowed American tacair units to remain deployed but refused American requests to pre-position a brigade set of heavy armor.[7] And those deployed air forces are not always available for use in a crisis, as during Operation Desert Fox in December 1998, when the Saudis refused permission for strike aircraft to fly from their bases.[8]

Many factors explain this Saudi reticence. The Saudi regime is a Sunni feudal monarchy that sits on a peninsula surrounded by Shia fundamentalism: It is an Arab state enjoying good relations with Israel's largest supporter: It is wealthy state with a low population that abuts several poorer states with large and growing populations. For all these reasons, as well as others, the United States can solve only some of the Saudis' security problems, and is in fact the cause or a cause of others, which limits its access to Saudi bases.

Both the December 1997 *Report of the National Defense Panel* and the more recent and less exhaustive Hart-Rudman Commission report *New World Coming* have discussed other reasons why access to local bases in future conflicts will remain uncertain. For example:

> "In dealing with security crises, the 21st century will be characterized more by episodic "posses of the willing" than the traditional World War II-style alliance systems. The United States will increasingly find itself wishing to form coalitions but increasingly unable to find partners willing and able to carry out combined military operations."[9]

When the alliances which produce base access are episodic and temporary, the access they produce will be as well.

Finally, and perhaps most importantly, those like the Saudis who today grant access to U.S. forces do so without the security guarantees which the United States gave its important Cold War allies. Furthermore, they know that a regional threat that is very serious to them is likely to represent a less than total threat to a distant United States. This makes it harder for those potential allies to determine whether giving American forces access will actually increase or decrease their long term security, and may make it more likely that they will choose to bandwagon rather than balance with potential aggressors in their region. The National Defense Panel noted this increased vulnerability to coercion, particularly in cases where the regional rivals faced by a potential ally are armed with weapons of mass destruction.[10]

This is not to argue that U.S. forces will gain no access to bases abroad. Certainly, when faced with clear threats to their sovereignty, many smaller states will ask for help, and when it is in the interests of the United States to respond, its forces will be given access. But this access will often come late, after a conflict has already begun; it will often be austere, in that few preparations will have been made in advance; and it will often be withdrawn or sharply limited after the particular conflict which caused it is resolved.

Strategy and the Longer Term Security Environment

The longer term security environment is inherently less predictable than the near term, and it is therefore more difficult to make specific assumptions about its likely characteristics. But two assumptions seem credible: it is unlikely that the United States will have to make a major continental commitment in order to preserve a balance of power in Eurasia; and the battlefields on the Indo-Pacific littoral where the United States will need to make military commitments will

be much more lethal than today because its likely opponents will also be able to exploit the most modern military technology.

A Major American continental commitment on the Eurasian land mass will not be necessary because Germany, Russia, China, and India will be able to defend their land borders without outside assistance. The unification of Germany and the collapse of the Soviet Union made Germany and Russia much more equal in basic power potential, and also established a number of medium sized buffer states between them. Today, Germany's non-nuclear status is compensated by continuing NATO security guarantees, and NATO also serves to enmesh Germany in a series of multilateral relationships that limit the potential for insecurity among other powers like France and Poland. Both of these NATO functions can endure without the need for a major American commitment of ground forces.

The land border separating Russia and China has also acquired buffer states like Kazakhstan and Mongolia, so that the two larger countries abut only briefly between those two newly independent states in China's upper Xinjiang province, and more extensively along the border between Manchuria and the Russian maritime provinces. Both these borders could become future sources of instability, but those instabilities should be constrained both by the fact that China and Russia are likely to remain major nuclear powers, and by the fact that the vulnerabilities along their land borders are mutual. That is, China is vulnerable to separatism in Xinjiang province, which is near the base of Russian land power, and Russia is vulnerable to separatism in its maritime provinces, which are near the base of Chinese land power.

Finally, India is also likely to become and remain at least a medium nuclear power, and geography creates a powerful buffer against invasion along the entire Indo-Chinese land border. Central Asia and the Indian subcontinent are likely to be enormous sources of future instability, but it is unlikely that that instability will provoke a major ground war between India and China.

The most likely venue of future major great power competition and even war should instead have a more maritime focus. China and Japan is one obvious potential dyad, and China and India is another. A complicated, triangular competition among these powers over control of the energy flows from the Middle East and Central Asia is also possible, if not likely. The medium powers that sit astride the same sea routes, such as Singapore, Malaysia, Indonesia, the Philippines, Korea, and of course, Taiwan will all have stakes in the outcome, and will all face competing pressures to balance or bandwagon against different perceived threats to their own interests.

The role of the United States will be the balancer of last resort in these competitions, and the power which will determine the balance in these competitions will be seaborne.[11] This will put a premium first on forces that can independently survive in and gain control over contested sea and littoral battle spaces against all comers, and when necessary, project power rapidly ashore. The requirements for power projection ashore will stop short of an independent ability to wrest control of significant land areas from another great power, and will be focused instead on two capabilities: the ability to rapidly deploy long range fires as an equalizer in land conflicts between medium powers and larger powers; and the ability to rapidly deploy both long range fires and ground forces to a weak power threatened by a medium power in those rare instances when the former's survival and autonomy is an important U.S. interest.

Only in the first case would the United States be engaged alone with another great power in combat. The standard would be that it be capable of fighting and winning such sea battles alone. When fighting a peer competitor on land, the standard would be that it would fight alongside the army of a medium-sized ally. In both cases, the battlefields of the longer term security environment will be much more lethal because the asymmetry in wealth and technological prowess that favors the United States today will be gone or significantly reduced.

Future battles between great powers for control of the surface of the sea and land will be decided in prior battles for control of the undersea and space, and it will only be the winner of those battles whose forces will be able to survive on and gain control over the surface. Technology has already made almost all fixed land targets essentially indefensible from conventional attack by U.S. forces, and both the fiscal and human costs of mounting such attacks should drop even further should U.S. forces fully embrace standoff weapons with integrated GPS/INS guidance.[12] Technology will also soon greatly increase the ability of U.S. forces to attack a variety of moving or mobile targets such as SAM radars, tactical ballistic missiles (TBMs), and armored vehicles with long range fires.[13] These long range fires will be cued by wide area sensors which will initially be air-based, but which will eventually migrate to space-based platforms in earth orbit. This growing arsenal of capability to use long range fires to attack fixed and mobile land targets takes advantage of the enormous asymmetries in technological prowess which now favor the United States over its likely opponents.

Capabilities analogous to this were developed much earlier by the U.S. Navy in its Cold War struggle with the Soviet Navy, and particularly with the Soviet submarine force. The latter posed the greatest conventional threat to allied sea lines of communication, and as early as the late 1950s, the Navy was using undersea-based acoustic sensors to detect and track Soviet submarines on an ocean-wide basis, and to cue long range ASW platforms to prosecute them. This capability was also based on an asymmetry in technological prowess, in this case in the ability to understand the significance of and exploit narrow band, low frequency, acoustic signal processing, but that asymmetry was eventually eliminated by the Soviet Union, albeit too late to influence the course of the Cold War.

Major asymmetries in technological prowess are rare in great power conflicts, and usually evanescent when they do occur. The dominant technological characteristic of the longer term security environment is that America's current advantage over the rest of the world should

be eliminated or greatly reduced if one or several new great powers arise in Eurasia. In prospective battles with such a power, the United States will once again have to assume the golden rule of war between equals (or near equals); that which it can do unto others, they likely will be able to do unto it.

This will have many unpredictable consequences for U.S. military planning. For example, the military value of space-based sensors will likely transform space into the same type of warfare medium that the air became during and after World War I. It may also lead to a growing dependence on undersea platforms as a base for long range fires, because submarines may be the only weapon launchers able to approach an enemy coast early in a major conflict. In both cases, American military planners faced with an increasingly more lethal environment on or near the surface along the Eurasian littoral are likely to seek sanctuaries from which they can more safely obtain information and project power. But in a competition with a peer competitor, no operating medium will remain a sanctuary for long, and battles for control of those mediums will be much more intense than they would be in today's security environment.

American military planners are likely to be driven to seek sanctuaries in space and under the sea surface because the surface and near surface environment in areas contested by great power militaries will be exceedingly lethal. Fixed targets on the surface will be indefensible if within range of an opponent's likely arsenal of precision TBMs and cruise missiles, for as long as the supply of those weapons lasts. Even mobile targets will be at risk of prompt destruction if the opponent retains access to wide area battlefield surveillance assets. The fact that the latter are likely to be deployed in space is the main reason space will become a battle ground in the long term.

One main conclusion that should inform current defense planning concerns the issue of access to overseas bases. Where such access is uncertain and episodic in the near term security environment for essentially political reasons, it is likely to remain problematic in the longer term

for purely military reasons. Even if available, such bases are unlikely to be viable because like all large, fixed locations within a certain radius of the opponent, they will likely be difficult if not impossible to defend as long as the opponent has a supply of standoff weapons to attack them. Forces that nevertheless must operate on the surface and close with the enemy will be able to do so only if they operate in such a way as not to present large, predictable, fixed targets to the opponent, and if the opponents battlefield surveillance capabilities against mobile targets are degraded or destroyed.

A Metric For Analyzing Trends In Strike Warfare

The technical and political changes in both the near and the longer term security environment described above will force dramatic change in current methods of conducting strike warfare. Some, but by no means all, of these changes will be driven by new demands, such as the need to become better at striking mobile targets. Determining the likely content of those changes requires analytical tools that allow comparisons between old and new methods of conducting strike warfare. These tools must look at different strike warfare methods in a comprehensive fashion in order to capture all the effects the expected external environment will have in the sequence from the establishment of a base of operations to the delivery of weapons to the target. The key goals of such an analysis are to identify where current methods are encountering diminishing returns to investment, and where new methods have the potential of achieving increasing returns. This section will focus on general trends in strike warfare, while the next will focus on comparing the effects these trends are likely to have on individual platforms.

Strike warfare against mobile targets can be separated for analytical purposes into a sequence of five operational hurdles, all of which must be cleared successfully for a mission to be completed. First, a secure base must be established. This will involve both gaining political access to a base structure and surviving enemy attack while operating from that base structure.

Second, the forces assembled at that base must be able to establish and maintain the connectivity needed to manage their operations. Third, they must be able to penetrate an opponent's defenses in order to deliver their weapons. Fourth, targets must be found and identified for these weapons to attack. And fifth, weapons must be delivered against those targets in timely and lethal fashion, and their effects assessed. It is the cumulative performance at clearing all five of these operational hurdles that determines the effectiveness of any given method of conducting strike warfare, not its unique advantages or disadvantages at any one stage.

In comparing different methods of conducting strike warfare, it is important also to measure the rate and direction at which the technical challenges at each operational hurdle are evolving. In particular, one needs to be sensitive to the difference between diminishing and increasing returns to investment. For some platforms, clearing a certain operational hurdle in the future may demand increasing levels of investment to preserve current or even declining levels of capability. For other platforms, or for the same platform at another hurdle, the opposite may be the case, with a given investment producing a disproportionately large return in enhanced capability.

Broadly speaking, of all current strike warfare methods, land-based tactical aircraft are experiencing diminishing returns in clearing the largest number of operational hurdles. This should not be surprising because these are mature systems which have traditionally provided the bulk of any country's strike warfare capability. Therefore, great resources have also been invested in the technology to counter such capabilities. As Benjamin Peled, a former commander of the Israeli Air Force, put it in 1989, "the destructive power of aircraft has grown exponentially since World War I, but the investment in air defenses has exceeded the growth in capability of aircraft in attacks against ground targets. Part of the reason, he argued, is that "the value placed on the 'man in the loop' in air operations has risen at an astronomical rate."

Without putting it in these terms, his concern was that the traditional approaches to tactical air-to-ground operations were already beginning to experience diminishing returns on investment.[14]

By contrast, the submarine, which today is the least mature method of conducting conventional strike warfare, faces a very different future. At several operational hurdles it faces no resistance at all, and little sign of the development of such resistance in the future. On the other hand, it faces major obstacles at several other hurdles, where efforts have only just begun to clear them, but where those efforts are likely to face rapidly increasing returns on investment.

The following five sections look at the technical trends at each operational hurdle. This discussion is then followed by a comparison of how different precision strike platforms are likely to fare in the face of these trends.

Attacking Mobile Targets.

Ironically, today's mobile target problem, as experienced in Allied Force, comes at a time when the fixed target problem is finally about to be solved. This is ironic because in the beginning, the fixed target problem posed greater difficulties for air forces than the mobile target problem. The reason for this reversal introduces a factor of basic importance in assessing the evolution of trends in strike warfare methods: the mutual interaction between the steps one must take to clear the five operational hurdles. This interaction consists of a series of tradeoffs in which the force designer must trade capabilities at one hurdle for capabilities at another. In the case of attacking mobile versus fixed targets, one of the important tradeoffs has been with developments in air defenses.

During World War II, air forces gained a mobile target capability when they gained sufficient air superiority over opposing air forces to fly patrols over an opposing army in the field. When that army was forced by its opponents on the ground to move in large numbers, either to launch an attack or to retreat, it filled up the local road network and aircraft flying very

low and using short range cannon fire, bombs, and unguided rockets could relatively easily find and attack such columns. Deployed in the numbers and with the degree of air superiority achieved by the Allies in the campaign to liberate France, tactical air forces wrought havoc on the German Army at places like Mortain, where a German armored counter-attack was stopped from the air, and the Argentan-Falaise gap, where a German Army was decimated as it sought to escape encirclement by allied armies after they had broken out of Normandy.

