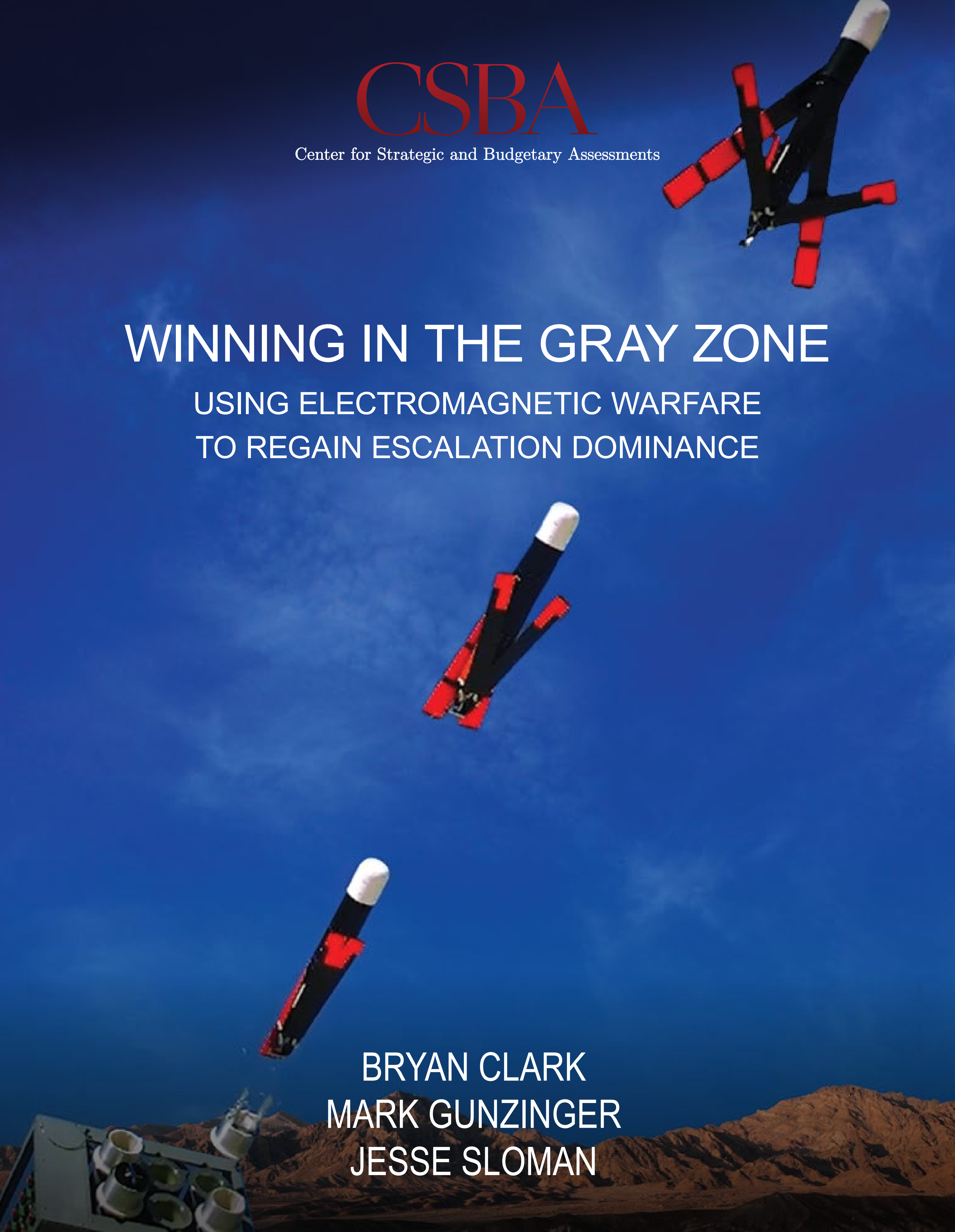

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WINNING IN THE GRAY ZONE

USING ELECTROMAGNETIC WARFARE TO REGAIN ESCALATION DOMINANCE

BRYAN CLARK
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Time lapse image created from an Office of Naval Research demonstration video of the LOw-Cost Unmanned aerial vehicle Swarming Technology (LOCUST) launcher deploying a Coyote UAV. Design by Dallas Gotschall.

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CHAPTER 1

The Imperative for Electromagnetic Warfare

The United States has again entered a period characterized by great power competition after a quarter century as the world's sole superpower. By expanding exports in a globalizing economy and exploiting the precision-strike weapons revolution,[1] China and Russia have improved their military capabilities and economic positions[2] over the last 20 years. They now seek to revise the international order in their favor, in part by undermining U.S. influence in their regions and beyond.[3] Their multi-dimensional efforts toward raising their own status while degrading that of the United States include China's infrastructure development and financial investment in strategically important countries,[4] Russia's securing control of energy supplies to its neighbors,[5] and both states' assistance to friendly regimes such as that of Bashar al Assad in Syria.[6]

1 See Barry D. Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: Center for Strategic and Budgetary Assessments, 2007), pp. 3–4.

2 In constant FY16 dollars, Russia's GDP grew from $405 billion in 1997 to $1.3 billion in 2016; China's GDP grew from $961 billion to $11.2 trillion in 2016. See World Bank, "GDP (current US$)," *World Development Indicators* database, 2017, available at https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CN for China and https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=RU for Russia.

3 Hal Brands and Eric Edelman, *Why is the World So Unsettled? The End of the Post-Cold War Era and the Crisis of Global Order* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017), pp. 11–15.

4 One Belt, One Road envisions a network of land (One Belt) and sea (One Road) routes forming a Eurasian economic infrastructure. China plans to invest some $4 trillion to realize its ambitions, or roughly thirty times what the United States invested in the Marshall Plan. See "Our Bulldozers, Our Rules," *The Economist*, July 2, 2016, available at http://www.economist.com/news/china/21701505-chinas-foreign-policy-could-reshape-good-part-world-economy-our-bulldozers-our-rules; and Xie Tao, "Is China's 'Belt and Road' a Strategy?" *The Diplomat*, December 6, 2015, available at http://thediplomat.com/2015/12/is-chinas-belt-and-road-a-strategy/.

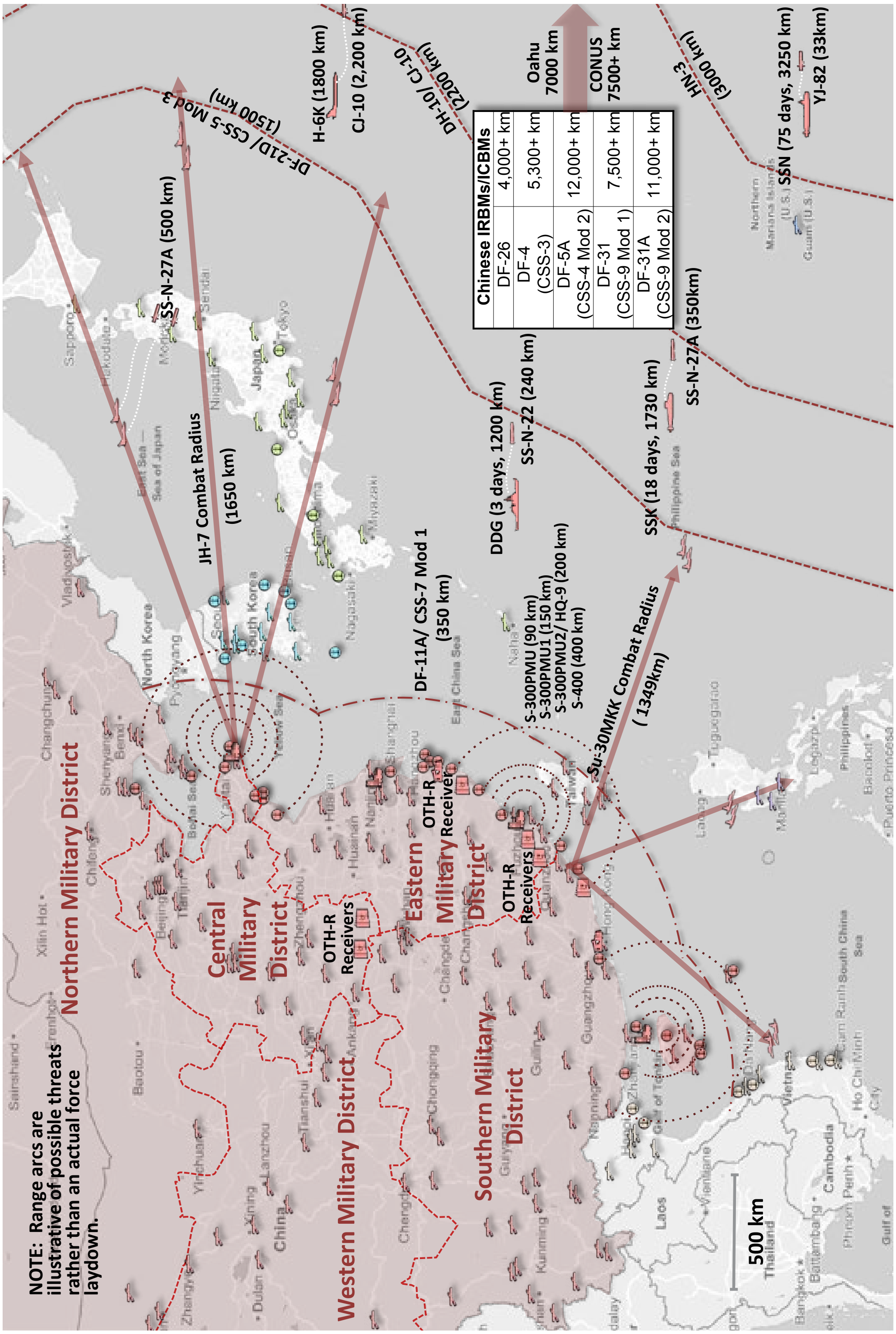
5 Damien Sherkov, "Gas in Europe: Fuel Supply Threatened by U.S. Sanctions, Warns Russia," *Newsweek*, June 21, 2017, available at http://www.newsweek.com/gas-europe-fuel-supply-threatened-us-sanctions-warns-russia-628022.