During the same period, Allied bombers, finally enjoying air superiority over the German homeland, were mounting enormous raids in their strategic campaign against German industrial installations. In those raids, few if any of the bombs dropped by as many as a thousand bombers at once were actually hitting the individual factory that they were aiming at. The problem lay in the nature of then current surface-to-air defenses. Based on relatively slow-firing and often unguided antiaircaft artillery (AAA), they depended on very high densities for their effectiveness, densities which could only be profitably maintained around large, high value, fixed installations. These defenses drove Allied bombers to high altitudes of 15,000 to 20,000 feet, which greatly reduced their exposure to AAA, but from which their bombing accuracy was measured in miles. By contrast, allied fighter-bombers, facing the much thinner and less organized defenses protecting German armies in the field, were able to operate in daylight at medium to low levels, where targets were easy both to find and attack with reasonable accuracy. Thus, under some circumstances, mobile targets were easier to attack than fixed targets of interest because only the latter enjoyed dense defenses.

The wide deployment by the early 1970s of vehicle-mounted, radar-guided, 20 and 40mm AAA and hand held, heat seeking (infrared or IR), surface-to-air missiles (SAMs) greatly raised the cost of all low altitude attacks, whether against fixed or mobile targets, and drove attacking aircraft to higher altitudes. At these altitudes, smaller, mobile targets were much more difficult to find and identify, even when they were concentrated. Equally important, bombing

accuracies from high altitudes had not improved much since World War II, and were still often measured in thousands of feet. At the same time, radar-guided SAMs were also eliminating the relative sanctuary heretofore provided at these higher altitudes from ground-based air defenses. An operational crisis resulted, experienced by both the American and Israeli Air Forces in their wars of this period, in which bombing effectiveness against fixed and mobile targets was low, and even high altitude operations faced serious opposition from ground-based defenses. This crisis led to major investments in technologies for suppressing radar-guided SAMs, and for increasing the precision of weapons dropped from medium to high altitudes.

Suppressing radar-guided SAMs would reestablish a high altitude sanctuary from ground-based defenses, while precision weapons would greatly increase the lethality and effectiveness of air operations from such altitudes. SAM suppression came to depend on specialized aircraft known as Wild Weasels, equipped with sophisticated, passive, direction-finding avionics which could identify and locate SAM radar emissions, and armed with high speed, antiradiation missiles (HARMs) which, once fired at an active radar, would either home on its emissions and destroy it, or force it to shut down, causing the SAM it was guiding to go ballistic and miss its target. The main method of increasing the lethality of bombing operations was the development of the laser-guided bomb (LGB). Aircraft equipped with a laser illuminator could drop bombs from high altitude which would home on laser energy reflected from the target. This greatly increased the accuracy of bombing attacks, now measured in tens of feet, and also made accuracy relatively insensitive to altitude, allowing effective operation from the high altitude sanctuary established by the suppression of opposing radar-guided SAMs.

First generation LGBs were day/clear weather systems, and were used only in the latter part of Vietnam after the Air Force and the Navy experienced repeated failure in attacking high value fixed targets around Hanoi.[15] Post-Vietnam development of forward looking infrared (FLIR) technology allowed night/clear weather LGB operations on aircraft which combined a

laser designator and a FLIR. This second generation capability was not demonstrated on a large

scale until Desert Storm, and even then, a relatively small percentage of the total force in that

conflict was so equipped.[16] The wide deployment since Desert Storm of FLIR/laser illumination

pods in both the Air Force and the Navy has greatly increased the percentage of the force with

such night/clear weather precision strike capabilities against fixed targets, as demonstrated in

more recent operations over Iraq, Bosnia, and more recently, Serbia and Kosovo.

LGBs allow clear weather, precision strikes from medium to high altitudes, but

operations from those altitudes frequently encounter cloud cover. This constraint prevents all

weather use of LGBs and therefore reduces LGB-based precision strike capabilities to the extent

that cloud cover over the target is common. Even over the deserts of Iraq and Kuwait, this

constraint proved troublesome, and it proved crippling at times in the more cloudy, climate

typical of Serbia and Kosovo, a characteristic obtaining throughout the temperate zones of the

world, including all of the Asian littoral.

The solution to this problem will be weapons that integrate GPS and inertial navigation

systems (INS). Integrated GPS/INS provides an all weather, through the cloud, weapon guidance

capability that is compact, relatively cheap, and which can be made robust against

countermeasures. As with second generation LGBs during Desert Storm, weapons reliant only

on INS/GPS were first introduced amidst great acclaim in Allied Force, but only on a limited

scale, mostly in the form of some 600 joint direct attack munitions (JDAMs) dropped over 78

days by 6 B-2s.[17]

INS/GPS guidance will revolutionize precision strike against fixed targets because,

compared to laser guidance, it will make the accuracy of precision weapons completely

independent of weather, range as well as altitude of delivery, and perhaps most important, a man

in the loop to identify and lase the target. In principal, this should mean that all strikes against

fixed targets will eventually be conducted with standoff weapons of sufficient range to put their

launch platforms out of range of surviving enemy defenses.[18] This does not mean that all

precision strikes against fixed targets will be made with 700 mile range weapons like Tomahawk

at $500,000 apiece. But it does mean that non-stealthy aircraft dropping cheap gravity bombs

like JDAM will not necessarily be the most cost-effective platform when the air defenses

opposing them demand the expenditure of upwards of 1000 HARMS at $250,000 apiece.[19]

That INS/GPS will enable a more robust, standoff, precision strike capability against

fixed targets is fortunate, because as we shall see in the section after next, enemy defenses will

likely become much more effective than they already are. But these defenses will also

complicate any solution to the mobile target problem by making it difficult to deploy survivable

sensor networks within line-of-sight of the mobile targets that need to be found and identified. In

the traditional approach to attacking both fixed and mobile targets, a man in the loop within line-

of-sight of both the target and its defenses combines the sensing and weapon aiming/guiding

functions. INS/GPS weapons can eliminate the need for a human to perform the latter function,

but other technologies must be developed if the human is to be replaced in performing the former

function.

Finding and Identifying Mobile Targets.

Fixed targets are often found and identified using traditional intelligence methods, often well in

advance of a conflict. Even when the value of certain fixed targets, such as command posts, can

only be determined in the midst of a conflict, their positions are still usually known with

precision in advance of the conflict, even if the time when it is optimal to strike them is not.

By contrast, though mobile targets can sometimes be preemptively struck at their bases

using pre-conflict intelligence, usually they must be searched for and identified while in the field.

Rather than traditional intelligence methods, this creates the demand for surveillance and

reconnaissance capabilities with continuous, wide area coverage that can search for and detect

potential targets, classify them as real targets, and locate them in both time and space with

accuracies compatible with the accuracy, lethal radius, and time late of the weapons that will be

used to attack them. As any practitioner of ASW will understand immediately, it is the ability to

find and identify these targets in a "noisy" environment with an acceptable false alarm rate that

will be the most difficult challenge. In different ways, and under different circumstances, both

the failure of the great SCUD hunt of Desert Storm, and the success of Serbian ethnic cleansing

activities in Kosovo during Allied Force, demonstrate that this challenge is a long way from

being met.

Other examples from the recent past might seem to vitiate this point. For example, in

two cases during the Gulf War, the Battle of Khafji and the later Iraqi retreat from Kuwait City

toward Basra, allied air forces pummeled Iraqi ground forces from the air, in the former case

stopping an attack, and in the latter case turning a retreat into a rout. The difference is that in

both these cases the false target problem was mute. At Khafji, this was because the battle took

place in a low or zero noise environment. In other words, detection equaled classification

because the only vehicles in the area were Iraqi military vehicles. Later, at the so-called

Highway of Death, where civilian and military targets were intermingled, the false target

problem was initially ignored, although this did not last for more than 48 hours, when the

decision was made to cease operations at least in part out of humanitarian concerns.[20]

The Desert Storm SCUD hunt and the effort to slow Serbian ethnic cleansing operations

in Kosovo during Allied Force were different because the false target problem was real. In the

SCUD hunt, one of the main problems was that allied aircraft had difficulty distinguishing SCUD

launchers from trucks and other vehicles. There were many more of the latter than the former,

and both used the same road networks. Thus, many fuel trucks were attacked and destroyed, but

few if any SCUD launchers. Another problem was that the best sensors were not always

available for the SCUD hunt because it occurred relatively deep in Iraqi airspace. This often

prevented assets like JSTARS and Rivet Joint from participating. In Kosovo, roughly the same

problem of distinguishing military from civilian vehicles was exacerbated further by an extreme

aversion to civilian casualties and collateral damage, political concerns that were entirely absent

from the SCUD hunt, which was dominated by the overwhelming political imperative of keeping

Israel out of the war by reducing, or of at least appearing to reduce, the SCUD threat. Also, there

is considerable evidence that the Serbians were more aggressive than the Iraqis in their use of

decoys, making an already noisy environment even noisier, and diverting Allied weapons from

their real targets.

An obvious first step toward addressing these problems is to find ways of providing

continuous, theater wide, synthetic aperture (SAR) and moving target indicator (MTI) radar

surveillance coverage in support of future conflicts. Such a step would not by any means be

sufficient as a solution to the mobile target problem, but it is almost certainly a necessary step

toward one.

SAR and MTI are two different radar techniques that can be combined in a single

surveillance platform.[21] SAR uses the movement of the radar platform over time to create an

artificially wide "aperture" or antenna that can be used to produce higher resolution images of a

fixed target than could be produced using the natural aperture of the platform's radar antenna.

With SAR, a radar gains an imaging capability with resolutions approaching those normally

provided only at much higher optical wavelengths. By contrast, MTI exploits the relative

movement of a moving target normal to the path of the radar platform. It does this by exploiting

the fact that radar pulses reflected back from a target moving toward the radar have a higher, or

doppler shifted, frequency than the pulses reflected from the stationary background around the

target. With doppler signal processing, the radar can therefore be instructed to "see" only moving targets, and the background clutter can be filtered out.

When combined, a SAR/MTI radar can detect and track moving vehicles over a wide area using the MTI mode, or provide high resolution, precisely located images of a series of spots within that area. The most advanced SAR/MTI radars can interleave these two different modes rapidly enough such that a target detected using the MTI mode can be imaged and geolocated using the SAR mode as soon as it stops moving, and then picked back up on MTI once it starts moving again. In theory, this will allow continuous, all weather tracking of high value mobile targets within the coverage area of the radar. In practice, this capability will be dependent on the density of SAR/MTI coverage over the battlefield.

SAR/MTI radars can be deployed on a number of different platforms. The Air Force's JSTARS aircraft puts a large radar on a large platform with an organic battle management staff. Smaller radars can be deployed on smaller surveillance platforms like the U-2 or various UAVs, which must downlink the radar's product to a ground processing station. Alternatively, smaller radars can also be deployed on combat aircraft, either organically or in a pod, thereby linking the sensor with the shooter in one platform. Most ambitiously, SAR/MTI radars could be deployed on satellites. A constellation of 20-40 low earth orbit, SAR/MTI satellites would be sufficient to ensure that one satellite was always overhead. If it remains funded, a two satellite, NRO-Air Force-DARPA development program called Discoverer II will look at the technical feasibility of such a constellation.

Each deployment mode has its advantages and disadvantages. JSTARS is autonomous in that it does not need to remain within line-of-sight of a ground processing station, and its 30-40 person battle staff can therefore control air-to-ground operations by communicating directly with strike aircraft, much like AWACS control air-to-air operations. On the other hand, it is a very large platform with an operational ceiling only a little more than 30,000 feet, which must also

stand off at least 25 miles beyond the range of the nearest SAM battery. Both factors limit JSTARS coverage: the altitude ceiling prevents it from looking past some terrain obstacles; and the standoff requirement can reduce the horizon-limited, 200-250 mile range of the radar by up to 125 miles when facing the most modern SAMs.

Long endurance UAVs like Global Hawk and the manned U-2 can fly at 60,000 to 70,000 foot altitudes, which tends to increase their coverage from the same standoff range that JSTARS must operate, but they also have smaller payloads, which means a smaller radar, which is particularly significant in the MTI mode, where the radar antenna's natural aperture determines its doppler frequency resolution. Also, because they must downlink their radar's output before it can be processed, they do not provide an autonomous battle management capability. Between Global Hawk and the U-2, the latter provides more payload, while the former's very long endurance provides global coverage from a limited number of bases to which the U.S. has assured access.[22]

Finally, SAR/MTI radars deployed on combat aircraft or on penetrating UAVs face the most severe weight and volume constraints, and are therefore most performance-limited. But they also provide coverage in areas denied a standoff platform, and in the case of combat aircraft, an autonomous sensor-to-shooter capability.

The most ambitious implementation of SAR/MTI battlefield surveillance capability is of course the space-based deployment mode which Discoverer II is designed to test. If successfully implemented, a space-based radar constellation would provide continuous global access, freedom from the shading effects that terrain obstacles can create at the horizon of side looking, aircraft-based radars, and immunity from air defense systems. The obvious caveat is that Discoverer II contains much more technical risk than the other approaches, and will only be available in the mid to far term.

Two major technical challenges will dominate SAR/MTI sensor development. One concerns the precision with which it can locate targets, and the other concerns the degree to which it can identify and classify the targets it detects. Mobile targets pose particular challenges in both areas. Current MTI radars cannot by themselves provide targeting quality geolocation information for moving targets, and their classification capabilities are limited to relatively gross distinctions like that between tracked and wheeled vehicles. There will certainly be great technical progress in both these areas, and it is well beyond the scope of this report to speculate about the details of what will result, but it is possible now to outline how different outcomes in SAR/MTI sensor development might broadly effect other elements of the mobile target problem.

At one extreme, perhaps in the near term, one can imagine SAR/MTI radars providing a cueing function to other platforms which would classify and attack the target. The latter two functions might be combined on one platform, probably a combat aircraft, which would result in the simplest architecture. At the opposite extreme, one could imagine SAR/MTI radars, probably linked with other sensors using different phenomenologies, in a global or theater-wide network which could find, classify, track, and target a variety of mobile targets of interest. This targeting information could be used to launch standoff weapons from platforms deployed outside the range of enemy defenses. The simplest and cheapest of these weapons might be capable only of quickly attacking a set of GPS coordinates provided by the network. This would be useful against a mobile target temporarily at rest, such as a SAM-10 radar. More complicated would be a weapon able to receive continuous GPS targeting updates from the network in flight, providing a closed loop between the sensor and the weapon, and making it possible to attack moving targets. Most complicated would be a fire and forget weapon with a terminal seeker able autonomously to reacquire and attack a moving target designated by the network using automatic target recognition (ATR) algorithms.

In all of these architectures a common theme is that targets are found, and in many cases identified and precisely located, by sensors separated from the weapon delivery platform. This separation implies an important additional characteristics about future strike operations against mobile targets. They will, in today's jargon, be net-centric, meaning that the strike platforms participating in such operations will be dependent on their connectivity to offboard sensors via a network for their effectiveness.

Penetrating Air Defenses.

Air defenses lying between strike aircraft and their targets fall into three broad categories: air-to-air interceptors, radar-guided SAMs, and short range air defenses (SHORAD) like man portable IR SAMs and AAA. In a fully integrated air defense system, all three elements are netted together and linked to a ground and air-based network of surveillance radars and battle management centers. Air-to-air interceptors, supported by a large force of AWACs aircraft, constitute the outer edge of an integrated air defense system and provide the only means of projecting an air defense capability well outside one's own air space. But the cost of entry here is very high, largely because it makes no sense to go half way down this road, particularly if one is anticipating potential conflict with the United States. Aircraft, and particularly large aircraft like AWACs, are inherently vulnerable to attack while at their bases, and are among the easiest targets for an opposing air force to destroy. Therefore, only those countries that can afford to mount a preclusive defense of their own air space can justify making a large investment in platforms which depend upon such a preclusive defense to survive. For the vast number of potential military opponents of the United States, such a preclusive defense is hopeless, due to the vast disproportion in resources available to the two sides.

Increasingly, this means that smaller countries which anticipate conflict with the United States do not plan on mounting a preclusive defense of their own air space. Instead, they depend

largely on radar-guided SAMs and SHORAD and assign them the operational goal of imposing costs rather than providing a preclusive defense. These costs can be measured in three ways: directly, as a function of opposing aircraft shot down; or indirectly, either as a function of opposing strike assets diverted to defense suppression missions, or of strike missions which the opponent was deterred from even attempting. There is also an operational tradeoff between air defense tactics designed to maximize direct costs and those designed to maximize indirect costs, and this tradeoff is manifest in the different approaches taken by Iraq in Desert Storm and Serbia in Allied Force.

For the first few nights of Desert Storm, Iraq mounted a strong defense against allied air operations within its own air space. The heart of this defense was its force of radar-guided SAMs, which the Iraqis used aggressively. In practice, this aggression played into the hands of allied defense suppression assets, the heart of which were specialized jamming and antiradiation missile firing, or Wild Weasel, aircraft which escorted allied strike formations. Jamming aircraft reduced the range of SAM engagement radars by effectively reducing the power of their returned signals, while Wild Weasels attacked the same radars by quickly locating them when they began illuminating a target and then launching high speed, antiradiation missiles (HARMs) that were provided both bearing and range to the radar. If the SAM engagement was to be completed successfully, the engagement radar needed to illuminate the target until it was hit by the SAM, but if it did this in the presence of a Wild Weasel, the engagement radar would often be destroyed by a HARM first.

In pressing home their SAM engagements, Iraq only succeeded in shooting down one allied aircraft that enjoyed a direct Wild Weasel escort, but their SAM units suffered enormous attrition from HARM attacks.[23] Within a week, these losses caused Iraqi radar-guided SAM activity to drop off precipitously, and allied aircraft were able to operate freely without HARM escorts at medium altitudes throughout much of Iraqi air space. Because they are much harder to

suppress, Iraqi SHORAD assets remained effective, but allied aircraft only really exposed themselves to these defenses when they chose near the end of the war, once ground operations had begun, to press home their attacks at lower altitudes against retreating Iraqi ground forces. Thus, by initially seeking to maximize the number of allied aircraft shot down, the Iraqis also rapidly expended their radar-guided SAM force.

The Serbians, faced with a similar operational challenge, chose instead to maximize the indirect costs incurred by allied air operations. In more than two months of operations, they only shot down three allied aircraft, but their radar-guided SAMs also managed to survive the war in large numbers. In particular, 19 out of 22 of their most modern, mobile SAM-6 batteries survived, even though these were the most used air defense asset, having fired at least 266 missiles.[24] The Serbian strategy appears to have been to preserve the threat of its most potent, ground based air defenses in order to force the allies to continue allocating the full panoply of defense suppression assets needed to suppress them on each strike mission. They did this by repeatedly refusing to press home SAM engagements, in many cases wasting their missiles, but making it quite clear that they were still extent and operational. They also repeatedly moved their SAM batteries after such engagements had revealed their position. Given the relatively low numbers and high value of allied defense suppression assets, and given the continuing demand for them, their availability put an upper bound on the rate at which the air war could be prosecuted, a ceiling which was much lower than would have been the case if Serbian radar-guided SAMs had been destroyed at the outset. This was one of the big indirect costs incurred by the allies.

This indirect cost was exacerbated by reductions in allied defense suppression capabilities caused by the retirement after Desert Storm of the best Wild Weasel aircraft, the U.S. Air Force's F-4Gs. F-4Gs had the ability, over a 360 degree azimuth, to provide a HARM missile the range, bearing, and elevation of an emitting radar within a minute of first detecting it.

The F-4G's replacement, the F-16CJ, equipped with the most recent software upgrades to its Harm Targeting System (HTS) pod, can provide range and bearing with precision and timeliness approaching the F-4Gs', but only in a forward sector of a little less than 180 degrees, meaning that at least two are required in order to assure continuous 180 degree coverage of a given sector, and four to assure the same 360 degree coverage provided by a single F-4G. But the Air Force only bought 112 HTS pods when it retired its 100 plus F-4Gs, which means that in practice only 28 of them have been fully replaced. Also, F-4Gs routinely carried 4 HARMs, while F-16CJs can only efficiently carry 2.

The Air Force originally planned to compensate for this reduction by having F-16CJs operate with RC-135 Rivet Joints as a team, but this cooperation can be difficult to arrange because of the scarcity and high demand of the latter platform, only eight of which are set up for radar ELINT as opposed to COMINT, and because, like AWACs and JSTARS, it must stand well off from opposing air defense assets, limiting its coverage. Because Rivet Joint and HTS pods are scarce, Allied planners were often driven to rely on a more primitive suppression technique which is both less capable and more expensive. This involves using HARM missiles fired by regular strike aircraft in what is known as the "pre-briefed" mode, which means that the SAM radar's expected position is loaded into the missile before takeoff. When used in this mode, HARMs are fired when the strike package approaches a target, whether or not the SAM radars expected to be in the vicinity emit. If the radars light up and come on the air, the HARMs will attack them, but if they stay silent, or if they have moved in the hours or days since they were originally located by intelligence assets, the HARMs are wasted. This technique is effective when an opponent is relying on older fixed systems like the SAM-2, and when the opponent is using those systems aggressively, as the Iraqis did. But as discussed above, the Serbians husbanded their radar-guided SAMs, and also, their SAM force was more modern than was Iraq's, as reflected by the much higher portion of mobile SAM-6s.

Thus, by husbanding their SAMs, the Serbians were able to limit the intensity of NATO air operations to that which could be supported by their limited defense suppression assets. Furthermore, because of the Allies' increased reliance on pre-briefed rather than reactive HARM shots, and because of the Serb's greater reliance on mobile SAMs, the Allies expended HARMs at roughly the same rate as they did in Desert Storm, but with much less effect.[25]

These problems will get much worse if and when Allied air forces encounter more modern, mobile SAM systems like the Russian SAM-10. SAM-10 missiles provide the greater than 100 km range of strategic SAMs like the SAM-2, with the mobility of shorter range systems like the SAM-6. Furthermore, its phased array main engagement radar has both a much higher power-aperture product and a much more agile beam than its mechanically scanned predecessors. This gives the radar a much longer detection range against even low radar cross section targets like the stealthy F-117 and the B-2, and allows it to more quickly acquire and track multiple targets.

Because an electronically scanned radar can acquire and track its targets so quickly, two could fully support a SAM engagement by alternately emitting for only 20-30 seconds at a time, as compared to the 3 minutes it takes for a SAM-6 engagement radar to acquire, track, and begin guiding a missile from a standing start. This will make obsolete the current Wild Weasel method of using only a single aircraft to acquire the range and bearing to the SAM engagement radar before taking a reactive, "range known" HARM shot. The single aircraft approach to radar geolocation, analogous in its basic method to the target-motion analysis long used by SSNs in passive acoustic ASW, requires access to a continuous radar signal of up to a minute in order to calculate range with the accuracy needed for a reactive HARM shot. Also, once launched, antiradiation missiles like HARM require a continuous signal if they are to actually kill the radar. Effectively used electronically scanned SAM engagement radars may be able to press home engagements without ever having to emit such a continuous signal. This might allow potential

adversaries to get back into the business of actually shooting down allied aircraft, and imposing the kind of direct costs political leaders are reluctant to incur in conflicts over less than vital interests.

But even if this particular capability proves beyond the reach of a less advanced adversary, systems like the SAM-10 will still greatly increase the indirect costs of defense suppression if traditional methods are maintained. This is because the greater effective detection range of the system will prevent even stealthy aircraft from attacking it without a weapon with a significantly greater range than the HARM. In this scenario, Wild Weasel aircraft would have to become stealthy, and their antiradiation weapons would need double or triple the 25 km range of the HARM. Thus, the F-16CJ replacement might need to be an F-22 carrying a more expensive version of today's $250K HARM. This dramatic increase in the cost of individual Wild Weasel platforms would at best buy an equal capability against new systems like the SAM-10 as its predecessors provided against systems like the SAM-6. Yet by refusing to press home its engagements, a modestly sized force of SAM-10s could still extract indirect costs, either by forcing the allies to limit their operations to the level that could be supported by scarce and now much more expensive Wild Weasel platforms, or by limiting them to the somewhat higher operations tempo that can be supported if they are willing to rely on pre-briefed antiradiation missile tactics using missiles even more expensive than HARM.

The unattractiveness of this scenario has led to consideration of an alternative approach to defense suppression. In it, SAM engagement radar locations are instantaneously and more precisely determined using multiple rather than single platform geolocation techniques. These techniques allow detection of even the briefest signals with a precision sufficient to target the emitter with an INS/GPS-guided standoff weapon rather than an antiradiation missile. Such an approach is attractive both because it deals with the advancing threat of opposing air defense

systems, and with the tactic of using them in ways that emphasize indirect rather than direct costs.

The heart of this new approach is the capability to precisely geolocate even the shortest signals. The most powerful of the techniques available to accomplish this rely on a minimum of three separate, data-linked receivers being within line-of-sight of the target signal. The receivers involved can be small, relatively unsophisticated, and therefore mounted on a variety of platforms. By comparing the exact time when the signal arrives at each receiver, and by knowing the position of each receiver, the location of the emitter can be immediately determined by measuring the differences in the signal's arrival times. Time difference of arrival (TDOA) is also powerful because its accuracy is much less range dependent than other geolocation techniques, allowing much greater standoff distances, as evidenced by GPS, a space-based system which uses TDOA in reverse to allow a single receiver to calculate its position on earth with great precision by comparing the signals received from at least three satellites some 12,000 miles away in medium earth orbit.

A TDOA-GPS approach to locating and targeting SAM engagement radars would therefore make it much easier to counter the most modern radar-guided SAMs by largely eliminating the capability added by their electronically scanned main engagement radars. The sensors used to geolocate the radars can be deployed at great standoff ranges on relatively cheap, non-stealthy, and probably unmanned platforms without penalty to their precision, and the effectiveness of the standoff INS/GPS weapons used to attack the radars will not be dependent on whether the opponent chooses to press home his engagements.

The reader will notice that this approach to the defense suppression problem has many characteristics in common with the new approach to the mobile target problem using SAR/MTI radars described above. Both rely on networks of standoff sensors that precisely locate targets for attack by GPS/INS weapons. This should not be surprising because the most modern air

defense systems like the SAM-10 are themselves mobile targets. There are indeed powerful synergies that will develop as both problems are pursued. The same platforms, whether long endurance UAVs or satellites, may be used to deploy SAR/MTI radars and ELINT or COMINT receivers. Whether deployed on the same platforms or not, the two sets of sensors would support each other in operations against any mobile target that also emits RF energy, ranging from a SCUD firing unit that uses a weather radar just prior to launch, to a mobile command post using radio.

Also, just as both problems demand networked sensors as part of their solution, they also both separate those sensors from the shooters. This in turn assumes the existence of a sensor-to-shooter network and illustrates how dependent both mobile target strike and defense suppression operations of the future will be on reliable data communication networks, and on the connectivity to those networks of each of its elements, whether sensor, shooter, weapon, commander, or information processor.

Establishing and Maintaining Connectivity.

Connectivity can be defined simply as the ability to receive and/or transmit information over a given circuit. One has connectivity when the circuit is in place, and connectivity is lost when the circuit is broken. The specific type of connectivity needed can vary widely from platform to platform, and from mission to mission. During the Cold War, SSBNs on alert needed to maintain connectivity to a VLF broadcast that allowed immediate receipt of very short, one way, messages while submerged. By contrast, future surface ships engaged in cruise or tactical missile defense will need to maintain connectivity to a high speed, two way, data link, known as the Cooperative Engagement Capability (CEC), which will allow each ship to share all of its sensor outputs with every other ship in the network, continuously, in real time, and within a common geographic grid. Because connectivity requirements can vary so much, it is important to describe the range

of capabilities which capture the variance. Because radio is the dominant means of establishing connectivity, the discussion will focus on that communication method.