6 Jane Onyanga-Omara and John Bacon, "Russia, China Veto U.N. Plan for Syrian Sanctions," *USA Today,* February 28, 2017, available at https://www.usatoday.com/story/news/world/2017/02/28un-resolution-syria/98518510/.

However, the governments of China and Russia have arguably made the most striking gains and displayed the greatest innovation in the development of their military capabilities. Both have deployed sophisticated long-range sensor and weapon networks along their borders and in occupied lands. Ostensibly this posture is intended to protect Chinese or Russian territory, but it enables their militaries to degrade the ability of the United States and other powers to intervene in aggressive operations in their near abroad. Figure 1 depicts the reach of Chinese surveillance and strike systems, assuming a notional military posture.[7]

7 Office of Naval Intelligence (ONI), *The PLA Navy: New Capabilities and Missions for the 21st Century* (Washington, DC: ONI, April 9, 2015), pp. 13–25, available at http://www.oni.navy.mil/Portals/12/Intel%20agencies/China_Media/2015_PLA_NAVY_PUB_Print.pdf?ver=2015-12-02-081247-687; and Office of the Secretary of Defense (OSD), *Military and Security Developments Involving the People's Republic of China 2016*, Annual Report to Congress (Washington, DC: DoD, 2016), pp. 22–29, available at http://www.defense.gov/Portals/1/Documents/pubs/2016%20China%20Military%20Power%20Report.pdf.

FIGURE 1: CHINA'S LONG-RANGE SENSOR AND WEAPON NETWORKS



Most U.S. military planning and national security scholarship regarding Russia and China's long-range precision strike capabilities concerns how they could be used in wartime against their neighbors.[8] The more likely and difficult challenge for U.S. forces, however, is how Russia or China could use long-range strike systems to protect low-intensity operations designed to expand their territory and destabilize neighboring governments in peacetime.[9] These efforts, often characterized as gray zone aggression, are designed to stay below the level of violence that would trigger an American or allied response. In addition to using small military units, gray zone operations often rely on proxy and paramilitary forces, allowing the Russian or Chinese governments to maintain plausible deniability of aggression.

Although gray zone operations are designed to not be escalatory, Russia or China retain the option of using their long-range sensor and weapon networks to attack the forces of the target nation and of allies coming to its aid. These attacks could be scaled from surgical strikes to catastrophic attacks, providing Moscow or Beijing escalation dominance in a future crisis or conflict. To defend themselves, intervening U.S. and allied forces would need to either suppress surveillance and strike networks inside Russian or Chinese territory or operate in large, heavily-defended formations. Either approach holds the potential to escalate what started as a local confrontation. U.S. and allied leaders may be unwilling to undertake this escalation and potentially be perceived as an outside aggressor interfering in a regional disagreement.

China and Russia are now exploiting the reticence of the United States and its allies to intervene in gray zone confrontations to ratchet up the intensity of their aggression.[10] Over the last several years, they have finely calibrated their peacetime military and paramilitary operations to increase their reach and lethality without reaching a level of violence that would trigger a large-scale U.S. response.[11] This places the United States at a disadvantage in its long-term competitions with both great powers.

Competitors Making Steady Progress Toward Their Objectives

China continues to expand its ability to control the South China Sea by occupying disputed islands, building new ones on existing reefs, and militarizing islands gained in the past. China has controlled the Paracel Islands since 1974, but in 2016 it emplaced air defense systems

8 OSD, *Military and Security Developments Involving the People's Republic of China 2016*, p. 49.

9 This dynamic has been described by Evan Montgomery and others. See Evan Braden Montgomery, *Reinforcing the Front Line: U.S. Defense Strategy and The Rise of China* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017), p. 21.

10 Michael J. Mazarr, *Mastering the Gray Zone: Understanding a Changing Era of Conflict* (Carlisle, PA: Strategic Studies Institute, 2015), p. 4, available at http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=1303; and Hal Brands, "Paradoxes of the Gray Zone," Foreign Policy Research Institute, *E-Notes*, February 5, 2016, available at http://www.fpri.org/article/2016/02/paradoxes-gray-zone/.

11 Montgomery, *Reinforcing the Front Line*, p. 21; "Russia's aggression in Ukraine is part of a broader, and more dangerous, confrontation with the West," *The Economist*, February 15, 2015.

and anti-ship cruise missiles (ASCM) there.[12] Over the last five years, China built islands on reefs in the Spratly Islands and equipped them with runways, aircraft support facilities, radar, electronic warfare (EW) systems, and surface-to-air missiles (SAM). These islands, some of which fall in the claimed Exclusive Economic Zones (EEZ) of the Philippines and Indonesia, now continuously host People's Liberation Army (PLA) troops and aircraft that can threaten freedom of navigation throughout the South China Sea.[13]

The Chinese government uses a combination of civilian fishing vessels, coast guard ships, and maritime law enforcement troops to protect its island-building efforts. In addition to preventing access to islands and features it has staked a claim to, these paramilitary units harass and impede the maritime forces of its neighbors, as well as those of the United States. Because they are unarmed, U.S. naval forces cannot respond with military force without significantly escalating the confrontation.[14] Under threat of the PLA's long-range sensors and weapons, however, unarmed U.S. ships are not employed to counter China's actions.

China's gray zone activities are part of an overall strategy of Informationized Warfare. This approach to military operations has been characterized as "warfare where there is widespread use of informationized weapons and equipment and networked information systems, employing suitable tactics, in joint operations in the land, sea, air, outer space, and electromagnetic domains, as well as the cognitive arena."[15] Unlike the industrial-age warfare of the past, which sought to defeat an enemy by attriting his means to fight, the primary objective of China's Informationized Warfare strategy is shaping the decision-making of an enemy's leadership to convince them to not fight or to deescalate.[16] Although enemy decision-making has

12 Thomas Gibbons-Neff, "New Satellite Images Show Reinforced Chinese Surface-to-Air Missile Sites Near Disputed Islands," *Washington Post*, February 23, 2017, available at https://www.washingtonpost.com/news/checkpoint/wp/2017/02/23/new-satellite-images-show-reinforced-chinese-surface-to-air-missile-sites-near-disputed-islands/?utm_term=.ac9e4c2d7152.

13 Mark Valencia, "South China Sea: America Needs a Better Strategy," *Straits Times*, June 30, 2017, available at http://www.straitstimes.com/opinion/south-china-sea-america-needs-a-better-strategy. For further assessments and a timeline of Chinese expansionism in the South China Sea, see Ross Babbage, *Countering China's Adventurism in the South China Sea Strategy Options for the United States and Its Allies*, revised edition (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

14 Harry Kazianas, "China's Expanding Cabbage Strategy," *The Diplomat*, October 29, 2013, available at http://thediplomat.com/2013/10/chinas-expanding-cabbage-strategy/; and Nicolas Fedyk, "Russian 'New Generation' Warfare: Theory, Practice, and Lessons for U.S. Strategists," *Small Wars Journal,* August 25, 2016, available at http://smallwarsjournal.com/jrnl/art/russian-%E2%80%9Cnew-generation%E2%80%9D-warfare-theory-practice-and-lessons-for-us-strategists.

15 Dean Cheng, Senior Research Fellow, Asian Studies Center, Davis Institute for National Security and Foreign Policy, "Information Dominance: The Importance of Information and Outer Space in Chinese Thinking," testimony to the House Foreign Affairs Committee, April 26, 2017, p. 3, available at http://docs.house.gov/meetings/FA/FA05/20170426/105885/HHRG-115-FA05-Wstate-ChengD-20170426.pdf. Chinese military sources have described Informationized Warfare as "an asymmetric way to weaken an adversary's ability to acquire, transmit, process, and use information during war and to force an adversary to capitulate before the onset of conflict." OSD, *Military and Security Developments Involving the People's Republic of China 2017*, Annual Report to Congress (Washington, DC: DoD, May 15, 2017), p. 58. For Russia, see Mazarr, *Mastering the Gray Zone*, p. 4; and Brands, "Paradoxes of the Gray Zone."

16 Fan Gaoming, "Public Opinion Warfare, Psychological Warfare, and Legal Warfare: the Three Major Combat Methods to Rapidly Achieving Victory in War," *Global Times* [Chinese], March 8, 2005, available at http://big5.xinhuanet.com/gate/big5/news.xinhuanet.com/mil/2005-03/08/content_2666475.htm, as cited in Cheng, "Information Dominance," p. 4.

always been a target of military operations, advances in electromagnetic sensors, communications, and countermeasures during the last 20 years make a singular focus on information a more viable warfighting strategy. China's current gray zone operations do this by presenting U.S. and allied leaders with the dilemma of either attempting to confront low-intensity aggression under the threat of long-range sensor and weapon networks or militarily suppressing those networks at the risk of significant escalation.

Over the last decade, Russia's gray zone aggression against its Eastern European neighbors has included invading Georgia, annexing Crimea, supporting an insurgency in Ukraine, and fostering protests by ethnic Russians in the Baltic states. The Russian government's approach, often called New Generation Warfare, uses propaganda, proxy and paramilitary troops, and material support to create pro-Russian movements in neighboring states.[17] The resulting protests and armed confrontations can erode the territorial integrity of a target country, provide a pretext for Russian military action, and create ongoing instability between pro-Russian irregular troops and the target government's forces. This consumes the attention of the country's government and its allies and friends, enhancing Russia's position in the long-term competition for influence in Eastern Europe.