The dominant influence on the capabilities of a given radio communication circuit is the frequency or wavelength chosen. Three broad capabilities or characteristics are largely determined by this choice: how the signal propagates; how much bandwidth it has; and what the impact or footprint of the communication system will be on the platform that uses it.

Radio signals at different frequencies can naturally propagate over the horizon or only via a line of sight path. Signals that propagate only via line of sight can be relayed over the horizon by creating artificial circuits, some classic examples being a satellite in the sky, or a line of microwave relays on the ground. Finally, different radio frequencies experience unique propagation windows and barriers under different environmental conditions. Thus, only a few frequencies can penetrate sea water to any significant depth, while others are reflected or absorbed by the ionosphere. Most military radio communications now use frequencies that experience line of sight propagation, and which therefore rely on artificial circuits or relays if they are to be used to establish over the horizon connectivity. These begin on the frequency spectrum with VHF, the band of frequencies ranging from 30 to 300 MHz (wavelengths from 10 to 1m) where radio signals stop naturally propagating over the horizon, and proceed in order of magnitude increments of frequency increase (and wavelength reduction) through UHF, SHF, and EHF, stopping in the latter band between about 50 and 100 GHz when the sub-millimetric wavelength signals start getting absorbed by similarly sized particles in the atmosphere, first atmospheric water droplets and then air molecules themselves.

Radio signals at different frequencies also vary in terms of their bandwidth. Bandwidth can be thought of as the amount of communication "work" a given circuit can accomplish. Bandwidth is determined by frequency because a radio circuit functions by turning an electromagnetic signal on and off, and the speed with which it can do this, and therefore the

number of discrete signals it can send in a given time, is determined by the frequency with which it can turn those signals on and off. Thus, frequencies and bandwidth rise and fall in a linear relationship.

The most obvious result of increased bandwidth is a higher potential data rate, a phenomenon many experience when they log on to the internet at home using a phone modem after using an ethernet line at work. Because the former connection has much less bandwidth, the World Wide Web becomes the World Wide Wait. But bandwidth also determines other characteristics which are less relevant to the civilian world, but very relevant to the military. These include jam resistance and covertness.

Military communications need to be made secure against intentional forms of the kind of unintentional interference a driver experiences when driving at the boundary between two radio broadcast areas, when two signals at the same frequency can drown each other out. In military parlance, they are jamming each other. Unprotected communication signals can be intentionally jammed anytime an opponent has line of sight to a communication receiver and a transmitter powerful enough to drown out the signal another transmitter is attempting to send to that receiver.

In many cases, military communications also need to be made secure against interception by a hostile receiver. Here, the situation is reversed from the jamming case, and the opponent is attempting to use a receiver to capture and exploit in some way a signal destined for another receiver. The desired exploitation might be to geolocate the transmitter, identify the transmitter, or read the message it is sending. Interestingly, the most powerful techniques for protecting radio communications from both hostile jamming and intercept also vary in effectiveness directly with increasing frequency. This is mostly because they are bandwidth intensive, but also because higher frequencies with narrow, more tightly collimated beams make it easier to design receivers that can ignore or null unwanted jamming signals, or by contrast, easier to prevent hostile

receivers from getting within line-of sight of the transmitter whose signal it is seeking to capture and exploit.

The most powerful techniques for providing jam resistant and low-probability-of-intercept (LPI) circuits use bandwidth to both repeat or spread the signal and hop it quickly over many frequencies. Thus, at any one time, a signal is being sent simultaneously over X different frequencies, and then that range or spectrum of X identical signals is hopped to another band of frequencies. The EHF waveform used with the Milstar satellite system was originally designed to provide extremely jam resistant, voice communications between nuclear CINCs and the National Command Authority in the midst of a nuclear war. Thus all the vast bandwidth available at EHF was consumed using spectrum spreading and frequency hopping to produce only a relative few circuits with the absolute minimum data rate necessary to sustain voice communication.[26] In a demonstration of the fungibility of bandwidth, new Milstar satellites are now being provided an added Medium Data Rate (MDR) payload whose waveform trades off some jam resistance in order to regain data rate, but which will remain compatible with legacy Milstar antennas designed for the original low data rate waveform. Given the benefits of bandwidth, there must be other important reasons to choose communication frequencies with low bandwidths. One, referred to above, is the need to penetrate seawater in order to communicate with a submerged submarine. Another has to do with cost and the footprint of the transmitter/receiver/processing equipment on different platforms.

Military platforms can be roughly divided up into four boxes in a matrix with axes that measure their size and/or their mobility and their numbers. Some platforms are large and/or immobile and exist in relatively small numbers. As a rule, these are less concerned about the cost and footprint of their communication equipment. At the other extreme, are those small, highly mobile, and numerous platforms which are extremely sensitive about the cost and footprint of their communications equipment. Overlaid upon these technical constraints are the

sunk costs associated with past practice. Again, these legacy constraints can play more strongly in cases where large rather than small numbers of platforms face the choice between developing new forms of connectivity or finding ways of maintaining old practices.

These different user environments lead to variances in available bandwidth for connectivity. Perhaps the extreme example is the manned aircraft, and especially the tactical fighter. Fighter aircraft are both weight and volume constrained, which leaves a limited footprint available for communication equipment, particularly large, high gain antennas. They are also numerous, which makes designers very sensitive to the unit cost of their communication suites. Finally, historically, once aloft they have been able to function as a largely self-contained unit, which placed very limited demands on their connectivity to other platforms. This is the main reason why, particularly in the U.S. Air Force, most tactical aircraft still link themselves to other platforms using only line of sight, UHF voice communications.

By contrast, aircraft bases obviously suffer no weight and volume constraints, and they are relatively few in number. At the same time, it is at such bases that all the extensive mission planning that precedes air operations is conducted. Thus, the connectivity requirements for air bases are both high, and also relatively easy to meet. Often, when in an established theater, they are met using land lines, but even in an expeditionary setting, air bases can easily be provided access to the highest capacity satellite communication systems. For example, near the outset of the satellite communication (satcom) era, the Air Force began using SHF satcom for such base communications, even though the antennas for those early C and X band systems were even larger than today's still large 20 foot diameter SHF dishes.

Because of both their tactical mobility and their traditional habit of long deployments over the horizon from established bases, Navy ships had intermediate connectivity requirements. The Navy's individual platforms had a tradition of largely autonomous operation, relying only on low bandwidth, high frequency (HF) radio. But the Navy's high Cold War operations tempo and

global reach soon began to exceed the limited total capacity available at HF. This led the Navy to pioneer in the development and deployment of UHF satellite communications, which combined the relatively low platform impact of traditional UHF and HF radio, with the over the horizon propagation of satcom. Still used primarily for voice and relatively low data rate, teletype communication, albeit with many more individual circuits now available, UHF satcom largely replaced high frequency (HF) radio for the Navy's over the horizon communication needs.

At the same time, tactically, the ships within a forward deployed battle group, often in harms way, increasingly had multi-mission responsibilities because each mission increasingly demanded a combined arms solution. This was particularly apparent in the Fleet Air Defense mission area, where the integrated fighter interceptor/SAM team was first developed and deployed. The efficient combination of these two combat arms led in turn to the first wide application tactically of digital data links in the late 1950s, known as the Naval Tactical Data System (NTDS). Today's data links, such as Link 16 (nee JTIDS) and CEC, operating mostly in line of sight mode at UHF, or the somewhat higher frequency L band, are all lineal descendants of NTDS. Together with the wide tactical use of UHF satcom in antisubmarine warfare (ASW) beginning in the 1970s, and in antisurface warfare with Outlaw Shark in the 1980s, these examples illustrate how long the Navy has in fact been "net-centric" in its tactical use of communication links to allow the separation of sensors and shooters.

During the Cold War, almost all of the bandwidth available to the Department of Defense, with the exception of SHF satcom, was therefore devoted to creating as many narrowband circuits as possible to support voice communications and digital data links operating at teletype rates. Furthermore, in creating these narrowband links, little if any margin was available for any antijam or LPI provisions. This constraint is particularly true of UHF satcom, which because it can be deployed on so many platforms, faces essentially unlimited demand. By

contrast, more bandwidth, and therefore some combination of increased data rate and jam resistance, is available using SHF satcom, but only at the price of an antenna too large for essentially all aircraft and ground vehicles, and many ships, and therefore suitable mostly for point-to-point communications between fixed installations which lack land line connectivity.

The end of the Cold War has created new connectivity demands which tend to be expressed, explicitly or not, in the desire for communications that retain the mobility, relative cheapness and global reach of UHF satcom with very high bandwidths. Many of these requirements are expressed implicitly because they are derivations of capabilities claimed by advocates of concepts like Net-Centric Warfare and the Revolution in Military Affairs. In many of the expressions of these visions, separate platforms supporting sensors, shooters, commanders, and information processing assets are all linked in seamless and timely fashion by communications compatible with even the most mobile platforms, able to support gigabit data rates, and presumably jam resistant and covert enough not to invite attack.

Technology is making some aspects of this vision for connectivity conceivable, and it is likely that cultural and organizational obstacles to achieving this vision will loom larger than technical ones. Technically, a key potential enabler of a more net-centric style of fighting will be a reduction of the antenna aperture size needed to support high bandwidth satcom. The extent to which this potential is actually exploited will depend on how vigorously DOD develops and deploys EHF satcom. At EHF, antenna apertures can be much smaller than SHF, but the available bandwidth is much greater. And although EHF will remain more expensive than UHF satcom, its footprint will be physically compatible with nearly any platform able to support UHF. This has been dramatically illustrated in the particular case of the submarine force, which could never have deployed an antenna with the aperture to support SHF satcom, but which can deploy an EHF antenna with a 17 inch aperture that will give it connectivity to both Milstar MDR and the Global Broadcast System (GBS). Thus, EHF eliminates what would have been a huge

asymmetry between the submarine force and the rest of the Navy if SHF had been the only path to getting higher bandwidth satcom.

The case of EHF satcom also demonstrates some of the cultural or organizational obstacles to achieving ubiquitous, broadband connectivity. EHF satcom is a relatively old technology, whose potential benefits both to DOD in general, and to the Navy and the submarine force, were first demonstrated in the late 1970s by Clarinet Omen, an experimental EHF satcom program that used two MIT Lincoln Laboratory satellites.[27] But the road from Clarinet Omen to an operating EHF satcom system proved a rocky one, with the first Milstar being launched only in 1994. In the years between 1976 and 1994, the Navy was able to deploy an interim EHF capability on two of its UHF satellites, but only by describing these two Fleet EHF Program (FEP) packages as adjuncts to Milstar development. One of the problems with EHF satcom development was that the Navy was the prime operational user of existing military satcom, and the service most likely in the near term to embrace the unique capabilities available at EHF, but the Air Force was given the Milstar program development lead because it had the largest number of potential EHF satcom users. In the end, Milstar development suffered from a too demanding set of requirements and arrived late and over budget, and today, only the Navy has bought and deployed a significant number of Milstar terminals.

Unfortunately, the same logic that assigned Milstar development to the Air Force informs many joint development programs, particularly for communication systems. This logic has the double effect of separating the developer from the largest current user, and of increasing the technical demands on the program at the outset, when the underlying technology is still immature. Thus, a similar story to Milstar can also be told about the contemporaneous modernization of line of sight, digital data links for aircraft. Naval aviation pioneered in the initial development and use of such data links, and not a single naval aircraft has been deployed since the late 1950s without one, but the Air Force, which did not use data links and remained

wedded to UHF voice, was given the lead in developing JTIDS in the late 1970s. Faced with the need to equip many more aircraft than the Navy, and therefore more concerned about unit costs; and lacking an existing user community to "pull" the system through the development process; the Air Force set very demanding cost, footprint, and performance requirements on JTIDS. Again, this led to delays, the cost targets were missed (although the performance targets were not), and yet today, the Navy remains the main user of these links. To name one example, only Navy air superiority fighters like the F-14 and F-18 have data links linking them to E-2 early warning aircraft, while the Air Force's F-15Cs still use UHF voice to link with AWACS. Furthermore, even when the Air Force is driven to adopt data links, as it has been in many of its air-to-ground mission areas, it has shied away from the expense of the JTIDS-derived Link 16, and chosen instead much cheaper and less capable data modems that use existing VHF/UHF voice radios. The latter provide less bandwidth, and therefore lower data rates (8-16 kbs versus 115 kbs); little or no jam resistance; and none of the relative navigation and identification capabilities provided by Link 16.

Link 16 and Milstar MDR are examples of the future of connectivity in a more net-centric environment because they combine reasonable data rates with a high degree of jam resistance. It is only systems like these that will provide the reliability and security necessary to split sensors from shooters, because absent such links, it will be at the network that the opponent will aim his most effective attacks. But the record of the past development of these systems argues that consideration be given to a different approach to modernizing them and developing their successors. In this approach, when joint programs are contemplated, development agents for communication systems would be chosen on the basis of those services or platform communities which are most dependent on the success of the development because they are the largest current users or have the largest current demand for the type of system in question. Such an approach runs counter to current instincts about how to manage such development programs,

which tend to assign development responsibility to the service or group willing to outbid its competitors in a contest over who will commit the most funds at the outset of the program. Unfortunately, the latter technique is often most effective at identifying the group that is most threatened by a new system or technology, not the group most committed to developing and deploying it. The submarine force in particular has a particular stake in such a new approach to developing and managing joint connectivity assets because it has some very unique connectivity demands and constraints that are not shared by other platforms. If it is to control the process that provides it connectivity, it will need in the future to reduce as much as possible the separation between those operational needs and the development process - whether joint or internal Navy - set up to meet them.

Establishing a Secure Base.

All strike warfare missions begin at a base from where the platforms which launch weapons are maintained, and in some cases, operated. For the United States, which is always projecting power far away from its own shores, such bases, with rare exceptions, can usually not be located on sovereign territory. Thus, the first step in the base-to-target sequence is usually the establishment of a secure base, or actually several secure bases, within the theater of operations. Security is here defined in both political and military terms. The security of a base in political terms is measured according to the degree of access to the base that is guaranteed. The military security of a base is measured in terms either of the ability of the base itself to survive attack, or of the survivability of the platforms it supports when they are deployed there. In assessing the degree of guaranteed political access, the main variation occurs between land and sea basing, while in assessing the degree of base survivability, the main variation in the near term will be between fixed and mobile bases, while in the longer term, the tradeoff is likely to be between all surface bases and undersea or space bases.

The political trends which are likely to limit access to foreign bases were discussed in the first section. Here it is necessary to elaborate on the distinctions in their effects on land and sea basing modes. The main difference is not that one mode needs overseas bases while the other does not, but that land bases launch weapons while naval bases do not. This distinction makes naval bases less threatening to the host nation, not just because it makes those bases less of a target, though it may certainly have that effect as well, but because it separates the host nation politically from the actions taken by the U.S. naval forces that use those bases.

This is a function of the range and endurance of naval platforms, which go to sea for months at a time, and often operate literally around the world from their bases. Certainly, when ships go to sea, they are supported by an extensive train of supporting vessels, which replenish supplies of fuel oil, dry cargo, and, in the midst of a conflict, ammunition. But this umbilical connecting deployed navy combatants to the shore is largely indistinguishable from that vantage point from normal commercial activity, and is in fact often conducted by civilian-crewed ships that are essentially indistinguishable from their purely commercial counterparts. Thus, for example, when the U.S. Navy first began regular Indian Ocean battle group deployments in the late 1970s, after the fall of the Shah, its oilers and stores ships were able obtain needed supplies from a variety of countries along the Indian Ocean littoral, none of which were willing to provide any level of base access ashore to land-based American forces.

This distinction is reflected in actual legal arrangements. For example, everywhere the United States has access to overseas bases for land-based forces it has an accompanying set of agreements with the host nation about how those forces will or will not be used. Thus, in a recent example, after the Taiwan straits crisis of 1997, the United States apparently sought to negotiate with Japan over future guarantees that bases on its territory which were not available in 1997, would be in the future under similar circumstances.

Certainly, this asymmetry in favor of sea basing does not come without its costs, and sea-based forces may be less cost effective than analogous land-based forces in those cases where the latter have assured access to local, prepared bases in advance of a conflict. But as the discussion in the first section noted, this level of access will be less common in the future security environment than it was during the Cold War.

Access for land-based forces can be constrained in both time and scope. For example, a country might deny American strike aircraft based there permission to bomb a neighbor, but allow aircraft flying supporting missions to operate, as apparently the Saudis did in Desert Fox. Similarly, a country that had allowed the United States to pre-position war material near its bases so that they could support rapid deployment of land-based forces in a crisis will be likely to support such a deployment only under a particular set of circumstances, against a particular opponent. A country with no U.S. forces normally stationed on its territory might or might not allow such forces to stage through its territory on the way to another country's bases, and again, in that context, there will be cases where a country will allow all forces to do so, and other cases where only support forces such as tankers and airlifters will be allowed access. Such access to enroute bases is necessary to any major deployment of land-based forces, both because Air Mobility Command airlifters must stage through them, and because air-refueling tankers must operate from them in order to refuel deploying aircraft. The same constraint applies to global bomber operations launched from the continental U.S., which are utterly dependent on access to enroute bases on foreign territory for use by KC-135s and KC-10s.

In addition to gradations in the scope of access granted U.S. forces, are gradations in the timing with which that access is granted. As noted in the first section, it took the Saudis four days after the Iraqis invaded Kuwait to decide that a massive deployment of American forces would be in their security interest. The speed of the deployment that followed was inestimably aided by the massive pre-positioning of U.S. equipment that the Saudis had agreed to during the

Cold War. Thus, a country that already had a major military relationship with the United States, and which had allowed extensive pre-positioned stocks of equipment to be deployed on its territory in anticipation of a scenario like the one it faced in August 1990, still took days to decide how to respond. A country with a more tenuous relationship with the United States to start, and one that would be lacking in the pre-positioned stocks that make large, rapid deployments of land-based forces possible, might understandably pause even longer over whether to grant U.S. forces access to its bases.

The technical trends effecting the military security of overseas bases provide a case where the demands of the near and far term security environments appear to reinforce each other, even though the source of this similarity is different. This is because fixed bases within a radius of 500 to 1000 kilometers of an opponent are likely to become increasingly vulnerable in the near to mid term to conventional attack by GPS/INS-guided ballistic and cruise missiles. Over the longer term, this vulnerability to over the horizon attack will extend to large ships at sea, but in the near to mid term, such ships are likely to be more survivable than fixed land bases as long as they stand off over the horizon from an opponent. Least likely to become vulnerable out through the far term, some 30 or more years from now, are undersea and space platforms, although the latter, particularly when deployed in low earth orbits, will likely eventually become more vulnerable than the former. Fast, quiet nuclear submarines will remain the least vulnerable of all basing modes because antisubmarine warfare (ASW) is least effected by the technical trends that will potentially transform other warfare areas. Thus, ASW against modern nuclear submarines will remain both extremely demanding technically, very expensive, and still a largely fruitless endeavor.

The trends in the vulnerability of fixed bases within a theater will be driven in particular by the marriage of cheap, widely available GPS/INS guidance technology and conventional sub-munition payloads with existing, mobile, tactical ballistic missiles (TBMs) and perhaps, with

cruise missiles. The latter may be chosen if an opponent wishes to extend his reach beyond

about 600 km.[28] Such cruise missiles might actually have more in common with small aircraft

than with current cruise missiles like Tomahawk, and might derive their survivability less from

high speed and low radar cross section than from their ability to blend in with a noisy

background and deny an opponent positive identification.[29] This discussion will focus on TBMs

because they are already ubiquitous.

Before discussing the impact of GPS/INS, it is important to establish what is already true

about existing mobile TBM capabilities. TBM defenses have already proven to be at the edge of

the scientific-technical capabilities of the United States, and even assuming effective TBM

defenses in the future, they will likely be on the losing end of the cost-exchange ratio between

the attacker and the defender. Directed energy weapons may change this relationship in the

distant future, but even directed energy weapons will be most effective against TBMs whose

warheads have terminal seekers, because it is more difficult to harden the latter against a laser's

heating than it is to harden an INS/GPS-guided warhead used in attacks against fixed targets.[30]

Heretofore, the TBM threat has been leavened by the fact that they have been very inaccurate.

Armed with conventional warheads, their military effects have been both low and unpredictable,

and armed with nuclear warheads, their use would bring the vastly superior American deterrent

into play.

GPS/INS will lead to a quantum leap in conventional TBM capabilities because it will

give them the accuracy needed to effectively attack fixed, soft military targets with conventional

submunition payloads. This is a capability that has already been deployed by the U.S. in the

form of the U.S. Army's Tactical Missile System (ATACMS), and it will be employed by the

Navy, initially with unitary warheads, in their Land Attack Standard Missile (LASM) and

Extended Range Guided Munition (ERGM). Single stage TBMs like the Chinese M series

already provide ranges of 300-600 km (185-375 miles), payloads of 500 kg (1100 lbs), and

conservatively estimated accuracies of 100-200 meters (330-660 feet). A 500 kg payload of simple submunitions like the M-77 grenade can destroy soft targets over a circular area of two million square feet centered at their point of release. Even with the relatively low accuracies assumed above, TBMs like this would wreak havoc on airfields and ports within their range. For the purpose of this discussion, I will focus on airfield vulnerabilities, and in particular on those vulnerabilities most relevant to the mid to far term security environment.

Airfields within range of opposing TBMs will be inherently vulnerable in the expeditionary environments typical of likely future air operations for four reasons. First, simply building the hardened shelters to protect five 72 aircraft wings of tactical fighters is a $1.5 billion investment that few potential allies are likely to make on their own. Second, in a world where the location of future conflicts is less predictable than it was during the Cold War, the U.S. will not be able to invest in hardening airfields in all the potential areas where it may be called on to fight. Third, even in cases where the United States did make this investment during the Cold War, as in Saudi Arabia, it still proved too expensive to provide shelter to the thousands of U.S. personnel which must live and work on the base; hence the enormous tent cities which were erected on base, which would remain a lucrative target even at the hardest base. Finally, it is simply impossible to provide hardened shelters for the various large, high value support aircraft which are integral to any expeditionary air operation, such as AWACS, JSTARS, Rivet Joint, KC-135 and KC-10 tankers, and outsize airlifters like the C-5 and the C-17.[31] For all these reasons, it is likely at some point in the mid to long term future that large scale, expeditionary deployments of tactical combat aircraft and supporting assets will become limited by the need to avoid bases within 1000 km from an opponent's territory.

This constraint will, at a minimum, reduce by half or more the sortie rate of a given size force of tactical aircraft, and increase the cost in terms of additional tanker support and bases for those tankers necessary to give that force the range to attack a given set of targets. Perhaps more

important, there will be circumstances due to the political geography of a particular conflict in which the only bases potentially available will be within range of an opponent's missile force. This will lead to cases where land-based tactical aircraft will be denied access to a given theater altogether, or at least until the threat to their bases has been suppressed or eliminated by other forces.

Air bases and other relatively soft, fixed targets will become more vulnerable because mobile, long range, GPS/INS guided weapons that are difficult to defend against will be increasingly available to potential opponents. But as the U.S. discovered in Kosovo, such weapons do not by themselves address the mobile target problem. Thus, potential opponents of the U.S. will likely succeed first at solving the fixed target problem before they become adept at the mobile target problem. As was discussed above, the key to the mobile target problem is a wide area, over the horizon search and surveillance capability. Different warfare areas will present different challenges to future opponents that wish to develop such surveillance capabilities. One such warfare area is sea denial, a posture normally forced on the weaker contestant in a naval battle that seeks to prevent its more powerful opponent from projecting power across or from the sea.

As a subset of the warfare areas where the mobile target problem dominates, sea denial presents an interesting set of extremes. In a purely technical sense, over the horizon surveillance of surface shipping is probably the easiest form of mobile target surveillance, while surveillance of submarines is by far the most difficult. Surveillance of surface shipping is relatively easy because surface ships present an easily detectable signature to airborne radars. The main reason is that the sea surface is a relatively clutter-free environment. For example, the sea presents itself as a flat, mirror-like surface to UHF radars of the type used on today's E-2. Therefore, ships on the horizon stand out against this background without need for resort to the doppler signal processing necessary for airborne radars to detect moving targets on land.

By contrast, the only effective long range surveillance technique against submarines has been and largely remains passive acoustics. Passive acoustic surveillance systems are quite effective against loud targets, and surprisingly simple, as demonstrated by the development and wide deployment by the U.S. of the Sound Surveillance System (SOSUS) quite early in the Cold War. Yet the key constraint on such systems is that, like all passive detection methods, they rely on a cooperative target. That is, systems like SOSUS are only effective against submarines which continuously or periodically put a narrow band signal into the water. Eliminate those narrow band tonals, as the U.S. submarine force began to do aggressively in the early 1960s when it discovered its own vulnerability to SOSUS, and passive acoustic detection ranges plummet against quiet submarines.

Recovering the detection ranges provided by passive acoustics against a non-cooperative submarine is extremely difficult. The Soviet Navy faced this problem throughout the Cold War and never came close to solving it. The U.S. Navy only began to face it near the end, with the Soviet deployment of submarines like the Akula SSN. On a much different scale, and in a much more confined set of circumstances, this problem continues for the U.S. in the form of modern, non-nuclear submarines.[32] There is no one solution to the surveillance problem against these submarines, but an example of what will be required is provided by current U.S. Navy efforts to incorporate legacy passive acoustic sensors deployed on individual platforms into a multistatic processing network for detecting faint echoes from a small target using an artificial sound source in an extremely high clutter environment.

Similar asymmetries exist in the weapons available to an opponent for ASUW and ASW. In the former warfare area, radar-guided, fire and forget weapons have been in operational use for more than 30 years, and rely again on the large, clutter free signature provided by the outline of a ship against a clearly defined horizon. Flying low and fast, antiship missiles are extremely difficult to defend against in the end game of their engagements, which is why the U.S. Navy's

traditional approach to countering such missiles has been to mount a major effort to attack their launch platforms. Despite the relative success during the Cold War of these efforts to kill the archer rather than his arrow, the Navy was still driven to develop the most sophisticated radar guided SAM system in the world, in the form of the Aegis defense system, which is devoted to killing the arrows that leak through a battle group's carrier-based outer air defenses or, in the more challenging case of a submarine launched antiship weapon, its ASW screen.

Today, the danger posed by antiship weapons is manifest in the proportion of a U.S. Navy guided missile destroyer's or cruiser's VLS tubes dedicated to carrying SAMs rather than offensive weapons like Tomahawk. On an Aegis equipped ship, this proportion is around 60-70 percent. The danger is also manifest in the development of sophisticated systems like the Cooperative Engagement Capability (CEC), which will form a network of the monostatic radars in a battle group. This network will allow those ships optimally located to detect an antiship missile from the side, where its radar signature is the largest, to guide the weapons of another ship, optimally located to attack the antiship missile, but unable to see it because of its low frontal aspect cross section.

ASW weapons, predominantly torpedoes, come in two types: wire-guided torpedoes that are controlled by their launch platform until the end game, when they go active; and all active torpedoes which use active sonar from the start. Wire-guided torpedoes are long range weapons primarily for use in cases where the weapon platform can approach and attack its prey passively and ambush it. That is why they have only been carried by attack submarines. In cases where the attacking submarine has a good enough acoustic advantage over its opponent, wire-guided torpedoes are by far the most effective ASW weapon. Because U.S. nuclear submarines are so quiet, and because they are normally immune to long range surveillance, they will encounter the submarines of a potential opponent in only two cases: when they are about to kill them, or in an

accidental encounter; which is why few countries will even bother to use their submarines in an ASW mode, except of course in self defense, when a wire-guided torpedo is relatively useless.