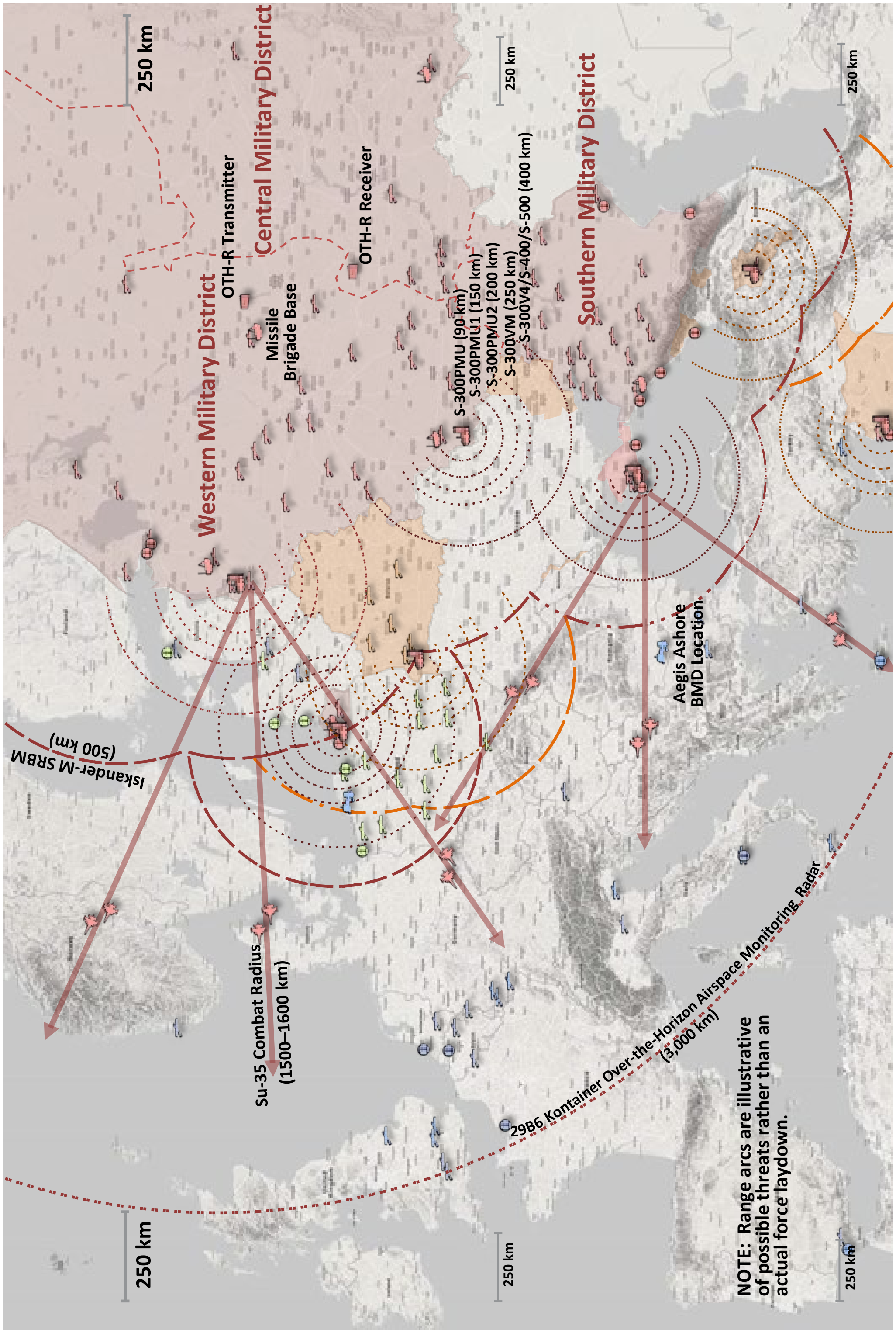
The use of insurgencies and proxies in neighboring countries can also obscure escalation by the Russian government, as in the annexation of Crimea.[18] What appears to be a local confrontation can quickly become a Russian military incursion without warning and without clear indications of its true nature. As the United States and other allies analyze an evolving situation, Russian forces could quickly occupy one or more target areas. Even if the United States and its allies do ascertain Russia's intent, U.S. forces must contend with the dilemma of either suppressing long-range sensors and weapons in Russian and allied territory, as shown in Figure 2, or accepting the significant risk of operating within range of those networks. The Baltic states could be particularly vulnerable to this approach given their lack of strategic depth and location along the Russian border.[19]

17 Philip Karber, "Russia's New Generation Warfare," *Pathfinder Magazine*, National Geospatial Agency, June 4, 2015, available at https://www.nga.mil/MediaRoom/News/Pages/Russia%27s-%27New-Generation-Warfare%27.aspx.

18 Andrea Macias, "A Detailed Look at How Russia Annexed Crimea," *Business Insider*, March 24, 2015, available at http://www.businessinsider.com/how-russia-took-crimea-2015-3.

19 David A. Shlapak and Michael W. Johnson, *Reinforcing Deterrence on NATO's Eastern Flank: Wargaming the Defense of the Baltics* (Santa Monica, CA: RAND Corporation, 2016), p. 1, available at http://www.rand.org/pubs/research_reports/RR1253.html.

FIGURE 2: RUSSIAN LONG-RANGE SENSOR AND WEAPON NETWORKS



China and Russia are aided in their gray zone efforts by the proximity and relatively modest geographic scope of their objectives. During the Cold War, the Soviet Union harbored global ambitions and openly threatened the United States and its North Atlantic Treaty Organization (NATO) allies. Today, China and Russia seek to increase their territory and influence by creating disorder in neighboring countries and occupying regions, including islands, on their periphery. Moreover, the asymmetry of costs and benefits in gray zone operations could dissuade U.S. leaders from intervening on behalf of an ally. For China or Russia, the costs of gray zone aggression are relatively small, and the benefits are significant. For the United States, the benefits are unclear because the nature of the aggression is uncertain, and the costs are potentially large if U.S. forces must suppress or defeat Chinese or Russian sensor and weapon networks to intervene.

The United States needs concepts and capabilities that will allow it to respond to gray zone aggression or confrontation, including countering Russian or Chinese long-range sensors and weapons, without dramatically escalating the confrontation. Previous CSBA studies have addressed how the Department of Defense (DoD) could improve its proportional options to respond to small-scale aggression.[20] This study will focus on new ways to use electromagnetic warfare (EMW) to counter or attack adversary sensor and weapon networks while minimizing the potential for escalation.

EMW encompasses all military actions taken in the electromagnetic spectrum (EMS), including communications, sensing, jamming, and deception. EMW expands on the current mission area of EW, which consists of electronic attack, electronic protection, and electronic warfare support.[21] The use of the term “electromagnetic warfare” reflects the need to consider *all* operations in the EMS holistically, not discretely. Due to the improving sensitivity, power, and sophistication of emerging electromagnetic (EM) systems, each action in the EMS increasingly impacts all other operations in the EMS. For the military, this makes the EMS more like the air, land, space, sea and other warfighting domains. In other words, if the EMS is a warfighting domain, EMW describes the form of warfare that is fought in it.

A New Generation of Air Defenses

Perhaps the most significant concern presented by Chinese and Russian long-range sensor and weapon networks is their integrated air defense systems (IADS). The newest air defense systems, such as Russia’s S-400 and new S-500, can reportedly threaten non-stealthy aircraft at long ranges and stealthy aircraft at shorter ranges.[22] Although the SAMs used by these

20 Bryan Clark et al., *Restoring American Seapower: A New Fleet Architecture for the United States Navy* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

21 DoD, *Electronic Warfare*, Joint Publication 3-13.1 (Washington, DC: DoD, February 8, 2012), pp. I-3–I-6, available at http://www.globalsecurity.org/military/library/policy/dod/joint/jp3_13_1_2012.pdf.

22 Dave Majumdar, “S-500: Russia’s Super Weapon That Could Kill the B-2, F-22, or F-35?” *The Buzz* blog, The National Interest, April 10, 2017, available at http://nationalinterest.org/blog/the-buzz/s-500-russias-super-weapon-could-kill-the-b-2-f-22-or-f-35-20107.

systems are relatively expensive, they could prevent U.S. bombers from approaching target areas close enough to deliver large salvos of short-range munitions such as Global Positioning System (GPS)-guided Joint Direct Attack Munitions (JDAM). And long-range SAM systems are often complemented by high-capacity short-range air defenses to defeat standoff attack weapons like the U.S. Tomahawk Land Attack Missile (TLAM).