Wire-guided torpedoes are also incompatible with air ASW platforms. Thus, during the Cold War, shorter range, active, lightweight torpedoes were the weapon of choice for maritime patrol aircraft and ASW helicopters. Lightweight torpedoes were used effectively during the Cold War by the U.S. Navy because they were deployed on air ASW platforms that could use passive acoustics to get very close to the target before launch, usually within the low thousands of yards necessary to detect the anomaly in the earth's magnetic field caused by its steel hull. Also, because Cold War air ASW was a largely a deep water exercise, these active torpedoes operated in a relatively clutter free environment, and because it occurred in blue water, their launch platforms were operating in benign air space.

Understanding the conditions which enabled air ASW and the use of lightweight torpedoes during the Cold War is important because this is the only ASW posture that will be available to potential opponents of the U.S. for the forseeable future. Yet none of the enabling conditions described above will apply. Opposing ASW forces will not be able to use passive acoustics to locate and track American submarines at long range. Instead, the only potentially useful detections will occur intermittently, when those submarines launch salvos of surface-to-surface weapons, and those detections will only be useful if they are made by radars deployed within line of sight of the those weapons soon after they break water, before trajectory shaping masks the point of break water beyond utility. Furthermore, even should these conditions be met, this initial datum will rapidly lose its utility as the submarine quickly leaves the launch area at maximum quiet speed. In order to take advantage of such a datum, the opponent would need to be able to close it with an air ASW platform quickly enough to allow the latter to search for and acquire the American submarine using active sonobuoys or a helicopter's active dipping sonar, both of which would be limited by reverberation to detection ranges of a few thousand yards.

Finally, assuming successful accomplishment of the preceding chain of events, the opponent's air ASW platform would need to be armed with lightweight, 45 knot torpedoes whose active seekers could filter out the very high clutter and reverberation characteristic of a shallow as opposed to a deep water environment, and still home on and run down a target which, upon detecting that it was being successfully tracked by the weapon, could quickly accelerate to a speed of 30 plus knots.

Given the difficulties inherent to the ASW problem, it is relatively easy to show that potential opponents will have more difficulty solving that problem than they will the antisurface sea denial problem. More important for our purposes is the question of how much more difficult the antisurface warfare (ASUW) problem will be compared to the problem of attacking soft, fixed targets like air bases. The most straightforward and technically manageable approach to an over the horizon, ASUW denial capability would resemble aspects of the old Soviet approach to this problem, especially its emphasis on long range patrol aircraft using surface search radars and ELINT to locate and classify hostile combatants. These assets could be used to cue attacks by surface ships, aircraft, and submarines. Of course the problem with this approach is that the patrol aircraft are not survivable in wartime.

It is important to note that this approach still allows a potential opponent to trail U.S. forces in peacetime and strive for a victory in "the battle of the first salvo" that would occur when conflict broke out. Certainly, this approach caused much concern when it was applied by the Soviets to the Sixth Fleet in the Mediterranean naval operations conducted in the midst of the October 1973 Yom Kippur War. But dissatisfaction with this limited capability led the Soviets to pursue a space-based solution to their over the horizon, ASUW surveillance problem. The constellation of radar and electronic ocean reconnaissance satellites (RORSAT and EORSAT) that they eventually deployed in the 1970s was the result.

It is not clear how successful this system was, but there is some evidence that the U.S. Navy developed tactical and technical countermeasures to it which reduced its effectiveness in detecting, identifying, and tracking the Carrier Battle Groups which were its prime target. This demonstrates two things: that the mere fact of an ability to deploy surveillance or reconnaissance satellites does not confer a surveillance or a reconnaissance capability; and that therefore one way of measuring the difference between addressing the fixed target problem and the ASUW sea denial problem is to measure the difficulty of developing an effective space-based ocean surveillance system. Clearly, the latter is far more challenging for a potential opponent than simply obtaining the GPS coordinates of regional air bases in advance of a conflict, and it is also more challenging than developing a space-based imaging capability for use in monitoring the use of those regional bases on a daily basis.

On this basis, one can certainly argue that an ASUW denial capability will be more difficult for an opponent to develop than an ability to attack soft, fixed targets. This means that naval surface combatants and aircraft carriers will be more successful for longer in defending themselves against opposing sea denial efforts than will land-based, expeditionary tactical air forces that seek to operate from soft bases within range of opposing TBMs and cruise missiles. But it also means that these surface naval forces will carry a much larger self defense burden than will fast, quiet nuclear submarines, which will be able to devote all of their payloads to offensive weapons because they will be essentially immune to opposing ASW sea denial efforts for the forseeable future.

The self-defense burden for surface forces will become particularly acute when potential opponents combine an over the horizon surveillance or reconnaissance capability with a force of modern non-nuclear submarines armed with submarine-launched, antiship missiles, like Exocet, Harpoon, or the Russian SS-N-19 Shipwreck. This threat combines two warfare areas - ASW

and cruise missile defense - where the cost of countering the threat is out of all proportion to the cost of mounting the threat in the first place.

Trends in Strike Warfare and Alternative Weapon Platforms

The five steps in the base-to-target sequence described previously can be negotiated using four clearly distinguishable techniques, centering on four different platforms or groups of platforms. The dominant platform historically has been land based tacair, and in the future, this technique will be represented by the U.S. Air Force's new expeditionary air wings. The other three techniques are carrier battle groups, long range bombers, and submarines. Although submarines often operate in concert with battle groups, just as long range bombers and tacair often are used together, the four methods are broken out here and treated independently for comparative purposes.

The heart of the comparison between these alternative platforms will be a series of judgments at each step of that platform's base-to-target sequence as to whether the obstacles to making that step will get more or less difficult in the future security environment. This comparison will show why it will be important for the submarine force to be looking at new sensors, payloads, and types of connectivity in the future security environment. As an example, the report's conclusion discusses of how submarines might contribute to the suppression and destruction of modern radar-guided SAM batteries.

Expeditionary Tacair in the Future Security Environment

Base access will likely become more difficult for expeditionary tacair in the future security environment for both political and military reasons. In the near term, the political obstacles will predominate. It will be rare that the U.S. will be involved in a major contingency without access to any local bases, although a contingency that involved Taiwan certainly might have that

characteristic. More likely will be cases when political constraints limit the scope and timing of access to local bases. Bases will be available, but gaining access to them will require political negotiations with host nations, and their use will also be constrained by those host nations.

In the more distant term, there will be increasing concerns about the survivability of tacair deployed on bases in the same region as their targets. This is both because of trends in the effectiveness of conventional TBMs and cruise missiles, and because future expeditionary air bases along the Indo-Pacific littoral will be much softer than their Cold War counterparts on the central front in Europe. These trends will either increase the standoff distance necessary in order to insure safe deployment and operation of expeditionary tacair, or result in the need for more effective TBM and cruise missile defenses. In practice, some combination of both steps will be necessary in most cases due to the fact that the political geography of a particular conflict will not necessarily provide a large number of bases located just outside the range of an opponent's weapons.

These trends in base access for expeditionary tacair will, at a minimum, have the effect either of reducing the sorties available from a given size force, or of increasing the cost of protecting the same sized force. Sortie rates would be reduced if aircraft were forced to operate from greater distances from their target in order to avoid attacks at their bases, and both the cost of protecting the force and the losses that would be sustained would go up if it were forced by geography to operate at bases that were within range of opposing conventional TBMs and cruise missiles.

Combat aircraft, and particularly tactical aircraft, are the most bandwidth constrained strike platform by a wide margin. This is because it is impractical to give them even the smallest satellite dishes, which limits them to low gain antennas that can support the full range of line of sight communication links, but which can only support UHF satellite communications for over the horizon connectivity. Furthermore, given the number of aircraft that would be involved, and

given the relatively high cost of even the simplest UHF satcom terminal, they have not in practice been deployed on tactical aircraft, thereby limiting these to line of sight communications. In the Air Force, as described briefly in the section on defense suppression, there has been the additional constraint that normally, data links will be deployed only using existing UHF radios, rather than the dedicated data links like Link 16 which provide substantially more bandwidth, but at the cost of a separate L band radio. Certainly, there are no physical reasons why data links like Link 16 could not be deployed on all combat aircraft, and it is likely that the Air Force will soon be driven to adopt this approach, as the Navy did many years ago. If and when this occurs, the connectivity provided by line of sight L band data links will probably become the point of entry into future ISR networks for finding and identifying mobile targets.

In the near term, penetrating opposing air defenses will continue to increase in cost for a given payload delivered. This will be true of all manned strike platforms, non-stealthy and stealthy. The main reason will be the growth in capability of radar-guided SAMs. These will increase the cost of traditional approaches to defense suppression by requiring both a stealthy launch platform and a more sophisticated and longer range antiradiation missile. They will also increase the cost of assuring the safety of even the stealthiest attack aircraft like the F-117 and the B-2. In Kosovo, both types of stealthy aircraft were supported directly on every mission by at least one and sometime two radar jamming EA-6Bs, because allied planners could not be sure of the location of Serbia's mobile SAM-6 batteries.[33] Both of these problems will get much worse when an opponent deploys more modern systems like the SAM-10, which are as mobile as the SAM-6 and which can detect stealthy targets at much greater ranges.

Finally, all manned aircraft will benefit, to the extent that their connectivity allows, from the networks of offboard sensors that will need to be developed to detect and identify mobile targets. They will also benefit from the ubiquitous deployment of GPS/INS weapons needed to attack both fixed and mobile targets precisely and in all weather from medium to high altitude.

In return for these benefits, manned aircraft will also lose two unique advantages they once enjoyed over long range, standoff weapons: the ability to get close to a target and identify it, a function that will in the future be conducted by an offboard sensor network; and the ability to guide weapons with great precision, a capability that GPS/INS provides without the need for a man-in-the-loop within line of sight of the target as with a laser guided bomb.

Thus, in summary, trends in base access for expeditionary tacair in both the near and the far term are negative, for both political and military reasons. With the growth in significance of offboard sensing networks, the trends in connectivity requirements will be for more bandwidth, but tactical aircraft are the most bandwidth constrained of all strike platforms. Near term trends in the cost to penetrate defenses are extremely negative, both because opposing air defenses are getting better, and because the tolerance for losing aircraft and their crews in conflicts over less than vital interests is near zero. And finally, new sensing and guidance technologies will make it easier to find and attack mobile targets in all weather, but in ways that eliminate the unique advantages that manned aircraft once had in these areas. The one unique advantage that manned aircraft will retain will be an economic one, which is that they will remain the most cost-effective method of conducting strike warfare when their bases are secure and the defenses they face have been suppressed or destroyed.

Long Range Bombers and Carrier Battle Groups in the Future Security Environment
Bombers and carrier battle groups are combined here because both these modes of conducting strike warfare share some but not all the characteristics of land-based tacair. Obviously, both face the same trends in the ability to penetrate opposing air defenses, though each has responded differently due to differences in philosophy between the Air Force and the Navy. The Navy has made a much deeper commitment to long range, standoff weapons like Tomahawk as a complement to the carrier's aircraft, while the Air Force has made a deep commitment to manned

aircraft like the B-2 with all aspect stealth, and has generally not invested in air-launched, long range standoff weapons. It is too soon to say how the future security environment will treat these respective choices, but the fact that B-2s and F-117s both required jamming support from EA-6Bs during Allied Force is not a good sign, because the Air Force went to great pains after Desert Storm to argue that the unique advantage of stealthy aircraft like the F-117s was that they did not need such support, even in attacks against the most heavily defended Iraqi targets.

Connectivity is another area where the trends for both these platforms are similar. Broadly speaking, bomber bases, aircraft carriers, and surface ships both have all the connectivity they need via satellite communications, though this is a recent development for the Navy. Likewise, carrier-based aircraft currently face the same physical constraints on their connectivity as those facing bombers and land-based tacair. Larger carrier aircraft like the Navy's E-2 and Air Force bombers both have UHF satcom and a range of line of sight data links and voice circuits, while fighter aircraft in both services are limited to line of sight links, with Navy fighters currently more committed to higher capacity L Band data links than Air Force fighters. Bombers and carrier battle groups will also experience the same broad trends in their ability to find, identify, and attack mobile targets as expeditionary, land-based tacair. That is, their targets will be found and identified by offboard networks, and all weather attacks against those targets will be launched using GPS/INS-guided weapons.

Long range bombers and carrier battle groups vary most significantly in how they gain access to politically and militarily secure bases. Carrier battle groups, like submarines, preserve their political freedom of operation by keeping their link to local bases an indirect one. Unlike submarines, carrier battle groups gain their security and survivability primarily through a combination of self defense and an ability to standoff from their targets. Bombers use their much greater range than land-based tacair to reduce the number and/or the political salience of the overseas bases they use, and to increase the standoff range of those bases from the opponent.

Politically, bombers can reduce their vulnerability to denied access simply by increasing the probability that an amenable ally can be found within range of the opponent. They can also reduce their vulnerability to being denied access by taking advantage of the fact that a country is more likely to allow tankers rather than combat aircraft to operate from its bases. Taken to its extreme, this latter tactic can involve 30-40 hour round trip missions for the bomber and its crew between the United States and a target half way around the world. In these operations, the bomber never uses a foreign base, but the vast array of tankers that must pre-deployed along its route must do so intensively. Thus, it is almost never the case that long range bombers eliminate all dependence on access to foreign bases. What they do in almost all cases is lessen that dependence.

Added range is not a free good, which is why bombers are much larger and much more expensive than tactical fighters, and tend to be slower. Also, though their size gives them larger payloads, the added range over which they carry those payloads leads to reduced sortie rates. These tradeoffs between bombers and land-based tacair will become more important when military vulnerabilities at overseas bases are added to the political vulnerabilities that already exist. Assuming that there will be limits on the range of these threats for the forseeable future, they will improve the relative advantages of long range aircraft compared to expeditionary tacair, because bases outside that range will not need to be defended and/or hardened.

Compared to both expeditionary tacair and bombers, carrier battle groups are essentially immune to political constraints on their operations in a particular conflict due to lack of access to overseas bases. This is because carriers are free to do as they please once they are deployed, and their deployments last for up to six months at a time. While deployed, the flow of consumables like fuel and dry goods can in theory be sustained directly from the United States, but in practice this has never been necessary because the Navy has always been able to get sufficient access to local stockpiles of such supplies.

Military forms of denial are the only problems that carrier battle groups are likely to have with access to a given region, and these problems will probably grow at a pace that lags behind the growth of threats to expeditionary airfields. Because they are mobile and already well-defended, the price of entry for developing an over the horizon, anti-carrier, sea denial capability is higher than it is for attacking unhardened airfields. In particular, the surveillance and targeting requirements, particularly in a conflict as opposed to peacetime, bulk much larger in the former case.

Thus, long range radar surveillance by maritime patrol aircraft, which many countries can accomplish today, may buy a capability to find and even track carriers in peacetime out to a range of several thousand miles. But these aircraft will not survive if used this way in a conflict. This means that most countries lose their over the horizon sea surveillance capabilities at the outset of a conflict because they can not contest the air space over the seas with American carriers. This will remain the case for as long as the U.S. Navy has an essential monopoly on carrier-based aviation, which is why most opponents who aspire only to sea denial rather than sea control will be attracted to a space-based ocean surveillance system to cue antiship-launching submarines. The latter are already within reach of many states because they are available for export in non-nuclear form. It is the former which will be the pacing item in determining the military threats to a carrier battle group's access to a particular region.

Clearly, a space-based sea surveillance capability is more of a challenge than finding the locations of air bases in advance of a conflict. It is also almost certainly more challenging than deploying a space-based imaging capability designed to periodically monitor the use of fixed air bases. But such a surveillance capability is also much less challenging than developing and deploying an undersea surveillance capability against very quiet nuclear submarines. This is why carrier battle groups will experience military limits on their access to a particular littoral region more slowly than will expeditionary tacair, and perhaps more slowly than will long range

bombers, but well before submarines experience analogous limits. These limits will not necessarily eliminate a battle group's access, but they will increase its self defense burden and reduce its offensive capabilities for as long as the sea denial threat they face is extent.

Conventional, Guided-Missile Submarines in the Future Security Environment

Submarines armed with conventional TBMs or cruise missiles face a very different set of opportunities and constraints as strike platforms in the mobile target mission. No platform is less effected by access issues than a nuclear submarine, whether the issue is political access to bases, or vulnerability to attack. ASW is probably the most challenging of all conventional warfare areas and there are no technical developments even on the distant horizon that are likely to change that fact. Thus, submarines will likely remain the most secure form of forward basing for strike weapons for the forseeable future.

Historically, due to the extreme demands for covertness placed on their Cold War activities, many of which brought them in close proximity for long periods of time to the Soviet homeland, the U.S. Navy's submarine force sought systems for connectivity which allowed them to remain submerged as long as they needed to in order to accomplish their mission, and which therefore emphasized one way, very low frequency broadcasts. Even though their mission determined their connectivity posture, a perception developed during the Cold War that submarines were inherently limited to such a posture because of physical constraints, and that moving submarines into more bandwidth intensive mission areas would therefore be fruitless, even if those mission areas imposed much less stringent requirements for covertness. This misperception is rapidly being corrected.

First of all, submarines have always enjoyed a full suite of line of sight and satellite communications, and were among the first navy platforms to adopt UHF satcom when it was first deployed in the 1970s. Through to the period of the Gulf War, submarines enjoyed the same

level of potential connectivity as other naval forces, and that potential was only limited by the need for covertness when submarines were operating in areas where no other naval platform could go. The Gulf War posed unexpected connectivity challenges to the Navy as a whole because the UHF satcom links that were the mainstay of their connectivity lacked the bandwidth needed to support the efficient transmission of Air Tasking Orders and Tomahawk targeting packages.

In responding to this challenge, the aircraft carrier and surface communities initially embraced SHF satcom as the quickest way to eliminate this constraint, and SHF satcom dishes are indeed too big for deployment on a submarine's communications mast. But the rush to SHF satcom was soon replaced by a longer term plan to migrate fully to EHF satcom, where bandwidths are even greater than at SHF, and where much smaller aperture antennas become possible. At EHF, with a small 17 inch antenna, the connectivity differences between a submarine and a surface ship once again become largely a question of mission requirements. When a submarine is engaged in a mission where it needs to maximize covertness, it may need to stay completely submerged, but the circumstances in which this will be necessary will be ones in which no other platform could safely operate.

Furthermore, technology is also increasing the connectivity available to a completely submerged submarine. There are a variety of approaches to this problem being pursued. One example, which builds on past practice, is to give a towed, buoyant cable antenna the ability to receive and transmit at UHF and L Band, as well as receive at VLF.[34] This would give a submarine continuous connectivity equal to a combat aircraft during those periods when it could not or chose not to access EHF satcom at periscope depth. Because the challenge of providing high bandwidth connectivity for the submarine force is relatively new, and because the basic technology involved is the same as that which is fueling developments in the commercial information processing and communications industries, the potential for both rapid growth in

capability and reduced cost is great. Also, because even the most advanced of potential

opponents are unlikely to possess robust ASW capabilities, the requirements for covertness are

likely to be greatly reduced.

Along with the navy's surface combatants, submarines pioneered in the deployment of

the Tomahawk land attack cruise missile, and today, these two communities represent the main

impetus from within the Navy for further long range, standoff precision weapon development.

Weapons that allow their launch platforms to stand off from opposing air defenses force those

defenses to shoot the arrow rather than the archer, and the trends in both TBM and cruise missile

defense strongly favor the offense over the defense. Like ASW, these are warfare areas where

the cutting edge of American technology and its vast wealth do not yet guarantee high leverage

on the problem, which makes the challenges for a much less well endowed opponent

overwhelming, even if they have access to systems like the SAM-10.

This is especially true in the near term security environment in which potential U.S.

opponents will lack the ability to engage in a direct military confrontation, but will instead be

preying on the U.S.' aversion to taking casualties in conflicts where there is a great asymmetry in

the relative stakes between it and its opponent. In these conflicts, advanced air defenses based

on systems like the SAM-10 will pose a danger to both manned aircraft and unmanned missiles,

but the former will require protection by the full panoply of defense suppression assets, while the

potential loss of a few of the latter will be a non-event politically and will be easy to compensate

for militarily.

This is why the marriage between GPS/INS and long range precision weapons is so

important. It gives a weapon that is much less vulnerable to opposing defenses than manned

aircraft the precision heretofore only available from laser-guided bombs delivered by manned

aircraft. This combination is already becoming the weapon of choice against many fixed targets,

and its lethality will grow exponentially in the future. This is because GPS/INS accuracies are

improving by an order of magnitude every few years, and will soon be measured in feet rather than tens of yards. As accuracies improve, the size of the warhead needed for a given lethality against a fixed target goes down as the cube of the reduction in miss distance, which means in turn that as payload weights go down, missile throwweights go down, missile sizes go down, and finally missile costs go down.[35]

The same trends that will improve the lethality and reduce the costs of standoff weapons will also improve the payload capacity of their launchers. This is because smaller missiles with the same lethality as weapons like the Tomahawk or the Army's TACMS will give both submarines and surface ships much larger magazines without changing the internal volume of their vertical missile tubes.

For example, with minimal modifications, a Trident SSGN could carry seven 21 inch diameter and 20 foot long weapons like Tomahawk or ATACMS in each of its 24 tubes for a total of 168.[36] Given a 20 meter CEP, and using existing propellants, a TBM with a 250 lb warhead and a 500 km range could be developed with the same diameter and two thirds the length of today's ATACMS, and over 500 of these could be triple stacked in an SSGN's tubes if they were designed with an eye to that purpose. The reason for the improvement is that today's ATACMS requires a much larger warhead because it is less accurate, and therefore it also has a much shorter 160 km range.

This is what engineers call a virtuous rather than a vicious circle and it represents a perfect example of the difference between increasing rather than decreasing returns on investment. The improvements in lethality of standoff weapons made possible by INS/GPS have already shifted the burden of proof needed to justify the use of a manned aircraft against a well defended fixed target. This burden of proof will continue to shift in favor of standoff weapons for the forseeable future, assuming their continued development is pursued with vigor. There will remain a relatively small though high value part of the fixed target set, consisting mostly of

deeply buried targets, for which manned aircraft will retain unique capabilities because of their ability to lift larger unitary payloads than are feasible for TBMs or cruise missiles. But for the rest of the fixed target set, as discussed above, the one advantage that manned aircraft will retain will be the economic one that the extra cost of a standoff weapon is wasted when its long range and ability to penetrate defenses is no longer needed. Thus, one obvious mission for secure, standoff precision weapon launchers like a submarine is to use their weapons in a way that creates security for manned aircraft, both at their bases, and while in opposing air space.

The same trends which will lead to a growing role in attacking fixed targets for standoff weapon shooters will also lead to a growing role for them in attacking mobile targets, but there are also particular aspects of the mobile target problem which will give submarines unique advantages because they will be the standoff weapon shooters with the most enduring and survivable forward base.

Because they provide a secure, long endurance, forward base, submarines can stay close to a hostile shoreline in contested waters and under contested air space. Thus, they are the standoff weapon launcher that can get and stay closest to the opponent before and during the early stages of a conflict. For those missions which require the most time urgent, TBM weapons, submarine launch platforms will give the deepest reach into an opponent's territory, and the most reliable method of ensuring that TBMs are always in range of specific targets.

Here, comparison with navy surface combatants is appropriate. Navy submarines and surface ships are the primary long range, cruise missile shooters, and they will likely be the primary shooters of TBMs like the Advanced Land Attack Missile (ALAM) in the future. The main difference between submarines and surface ships as strike platforms is the method they use to reduce their vulnerabilities to opposing sea denial efforts. Submarines exploit the fact that ASW is so difficult against an acoustically stealthy target. Thus, as long as their indiscretion rate remains commensurate with the ASW threat, they are relatively immune to attack and can focus

on the offense. Less stealthy surface ships survive by defeating an enemy's attacks, whether they come from the air, the surface, or from a submarine. Therefore their payloads are more diverse and normally more heavily weighted toward defensive weapons. The ratio that determines this division between offensive and defensive weapons is in turn a reflection of the expected intensity of opposing sea denial forces. When these defenses are most effective, the multi-mission pull experienced by surface ships is highest, and more defensive weapons need to be carried at the expense of offensive weapons. By contrast, when faced with a more intense ASW environment, submarines are more likely to resort to the operational measure of managing their indiscretion rate, which may reduce their rate of fire, but not their offensive payload.

Thus, because it survives by eluding an enemy's attacks, a submarine can operate alone and still devote most of its payload to offensive weapons, while a surface ship will always devote a larger portion of its payload to defensive weapons. On the other hand, surface ships have traditionally had more payload volume than attack submarines. For example, an Aegis cruiser has 122 VLS tubes for 21 inch diameter weapons, a Burke class destroyer has 80, and a Spruance destroyer has 61, while a modern attack submarine has the equivalent of 38.[37] Assuming that 65% of an Aegis ship's VLS cells carry SAMs, guided missile cruisers and destroyers still carry about 40 and 25 strike weapons respectively. Non-guided missile destroyers like today's Spruance (61 cells) and tomorrow's DD-21 (~120 cells) devote essentially all of their payload to strike weapons, but at the cost of a much more limited air defense capability, which means that they do not operate independently of a battle group except in the most benign environments. By comparison, even assuming an SSN reverses the ratio between offensive and defensive weapons on a CG or a DDG, it would carry about 25 strike weapons.

Unlike the platforms described above, Trident SSGNs and DD-21 are examples of purpose-designed land attack strike platforms, and a comparison between them gives a better example of what future submarines and surface ships will be capable of. DD-21 doubles the

Spruance's VLS capability to about 120 cells, of which about 100 will carry strike weapons, but an SSGN will have almost five times as many weapon positions as an SSN, and will therefore carry 154 strike weapons.[38] This demonstrates that payload need not be a constraint for submarines compared to surface ships in the land attack mission, even when the comparison is with a dedicated strike platform like DD-21, which relies on the Battle Group for much of its air defense.

This point is further reflected in analysis that looks first at the comparative cost of forward deploying analogous strike weapons on platforms like SSGN and DD-21 in a benign sea denial environment, and then at the comparative cost of forward deploying weapons on these platforms when they must survive and endure in the face of vigorous efforts to destroy them.

In the first case, surprisingly, SSGN will be significantly more cost effective than DD-21 for four reasons: its acquisition costs are low because it is a conversion rather than new construction; its operating costs are only a little higher than those projected for DD-21 even though those costs include a second crew; the second crew means that an SSGN's presence factor will be more than double that of other naval combatants (.5 versus .2); and its payload is half again as large. This comparison is instructive as a guide for future submarine and surface ship development, which should be more focused on the second case, in which the metric is no longer mere forward presence, but surviving and enduring forward presence in contested seas, and power projection from those seas. In this case, the advantages enjoyed by large payload submarines will grow as surface combatants must allocate more of their payloads to defensive weapons.