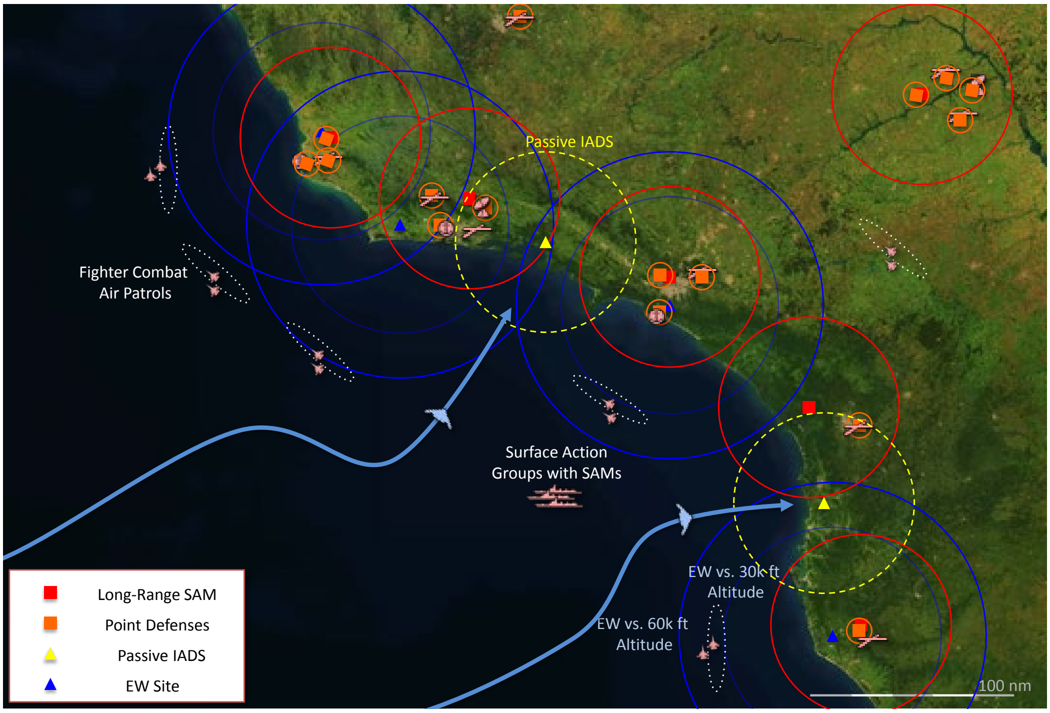
U.S. and allied militaries have been countering SAMs since the Vietnam War and air defense networks since World War II.[23] They have relied predominantly on the use of EW systems and anti-radiation missiles (ARM) because IADS have generally used active radars to locate and track targets and guide SAMs to achieve successful intercepts. Russia and China are now responding to the improving effectiveness of EW and ARMs with IADS that employ passive radiofrequency or electro-optical/infrared (EO/IR) sensors to find incoming aircraft and weapons instead of using active radars that can be more easily detected and jammed.[24]

Figure 3 illustrates a notional IADS laydown that combines traditional active air defenses, passive sensors and SAMs, and fighter combat air patrols (CAP). In this laydown, longer-range active air defenses would be used to limit the ability of non-stealthy aerial refueling tankers and early warning radar aircraft to support operations in Russian or Chinese airspace. Relocatable, medium-range SAMs would threaten attack aircraft, complemented by short-range high-capacity defenses to shoot down individual weapons launched at important targets. As shown, passive IADS could be arrayed to create the perception that there are gaps in air defense sensor coverage in order to create traps for an opponent's incoming air forces.

23 Alfred Price, *The History of Electronic Warfare*, Volume 1 (Alexandria, VA: Association of Old Crows, 1974), p.12.

24 Ankit Panda, "How Effective is China's New Anti-Stealth Radar System, Really," *The Diplomat*, October 26, 2014, available at http://thediplomat.com/2014/10/how-effective-is-chinas-new-anti-stealth-radar-system-really/.

FIGURE 3: NOTIONAL IADS LAYDOWN



The Emerging Salvo Competition

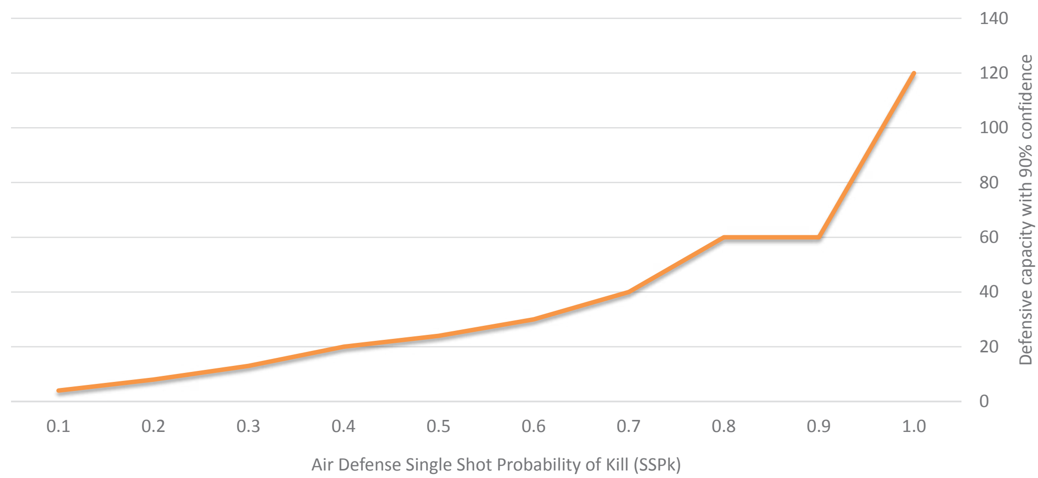
The growth and spread of precision munitions has led to the emergence of a salvo competition between offensive precision strike weapons and precision air defenses.[25] As air defenses become more capable, strike salvos will need to grow larger or become more survivable to reach defended targets, including the air defense systems themselves. As shown in Figure 4, a notional IADS laydown consisting of three HQ-9 long-range SAM launchers, four HQ-16 medium-range SAM launchers, and four TD-2000 point-defense SAM launchers would have the capacity to defeat up to 120 incoming weapons in two minutes.[26] Even if these air defenses have a single shot probability of kill (SSPk) of only 0.7, more than 40 weapons would be needed to ensure that an aimpoint defended by them is struck with 95 percent

25 Former Deputy Secretary of Defense Robert Work referred to this competition in recent speeches. See Deputy Secretary of Defense Robert Work, remarks at the CNAS Inaugural National Security Forum, Washington, DC, December 14, 2015, available at https://www.cnas.org/publications/transcript/remarks-by-defense-deputy-secretary-robert-work-at-the-cnas-inaugural-national-security-forum; and Deputy Secretary of Defense Robert Work, speech delivered at the McAleese/Credit Suisse Defense Conference, Washington, DC, March 17, 2015, available at http://www.defense.gov/News/Speeches/Speech-View/Article/606653/mcaleesecredit-suisse-defense-programs-conference. The competition was also analyzed in recent CSBA reports. See Mark Gunzinger and Bryan Clark, *Sustaining America's Precision Strike Advantage* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

26 This chart shows the number of weapons in a salvo needed to have 90 percent confidence that the salvo would deplete the capacity of air defenses with the single shot Pk capability indicated.

confidence. A 40-weapon salvo would require at least one B-2 payload (depending on the size of the weapons) or nearly all the TLAMs on a typical U.S. guided missile destroyer (DDG).[27] It is also about the same number of weapons a carrier air wing (CVW) can deliver in a single airstrike salvo.[28]

FIGURE 4: WEAPONS NEEDED TO OVERCOME TYPICAL IADS COMPLEX



This is merely the minimum salvo size needed. Figure 4 depicts the number of weapons required to exceed the defensive capacity of the example IADS and strike only one aimpoint. To strike multiple targets, the same number of weapons may need to be launched at *each* aimpoint, since an attacker would not necessarily know which weapons will be intercepted by enemy defenses.[29] With 40 weapons needed per aimpoint, as in the previous example, the total needed to attack a target set could rise into the hundreds and possibly thousands depending on the total number of aimpoints.

A defender could increase the number of weapons required to conduct a strike by using active and passive countermeasures. Active countermeasures such as EW jammers can cause

27 A B-2 can carry 40,000 lbs. of payload, which would equate to about 20 2,000-lb. GBU-31 JDAMs. See U.S. Air Force, "B-2 *Spirit* Bomber," *Fact Sheet,* December 16, 2015, available at http://www.af.mil/About-Us/Fact-Sheets/Display/Article/104482/b-2-spirit/. Because DDGs and CGs (aircraft carriers) are used for air defense of aircraft carriers, amphibious ships, and areas ashore, it is reasonable to assume half of their VLS magazines are devoted to air defense interceptors. A DDG has 90 or 96 VLS cells, leaving about 40–50 cells for strike weapons, whereas a CG has 134 VLS cells, leaving perhaps 60–70 cells for strike weapons.

28 A CVW includes 44 strike fighters. If they have an average operational availability (Ao) of 0.7, then six are conducting air defense for the CVN, four are escorting the strike aircraft, and four are conducting tanking, and therefore 15–16 remain to carry strike weapons. An F/A-18 can carry four JASSM-type weapons, resulting in a total of about 60–64 weapons per salvo.

29 The ability of all components of the IADS to defend all the aimpoints to be attacked would depend on the size, configuration, and geography of the defended area. Some aimpoints may only be covered by part of the IADS, reducing the defensive capacity for those aimpoints.

radar-guided munitions to miss their targets by deceiving a weapon's seeker regarding the precise position of a target, disrupting a weapon's understanding of its own position using GPS, or obscuring the target to cause the weapon to "break lock" and go off course. Lasers can be used similarly against EO/IR-guided weapons. Because they defeat individual weapons, active countermeasures have a similar effect on strike salvos as air defense interceptors and similarly require an attacker to launch more weapons to strike the same number of aimpoints.

Passive countermeasures include decoys, camouflage, and the hardening of targets. Decoys of targets such as air defense systems, aircraft, artillery, and radars can increase the perceived number of aimpoints in the target area, requiring more weapons for a successful strike. Camouflage can enhance the effectiveness of decoys by obscuring the signature of real and decoy systems, increasing the likelihood an attacker would be unable to discern between them. If an attacker does not increase the size of its strike salvo, decoys and camouflage will reduce the likelihood weapons will hit actual targets.

In a salvo competition, reducing an attacker's offensive capacity can create the same effect as increasing the defender's air defense capacity. Increasing the range required of standoff weapons is one way of accomplishing this. If U.S. strike aircraft must remain outside the lethal range of enemy air defenses, they would need to use larger, longer-range weapons to strike targets in the defended area. Powered weapons like cruise missiles must increase in size as their maximum range increases because they need to carry more fuel. As a result, a strike aircraft's salvo size decreases as the launch point moves farther away from the target.

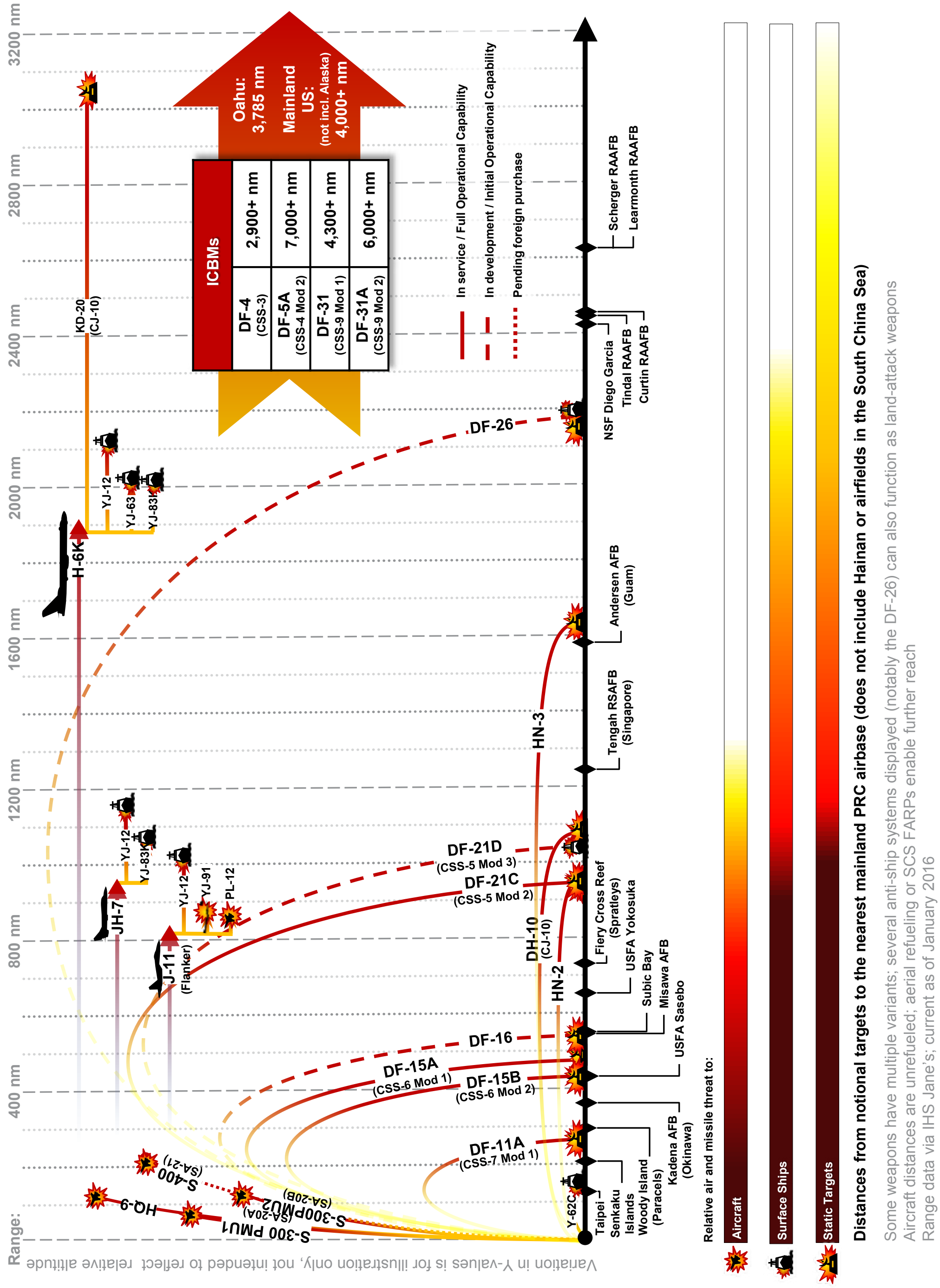
As noted above, China and Russia deploy land-based ballistic missiles; land-, air-, and ship-launched cruise missiles; and strike aircraft with precision-guided powered or glide weapons. Many of these weapons were designed to attack targets at bases that U.S. and allied forces use to generate strikes, which could further reduce U.S. offensive capacity. Although moving U.S. air operations to more distant bases could reduce this threat, U.S. strike capacity would still shrink because aircraft sortie rates decrease as range and travel time increase.

China and Russia are both deploying a wide array of offensive and defensive precision weapons to improve their position on both sides of the salvo competition. There are some differences in each country's weapons portfolios based on their overall strategy, objectives, and geographic situation. Chinese and Russian precision weapon capabilities and operational approaches are described in more detail below.

China

As indicated by Figure 1, the PLA's air defense and long-range strike systems are focused on the East and South China Seas—the location of Chinese strategic objectives such as the Senkaku or Spratly Islands—as well as on regional rivals Japan, Vietnam, Taiwan, and the Philippines. U.S. forces intervening in a conflict between China and a U.S. ally would also be expected to approach Chinese territory from the east or south. Figure 5 shows the maximum published ranges for China's air defense systems and cruise and ballistic missiles.

FIGURE 5: CHINESE AIR DEFENSE AND STRIKE WEAPON RANGES[30]



30 Data to build this chart was derived from OSD, *Military and Security Developments Involving the People's Republic of China 2017.*

The range of a typical ground-based air defense system sensor is constrained by the horizon, and the effective range of its interceptors is limited by the need for those weapons to have enough kinematic energy and fuel at the end of those maximum ranges to engage missiles or aircraft that are maneuvering to evade intercepts. Cruise and ballistic missiles, by comparison, can achieve longer ranges because they do not necessarily need high-speed kinematic capability and can be guided to their targets by GPS or inertial guidance rather than a radar. China's strike weapons are weighted toward longer ranges due to the distance between China and its neighbors. Although Taiwan lies only 90 nm from mainland China, Japan and the Philippines are more than 400 nm away, and the closest U.S. territory, Guam, is more than 1,500 nm away.

Because they can hold U.S. bases in Japan and Guam at risk, Chinese long-range strike systems may compel U.S. strike aircraft to operate from more distant locations. In terms of the salvo competition, this would reduce the number of strike sorties U.S. air forces can generate over time. China's long-range ASCMs could also reduce salvo sizes from U.S. ships such as DDGs; ships operating within range of Chinese ASCMs would need to shift more of their vertical launch system (VLS) weapons capacity to air defense interceptors to protect themselves from missile attack.

Another element of China's effort in the salvo competition will be to degrade U.S. communication networks and sensors across the theater and around areas that may be targeted by U.S. forces. This will reduce the ability of U.S. sensors to find, classify, and identify targets; it will also reduce the likelihood that strike weapons will hit genuine aimpoints. U.S. forces will need more weapons to ensure the correct targets are struck, giving PLA forces a further advantage in the salvo competition.

Russia

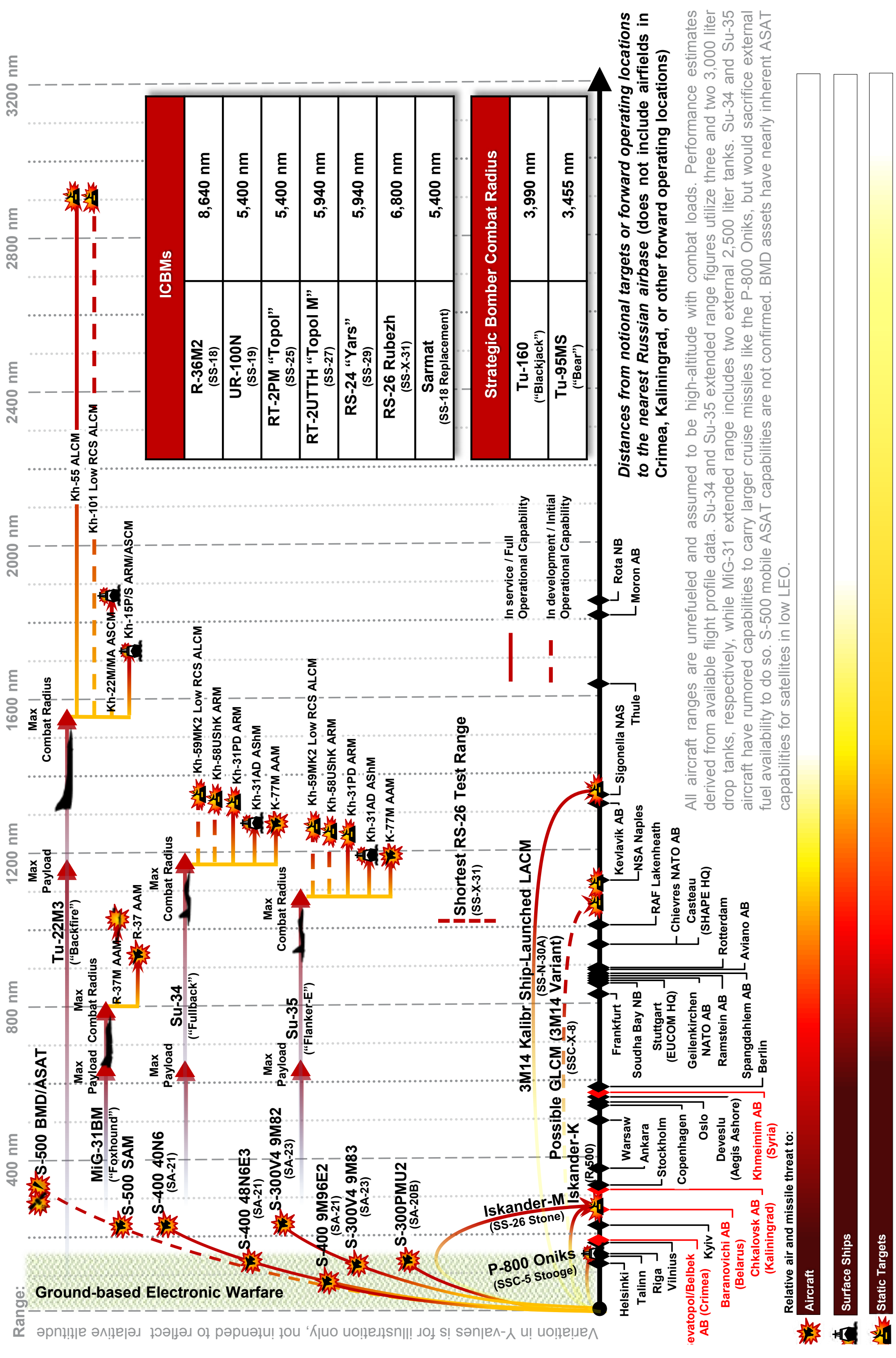
Russia shares land borders with many of its potential territorial and political objectives. This proximity could enable it to complete an invasion or other military action before NATO or U.S. forces could respond. Moreover, Russia could use its long-range precision strike and air defense systems, shown in Figure 2, to delay foreign military intervention. For example, the 60-mile Suwalki Gap located between Russia's Kaliningrad enclave and its ally Belarus connects Poland with Lithuania and provides the only land route from the Baltic States to their NATO allies to the south. This gap could be quickly cut off by a combination of Russian precision surface fires and air defenses.