Future submarine and surface ship development oriented toward the strike mission should also focus on ways of replenishing their strike payloads at sea. This may be an area where surface ships will benefit first, especially in their role as high volume shooters of gun/TBM weapons like ERGM and VGAS. High volume, close in use of these weapons in

support of engaged Marines presumes an environment in which all or most sea denial threats have already been suppressed or destroyed. In such an environment, the submarine's stealth provides less of an advantage, and at sea replenishment of the surface ship's gun magazines will give it essentially unlimited payload volume for the fire support mission. Here, a division of labor may come to exist between the submarine and the surface ship whereby the latter's niche in the strike warfare mission may be the ability to mount high volume, level of effort, precision fires once opposing sea denial capabilities have been suppressed, and the former may focus a portion of its efforts on suppressing those sea denial capabilities.

This division of labor would resemble the one that is already emerging between standoff weapons and manned aircraft in which the former will increasingly suppress air defense threats to the latter, thereby enabling the use of manned aircraft in the kind of low threat, high sortie rate environment in which their relative capabilities are maximized.

Conclusions: New Sensors and Payloads to Support a New Submarine Mission

Three near term and two long term trends appear likely to continue in the future security environment. In the near term, the United States is most likely to become involved in conflicts over less than vital interests, against relatively weak opponents, alongside relatively uncertain allies. Hopefully, this will make the United States cautious about entering such conflicts. When it nevertheless does become involved, the bar will be set very high for the U.S. military because American political leaders will be averse to incurring casualties; their opponents will see that such casualties rather than traditional military victories are the key to political-military success; and their Allies will grant access to local bases only after the U.S. has made its commitment to the conflict clear. In the longer term, the reemergence of a peer competitor could reverse these particular trends, but in ways likely to reinforce rather than reduce the demand for military forces

that do not rely on local, fixed bases, and that evade rather than confront the heart of an opponent's defenses.

These trends will demand change in how the United States projects power abroad, and particularly in how it conducts strike warfare against both fixed and mobile targets. The U. S. military has become extremely effective at destroying fixed targets, and is poised to exploit innovations that will make it even more effective. By contrast, it is relatively ineffective at destroying mobile targets, and needs to begin a process of innovation in that mission area with the ultimate goal of equaling or approaching today's capabilities against fixed targets.

The leaders of the Navy as a whole, and of its individual platform communities, will have a particular responsibility in this process for two reasons. First, because power will increasingly need to be projected from the sea, the Navy will find itself bearing a larger relative burden of the overall defense effort. Second, bearing this burden will require innovation, and the Navy's individual platform communities will need to be aggressive in maximizing their own relative contributions. The most relevant military service in the future security environment can not afford to have any of its platform communities ignore important missions where they will have unique advantages.

One such mission that the near term security environment has already identified is the destruction rather than mere suppression of modern, mobile, radar-guided SAMs. In terms of numbers, mobile SAMs are a small part of the mobile target problem that this report has discussed. But their destruction early in a future conflict would help compensate for the relative scarcity of manned aircraft in an access-constrained environment by maximizing their efficiency. Given the ability to operate freely over a battlefield at medium altitude, manned aircraft can fully exploit what will likely remain their unique advantages - a large payload and infinite reusability. These advantages will remain important if the U.S. military is to become capable of attacking truly large numbers of mobile targets, as it must , for example, if it aspires to halt an invading

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army with long range fires. Platforms with these advantages will also be relatively scarce in an access constrained environment, which further emphasizes the need to maximize their leverage.

The destruction rather than mere suppression of opposing air defenses may be an important part of the mobile target problem for the submarine force to embrace for four reasons. First, existing methods of performing the mission using manned aircraft are encountering diminishing returns. Second, air defense destruction will likely require immediate attacks on SAM engagement radars initially detected, identified, and precisely located by a network of ELINT sensors using TDOA processing. Such attacks can best be accomplished with a TBM, and SSGNs are likely to be the most survivable and enduring, close in TBM shooters early in a future conflict. Third, it is a part of the mobile target problem where the target set is finite, because the targets in question - sophisticated, phased array SAM engagement radars - are expensive, and therefore limited in numbers. And fourth, the synergistic benefits of destroying as opposed to just suppressing enemy air defenses are huge because it enables the unrestricted use of manned aircraft in the mode in which their advantages over standoff weapon launchers are maximized.

The second and third points in particular are, respectively, what may initially pull submarines toward the air defense destruction mission, and what will be the key enabler of their success in contributing to its accomplishment. For those missions which do not require a time urgent weapon, there is no reason not to stand well off from the target and use a cruise missile. And cruise missiles with 700-1000 mile ranges can be based on a variety of platforms without sacrificing their survivability. Likewise, even an SSGN carrying more than 500 TBMs could easily exhaust its magazine if used in attacks against the thousands of vehicles of an invading army. But 500 TBMs is just less than half the number of HARMs fired during the entire 78 days of Allied Force, and TBMs that know where their targets are with precision will be vastly more effective than antiradiation missiles which depend on their target's cooperation for their

effectiveness. For the reasons described in this report, a near term effort by the submarine force to apply its unique capabilities to this mission area is likely to pay formidable dividends in the longer term if successful.

NOTES

[1] See, for example, Michael Mastanduno, "Preserving the Unipolar Moment," *International Security*, Vol. 21, No. 4 (Spring 1997) pp. 49-89 and Mark S. Sheetz, "Correspondence: Debating the Unipolar Moment," *International Security*, Vol. 22, No. 3 (Winter 1997/1998) pp. 168-175. See also Samuel P. Huntington, "The Lonely Superpower," *Foreign Affairs*, Vol. 78, No. 2 (March/April 1999) pp. 35-50.

[2] This is not to say that there will be peace along these borders, or that the U.S. will not have interests at stake should conflict occur along them, just that it will be unnecessary for the United States to provide the main source of balance on the ground among the competing powers in the form of a large, forward deployed Army. For a strong statement of this view regarding Germany and Russia, see John J. Mearsheimer, "Back to the Future: Instability in Europe After the Cold War," *International Security*, Vol. 15, No. 1 (Summer 1990). I make the same assumption here regarding China and Russia for similar reasons.

[3] For a summary of this debate, see Harvey M. Sapolsky and Jeremy Shapiro, "Casualties, Technology, and America's Future Wars," *Parameters*, Vol. XXVI, No. 2 (Summer 1996) pp.119-127.

[4] The best account of those events is Mark Bowden's masterful *Black Hawk Down: A Story of Modern War* (New York: Atlantic Monthly Press, 1999).

[5] Stpehen Walt, "Muscle-bound: The Limits of U.S. Power," *Bulletin of Atomic Scientists,* March-April 1999, p.44.

[6] *Conduct of the Persian Gulf War,* U.S. Department of Defense, Washington, D.C., April 1992, p. 35.

[7] Peter Grier, "Pentagon Speeds Forces to Hot Spots, " *Christian Science Monitor*, October 18, 1994, p. 1.

[8] Douglas Jehl, "Saudis Admit Restricting U.S. Warplanes in Iraq," *New York Times*, March 22, 1999, p. 6.

[9] The U.S. Commission on National Security, *New World Coming*, p. 7 (http://www.nssg.gov/Reports/)

[10] *Report of the National Defense Panel*, December 1997, pp. 12-13.

[11] On the U.S. being an offshore balancer of last resort, see Christopher Layne, "From Preponderance to Offshore Balancing: America's Future Grand Strategy," *International Security*, Vol. 22, No. 1 (Summer 1997) pp. 112-123. I am predicting that the United States will adopt that broad role for reasons that are quite different from Layne's, but his description of how such strategy might work in practice is useful.

[12] The most comprehensive treatment of the technology underlying this statement is Naval Studies Board, National Research Council, *Technology for the United States Navy and Marine Corps, 2000-2035*, Volume 5, Weapons (Washington, D.C.: National Academy Press, 1997), especially pp. 106-120.

[13] For an excellent analysis of the prospects for using long range fires to halt an armored/mechanized force attack, see David A. Ochmanek, Edward R. Harshberger, David E. Thaler, and Glenn A. Kent, *To Find and Not to Yield: How Advances in Information and Firepower Can Transform Theater Warfare*, Project Air Force, The Rand Corporation, 1998.

[14] Benjamin Peled, "Technology and the Future of Air Operations," in Shai Feldman (ed) *Technology and Strategy: Future Trends* (Jaffee Center for Strategic Studies, Westview Press: 1989) pp. 44-49.

[15] For a vivid description of these early LGB operations, see Jeffrey Ethell and Alfred Price, *One Day In A Long War* (New York: Random House, 1989).

[16] Only F-111Fs, A-6Es, F-117s, and a small number of F-15Es combined a FLIR with a self-lasing capability.

[17] Cruise missiles, though largely dependent on INS/GPS, rely on a terminal seeker which compares what it sees during the last phase of the missile's attack with a pre-stored image of what it should be seeing.

[18] There will always be exceptions to this rule when the target demands a weapon whose characteristics prevent standoff delivery, as will perhaps some deeply buried targets that require weapons of such size that their launch platform will need to overfly the target.

[19] That NATO expended more than 1000 HARMs in Allied Force was reported in Philip Klass, "New AGM-88 Missile Will Be Smarter," *Aviation Week & Space Technology*, November 15, 1999, pp. 90-92.

[20] A critique of this decision is one of the main themes of Michael Gordon and Bernard Trainor*, The General's War: The Inside Story of the Conflict in the Gulf* (Boston: Little Brown, 1995).

[21] On the origins of SAR and MTI radars, see Charles A. Fowler, "The Standoff Observation of Enemy Ground Forces: From Project Peek to JointSTARS", *Aerospace and Electronic Systems Society Magazine*, June 1997. Also, see the discussion with John Entzminger in David Fulghum, "Future UAV Sensors to Scan Vast Areas," *Aviation Week and Space Technology*, February 7, 2000, pp.58-61.

[22] Global Hawk gets around the need for a local ground station by carrying a high data rate, Ku Band SatCom antenna.

[23] Four other allied aircraft without direct Wild Weasel escort were lost to radar-guided SAMS, and 33 other allied aircraft were lost to other air defense assets for a total of 38 aircraft lost out of about 70,000 combat sorties. Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Summary Report*, Washington, D.C., 1993, pp. 229-230.

[24] DOD News Briefing, Thursday, 10 June 1999, Air Defense BDA slide. Available in archives at http://www.defenselink.mil/news/.

[25] In Desert Storm, the Allies flew about 70,000 strike sorties and expended a little over 1900 HARMs, while in Allied Force, the numbers were 35,000 sorties and a little over 1000 HARMs. In the latter case, the cost of the HARMs expended was at least $250 million.

[26] Those who have used these circuits describe the experience as akin to a conversation between Donald and Daffy Duck with a 30-45 second latency.

[27] The two satellites, launched in 1976, were numbers 8 and 9 in a series of Lincoln Experimental Satellites and were therefore known as LES 8 & 9. Antennas for use with LES 8 & 9 were deployed and tested successfully on USS Finback as part of Clarinet Omen. On LES 8 & 9, see William W. Ward and Franklin W. Ford, "Thirty Years of Research and Development in Space Communications at Lincoln Laboratory," *The Lincoln Laboratory Journal*, Vol. 2, No. 1 (Spring 1989) pp. 5-34.

[28] At about 500-600 km range, missile designers must start considering staging if they wish to preserve a reasonable payload. Though a two stage TBM is far from infeasible, it is a leap ahead in both technology and cost, and given the simplicity of the cruise missile alternative, the latter may be preferred.

[29] For an excellent discussion of such TBMs and cruise missiles, from which this discussion of the vulnerability of fixed targets draws liberally, see John Stillion and David T. Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks: Technology, Scenarios, and U.S. Air Force Responses* (Santa Monica, CA.: Project Air Force, RAND, 1999).

[30] Again, in the long run, the U.S. Navy's recent decision to give its next surface combatant electric drive may prove fortuitous if this provides the power supply for terminal, directed energy defenses using solid state or free electron lasers if and when the latter become feasible. A surface ship is the perfect candidate for such a terminal defense because it is continuously moving, which means it can only be attacked by weapons with terminal seekers that a laser can burn. At the same time, it is among the largest and highest value moving targets, which means that unlike ground vehicles it has a large, organic supply of power which, on an electric drive ship, can be rapidly turned into electricity.

[31] These are all points made by Stillion and Orletsky, *Airbase Vulnerability*, p. 31.

[32] For the U.S., today's ASW problem occurs primarily in shallow water, against submarines which are operating near their bases and waiting for their prey to come to them, and under circumstances in which the political tolerance for any ship losses is extremely low.

[33] Robert Holzer, "New Support Mandate Taxes EA-6Bs: Escorting F-117s, B-2s Overburdens U.S. Navy Radar-Jamming Fleet," *Defense News*, May 17, 1999.

[34] G.R. Thompson, H.P. Widmer, K.A. Rice, R.E. Ball, and J.H. Sweeney, "Buoyant Cable Antenna Technology for Enhancing Submarine Communications at Speed and Depth," *Johns Hopkins APL Technical Digest*, Vol. 20, No. 3 (July-September 1999) pp. 285-295.

[35] On the benefits that flow from improved accuracy, see Committee on Technology for Future Naval Forces, Naval Studies Board, *Technology for the United States Navy*, Volume 5, p. 117.

[36] The current plan to fill SSGN tubes with only 7 Tomahawks only uses half the tube's volume and is a measure to avoid the cost of developing a double stacking technique. It reflects a desire to minimize the cost of the initial SSGN conversion rather than a concern about the technical feasibility of double stacking.

[37] Modern attack submarines include Virginia and Improved Los Angeles class SSNs, which have 12 VLS tubes and room in their torpedo rooms for an additional 26 weapons.

[38] A Trident SSGN will have a total of 185 21 inch weapon positions, 17 in its torpedo room and 168 in its missile tubes. 14 weapon positions in two missile tubes will be used for SOF delivery, and I am assuming that no strike weapons will be deployed in the torpedo room of an SSGN.