Russia's IADS in its Western Military District, Kaliningrad, and Belarus reach well into Eastern Europe, threatening the entire airspace of NATO's Baltic allies and the Baltic Sea, much of Poland's airspace, and the skies above some of the bases U.S. forces would use for air defense and strike operations in a conflict. They are complemented by air defenses in areas recently brought under Russian control such as the Crimean Peninsula and Georgia's autonomous regions of Abkhazia and South Ossetia.

The long ranges of its air defense systems enable Russia to deny or control the airspace around its periphery, providing Russia leverage in gray zone confrontations with its neighbors. NATO forces may need to attack IADS inside Russian territory in order to gain sufficient localized air superiority to support friendly troops in northern Poland and the Baltic. Without air strikes and close air support, NATO troops could suffer higher rates of attrition from the fires of Russian-supported proxy and paramilitary forces.

The design of Russia's long-range air defense networks exploits the salvo competition to raise the level of escalation needed to degrade them. Long-range SAMs could compel NATO bombers to launch weapons from greater standoff distances, requiring larger weapons that result in smaller salvos per aircraft, and therefore requiring more aircraft for an attack. To further raise the number of weapons needed, long-range SAMs are often defended by higher-capacity, shorter-range air defenses, which may include high-power lasers and high-powered microwave (HPM) weapons in the next decade. Small Russian fire units use camouflage, concealment, and deception (CCD); limit their emissions; and can relocate within the flight time of typical U.S. or NATO standoff missiles to reduce the probability a strike weapon will hit their radars or SAM launchers.

FIGURE 6: RUSSIAN AIR DEFENSE AND STRIKE WEAPON RANGES[31]



31 Data to build this chart was derived from IHS Jane's in January 2016.

Russia's surface-to-surface missiles are notionally limited to 499 km by the Intermediate-Range Nuclear Forces (INF) Treaty with the United States,[32] but Russia has been accused of violating the treaty by testing longer-range ground-launched cruise missiles based on its 3M-14T Kalibr and Granat sea-launched land attack cruise missiles (LACM).[33] Even within INF limits, however, Russia can easily threaten its neighbors. Russian missile brigades equipped with Iskander short-range ballistic missiles (SRBM) can reach 250 nm and target NATO forces and key infrastructure, including military facilities and logistics nodes, as far west as Germany. Russia's ground forces are supported by precision-guided multiple launch rocket systems (MLRS) that can reach 70 nm. And even if Russia does not field ground-launched versions of its sea-based LACMs, its naval forces could still launch them from coastal areas or inland seas to attack many of the same targets.[34]

Challenges for U.S. Strategy

The combination of long-range surveillance and weapon networks and low intensity gray zone approaches to warfare creates a formidable challenge for U.S. strategists and planners. Because many of China's and Russia's likely objectives are located close to their own territory, responding to their aggression after the fact, as the United States did in Kuwait, Kosovo, or Afghanistan, may be increasingly costly. The aggression will likely be over before U.S. and allied forces are able to mobilize and deploy, and a counter-offensive to retake the territory may be too costly to be politically palatable.

To counter great power gray zone aggression when it occurs, American forces would need to be positioned close to China's or Russia's likely objectives. This posture could place U.S. forces well within reach of adversary air defense and strike weapons. Today's multi-mission ships, aircraft, or combat brigades are too expensive to risk operating in these areas without first degrading relevant air and missile threats. Because many of the sensors and missile launchers supporting Chinese and Russian strike networks will be based in their territory or in space, attacking them could be highly escalatory and disproportionate to the original gray zone aggression that triggered the confrontation. Moreover, using large U.S. formations that would be able to defend themselves may be perceived as disproportionate in confrontations with paramilitary or civilian forces and could provoke a ramp-up in the aggression. U.S. forces that cannot deploy or conduct operations effectively in contested areas during gray zone confrontations will undermine America's security assurances to

32 Treaty Between the United States of America and the Union of Soviet Socialist Republics on The Elimination of Their Intermediate-Range and Shorter-Range Missiles (INF Treaty), December 8, 1987, available at https://www.state.gov/t/avc/trty/102360.htm.

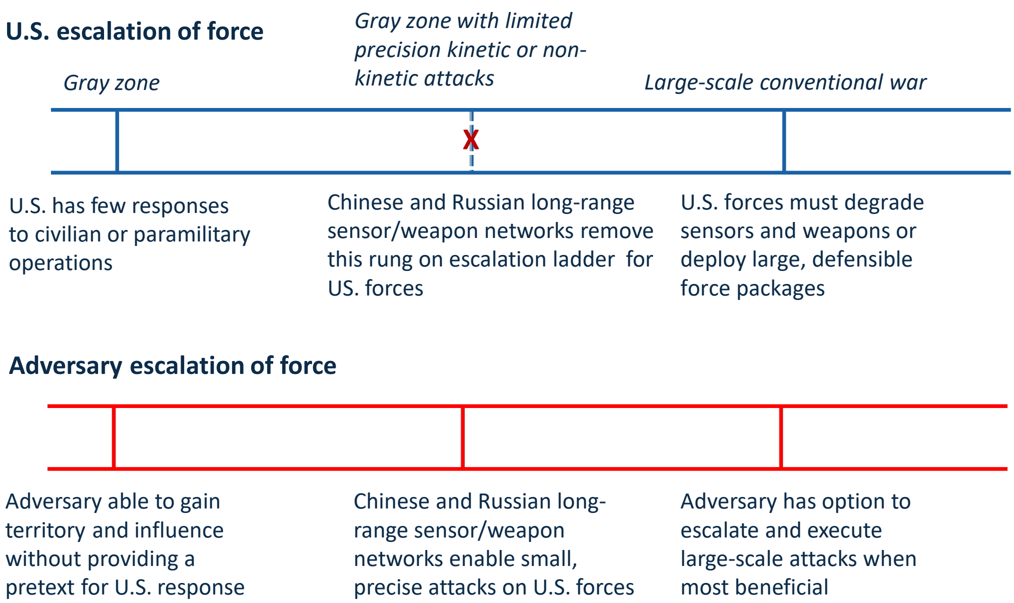
33 Michael R. Gordon, "Russia Has Deployed Missile Barred by Treaty, U.S. General Tells Congress," *The New York Times*, March 8, 2017, available at https://www.nytimes.com/2017/03/08/us/politics/russia-inf-missile-treaty.html?mcubz=0&_r=0.

34 Christopher Cavas, "Is Caspian Sea Fleet a Game Changer?" *Defense News*, October 11, 2015, available at http://www.defensenews.com/story/defense/naval/ships/2015/10/11/caspian-sea-russia-navy-missiles-attack-strike-military-naval-syria-frigate-corvette-lcs-littoral-combat-ship/73671188/.

its allies and friends. This in turn will create opportunities for China and Russia to extract concessions from target states.

Figure 7 shows the asymmetry created by the strategies being pursued by China and Russia, which gives them multiple options for escalating a conflict while denying U.S. forces the same.

FIGURE 7: TODAY'S ESCALATION LADDER FOR GRAY ZONE WARFARE



Improving the U.S. military's ability to overcome gray zone challenges and restoring U.S. escalation dominance will require two main lines of effort:

1. Fielding forces that can more proportionally respond to small-scale, low intensity aggression; and
2. Developing new concepts and capabilities to suppress or degrade Russian or Chinese sensor and weapon networks to protect U.S. forces without requiring large-scale, escalatory strikes.

Previous CSBA reports addressed new platforms, force packages, and deployment postures that can more proportionally respond to low-intensity aggression.[35] This study will focus on new operational concepts, platforms, weapons, unmanned vehicles, and mission systems for EMW that could support operations to degrade enemy surveillance and strike networks. Chapter 2 describes overall EMW approaches to conducting less escalatory strikes that could degrade enemy sensor and weapon networks and reducing the ability of China or Russia to use these networks to threaten or attack U.S. forces. Chapter 3 details operational concepts and capabilities that U.S. forces can use to implement these approaches.

35 Clark et al., *Restoring American Seapower*.

CHAPTER 2

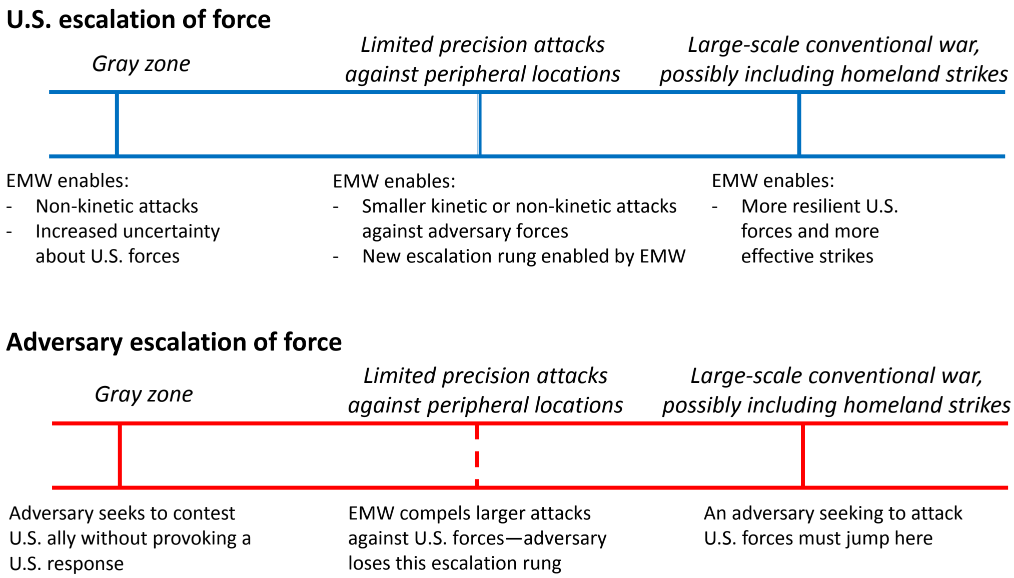
Using Electromagnetic Warfare to Restore U.S. Escalation Dominance

Competitors such as Russia and China exploit gray zone warfare in part to avoid providing the United States sufficient rationale to intervene in support of allies in Eastern Europe or the Western Pacific, respectively. Chinese and Russian gray zone aggression is complemented by their long-range sensor and weapon networks, which can put U.S. forces operating within range at high risk, raising the threshold for American intervention. To dissuade this form of aggression and provide more viable options to U.S. commanders and leaders, DoD requires new operational approaches to protect forces that are postured in range of enemy sensor and weapon networks, as well as to degrade those networks, if necessary, without significant escalation.

U.S. forces could employ EMW techniques to counter enemy sensors and weapons and launch smaller precision strikes to degrade sensor and weapon networks.[36] In this manner, EMW concepts and capabilities could give U.S. forces escalation dominance by adding another rung to their escalation ladder in gray zone conflicts, while removing one for Russian or Chinese forces, as shown in Figure 8.

36 As noted in Chapter 1, EMW includes all military operations and capabilities in the EMS, including EW, C3ISR, and directed energy systems.

FIGURE 8: FUTURE ESCALATION LADDER FOR GRAY ZONE WARFARE



Today, U.S. forces intervening in a gray zone confrontation must do so at considerable risk from Chinese or Russian strike networks. To suppress these networks would require a large-scale campaign. However, new EMW concepts and capabilities could provide U.S. forces the ability to conduct small-scale precision attacks to degrade enemy sensors and weapons without necessarily triggering a larger conflict. At the same time, EMW operations could prevent gray zone aggressors from being able to conduct small-scale strikes against U.S. forces coming to the assistance of an ally, leaving the aggressor with only the option of a large-scale conflict to resist U.S. intervention.

EMW capabilities could enable smaller kinetic strikes to be effective, or they could use non-kinetic RF or laser energy to disrupt or damage enemy electronic systems. These attacks could be difficult for an adversary to attribute, further delaying a response to U.S. and allied intervention. Furthermore, if a gray zone confrontation evolves into a larger conflict, EMW concepts and capabilities would improve the resilience of U.S. forces operating in contested areas.

The most promising EMW approaches to counter gray zone actions and related forms of aggression include:

1. Degrading enemy search and targeting sensors to require fewer U.S. defensive weapons and greater enemy attack salvos, removing the option of small-scale attacks against U.S. forces;

2. Sustaining friendly targeting despite enemy countermeasures, enabling small-scale U.S. strikes;

3. Increasing the survivability of U.S. strike weapons to reduce the number of platforms and weapons required for attacks; and

4. Increasing the number of weapons U.S. low-observable strike aircraft can deliver to enable smaller strike packages.

Chapter 2 describes these applications of EMW, and Chapter 3 will describe in detail their associated operational concepts and capabilities.

Degrading Enemy Search and Targeting Sensors

The ability of China or Russia to hinder foreign military intervention in their near abroad hinges on their command, control, communications, intelligence, surveillance and reconnaissance (C3ISR) operations rapidly finding and precisely targeting opposing forces at long range. Since Chinese and Russian strike networks are likely to use hard-wired or low probability of intercept/low probability of detection (LPI/LPD) line-of-sight RF (radiofrequency) communications, U.S. counter-C3ISR efforts should focus on degrading enemy search and targeting sensors.

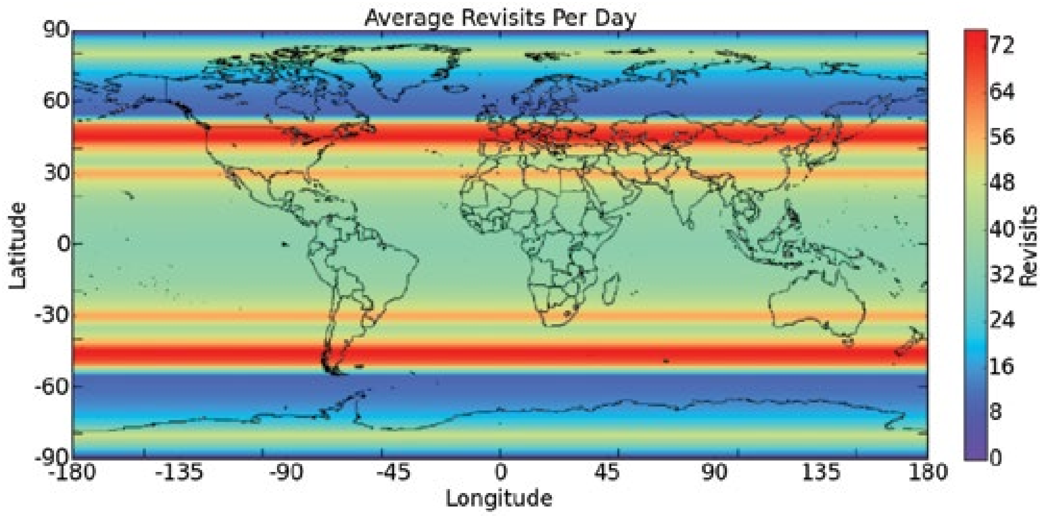
Degrading search sensors

In a confrontation, China and Russia would likely first use their widest-area search sensors, such as land-based high frequency (HF) over-the-horizon (OTH) radars and passive space-based electronic intelligence (ELINT) or signals intelligence (SIGINT) receivers, to rapidly locate and identify an enemy's forces. Although these sensors have large fields of view and can continuously survey an entire region such as the South China Sea or the Baltics, they do not provide target-quality data across the entire searched area. They are therefore often used to cue airborne or space-based electro-optical (EO), infrared (IR), or radar sensors that can track targets with greater precision.

The emerging generation of commercial satellite constellations with EO/IR sensors will soon provide another search sensor with near-continuous surveillance of important regions. These networks do not provide targeting-quality information, and are designed to supply imagery to a wide variety of customers, from farmers to climate change researchers. They can, however, support military operations for only the cost of a subscription. One prominent company, BlackSky, is developing a constellation over the next decade that will provide two-to-three images per hour of the most populated latitudes. Figure 9 depicts the projected revisit rates for its planned constellation.[37] Other companies and rival militaries are pursuing similar constellations.

37 "Transforming How We Look at Our Planet," BlackSky homepage, available at https://www.blacksky.com.

FIGURE 9: BLACKSKY'S PROJECTED VISUAL SATELLITE COVERAGE



Map image courtesy of BlackSky.

U.S. forces will not be able to avoid detection by this combination of RF, visual, and IR search sensors. They can, however, make U.S. operations difficult to attribute or, more likely, slow an enemy's ability to identify and classify potential U.S. targets. U.S. forces could use emissions controls (EMCON) to eliminate their own RF emissions; employ RF decoys to deceive enemy SIGINT and ELINT sensors; use jammers to obscure their location to OTH radars; and deploy visual and IR decoys and lasers to deceive and degrade space-based EO/IR sensors like those deployed by BlackSky. These measures would increase the time needed to find U.S. targets and possibly force an enemy to use more precise radar, visual, or IR targeting sensors to differentiate actual targets from decoys. The alternative would be to use more sorties and weapons to engage every potential target, which would place an enemy at a significant disadvantage in the salvo competition.

Degrading targeting sensors

Once a potential target is classified and identified, an enemy must determine the target's location with sufficient precision to enable an intercept, including the target's course and speed if it is moving. Targeting sensors such as very high frequency (VHF) and ultra high frequency (UHF) radars, VHF/UHF passive radars and RF receivers, and visual and IR sensors can provide the needed level of precision.

Because they use similar phenomenologies, targeting sensors would be susceptible to some of the same countermeasure techniques used against search sensors.[38] Approaches to degrading targeting sensors could include using EW systems to jam or deceive targeting radars, decoy emitters to confuse passive RF sensors, and lasers to obscure visual and IR sensors. These countermeasures would also be effective against radar, EO, or IR seekers on individual precision-guided munitions (PGM).

Many U.S. platforms carry targeting and seeker countermeasures. On U.S. aircraft, these include anti-missile EW and counter-IR systems, and on U.S. Navy ships, these include EW systems and Nulka RF decoy launchers. In the future, unmanned vehicles acting as adjuncts to manned platforms will increasingly carry these countermeasures. The use of unmanned vehicles with countermeasures such as a jammer that can operate at some distance from a defended ship or aircraft would reduce the potential that the ship or aircraft would be detected by the enemy due to the countermeasure's emissions.

Assessing Counter-C3ISR Operations

The probability of negating (Pn) enemy sensors will not be the most useful metric for assessing counter-C3ISR concepts and capabilities. As noted above, it is unlikely that sensor countermeasures will be able to completely defeat enemy sensors. Rather, U.S. forces will need to combine countermeasures with decoys and mobility to slow down and complicate enemy targeting. Quantifying delays and complications created by counter-C3ISR measures, however, is a challenging task. The impact of counter-C3ISR operations could instead be assessed in terms of the potential increase they may impose on an enemy's salvo size, assuming the enemy was to attack all the possible targets instead of delaying an attack to clarify the targeting picture.

Because an aggressor would likely want its strike salvos to exceed, if not completely overwhelm, their opponent's defensive capacity, an effective counter-C3ISR approach could cause the required salvo size to be so large and costly that the aggressor would be dissuaded from attacking. In a gray zone confrontation, this would remove the ability of the aggressor to threaten small-scale attacks against intervening forces. Salvo size, therefore, is the metric most directly applicable to countering gray zone aggression with EMW.

38 These techniques would be adjusted to account for the characteristic of targeting sensors.

The salvo size metric also allows analysis of the synergy between different types of active and passive countermeasures, which can enable reductions in the cost and complexity of a counter-C3ISR system of systems (SoS). Because these systems mutually support one another, each individual capability need not be perfect; each just needs to be good enough to enable other countermeasures to be effective. For example, camouflage and jammers need only be good enough to make an actual target look like a decoy to search sensors. Conversely, decoys only need to have enough fidelity to look like real targets when both are obscured by camouflage and jamming. Together, camouflage, jammers, and decoys increase the salvo size required to ensure an attack hits all desired actual targets. Camouflage and search sensor jammers, even if only partially effective, can also lead attackers to use weapons with seekers that are better able to discern real from false targets. These weapons may, in turn, be more susceptible to active targeting countermeasures such as RF and EO/IR jamming—requiring still more weapons to attack the same number of targets.

Sustaining Friendly Targeting Despite Enemy Countermeasures

It is highly likely that China and Russia would also use countermeasures against U.S. and allied targeting sensors in and around potential conflict areas such as the South and East China Seas, the Baltic Sea, or the Eastern Mediterranean.[39] These countermeasures would reduce the ability of U.S. forces to conduct less-escalatory surgical attacks in a gray zone confrontation against Chinese or Russian weapons and sensors. If U.S. targeting sensors cannot precisely locate key enemy threats, U.S. forces may need to conduct larger, wider-ranging attacks that would be more escalatory. If such attacks are greatly disproportionate to the original gray zone confrontation, U.S. leaders may be dissuaded from intervening, enabling the Chinese or Russian aggression to continue.

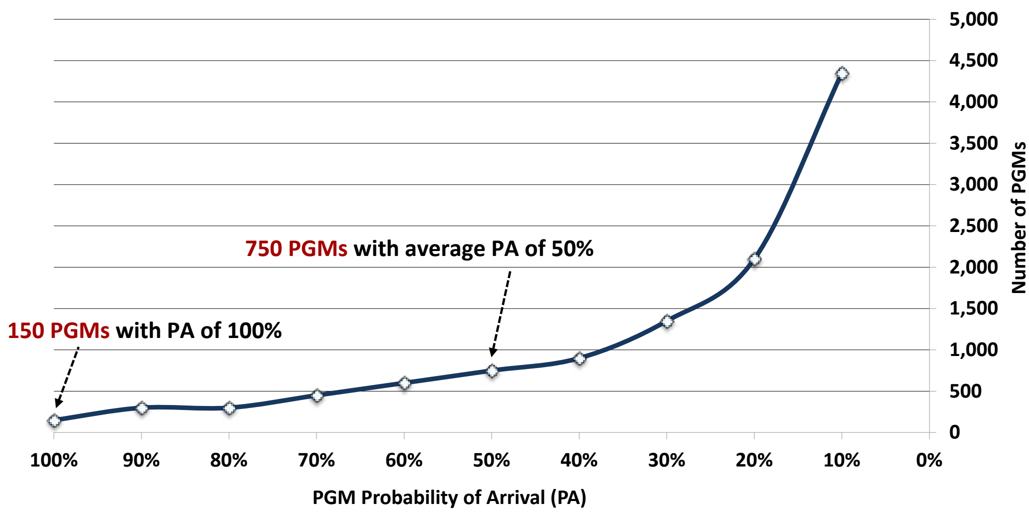
U.S. forces could regain the ability to conduct precise, surgical attacks against enemy long-range strike networks by deploying sensors and weapons together into highly contested areas. Teams of unmanned vehicles carrying EMW systems could find, classify, and identify targets and collaborate with weapons to attack the aimpoints most likely to degrade Russian or Chinese long-range sensors or weapons.

39 Electronic warfare is viewed by Russia and China as a key defensive capability to protect their sovereignty and military forces. See John Costello and Peter Mattis, "Electronic Warfare and Renaissance of Chinese Information Operations," in Joe McReynolds, ed., *China's Evolving Military Strategy* (Washington, DC: The Jamestown Foundation, 2016), p. 173; and Timothy Thomas, "The Evolving Nature of Russia's Way of War," *Military Review,* July–August 2017, p. 34.

Increasing Salvo Probability of Arrival

Reducing the probability that a weapon will arrive at its designated aimpoint (reducing the probability of arrival, or Pa, of a PGM) could increase the number of weapons and strike platforms U.S. forces must use to strike the same number of aimpoints.[40] As illustrated in Figure 10, 150 weapons would be needed to strike 100 separate aimpoints that are not protected by air defenses or countermeasures (100 percent Pa), assuming 1.5 PGMs are needed per aimpoint.[41] At a degraded Pa value of 50 percent, 750 PGMs would be needed to ensure the same number of actual aimpoints is hit.

FIGURE 10: IMPACT OF REDUCED PA ON REQUIRED SALVO SIZE



Instead of simply increasing the size of salvos to overcome the active and passive countermeasures employed by an adversary, U.S. forces could use EMW systems to improve the likelihood weapons will reach their targets despite enemy countermeasures. Targeting sensors in salvos alongside weapons, as described above, could discriminate between real and decoy targets and circumvent sensor countermeasures such as self-protection jammers and camouflage. To reduce the SSPk of enemy air defenses, weapons salvos could also include jammers and decoys that will degrade air defense sensors, distract fire control systems, and attract air defense interceptors away from strike weapons. Together, these capabilities would increase a weapon's Pa and reduce the size and scope of operations needed to counter long-range weapons and sensors.

40 Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*, pp. 12–15.

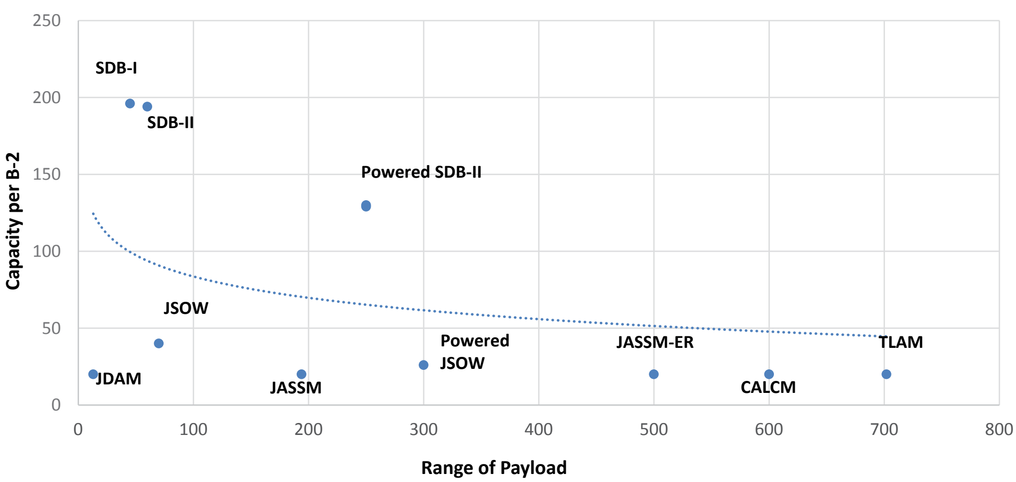
41 1.5 PGMs per aimpoint is consistent with weapons used by U.S. air forces to attack aimpoints with precision during the 2003 Operation Iraqi Freedom air campaign.

Enabling Penetrating Strike and Counterair Operations

The payload capacities of low-observable platforms such as submarines, B-2 bombers, or F-35 and F-22 fighters are constrained by the need to reduce their radar, acoustic, visual, and IR signatures; larger payload capacities also drive up their costs. The weapons capacity of these platforms could be improved by using shorter-range weapons that are smaller and can be carried in larger numbers. This will require launch platforms to approach targets more closely. Figure 11 shows the number of weapons that can be carried by a B-2 bomber compared to the standoff range of several weapons.[42]

As described in Chapter 1, Chinese and Russian air defense systems are designed to prevent weapons platforms from closely approaching targets. But large-scale Suppression of Enemy Air Defense (SEAD) operations could be overly escalatory as a U.S. response to Russian or Chinese gray zone aggression. To improve the ability of weapons platforms to approach targets without an escalatory SEAD campaign, the U.S. Air Force is pursuing new programs for Penetrating Counterair (PCA) and possibly a separate Penetrating Electronic Attack (PEA) capability.[43]

FIGURE 11: B-2 WEAPONS CAPACITY VS. WEAPONS RANGE



42 The figure uses a total payload capacity of 40,000 lbs. for the B-2, and the weights of each weapon type. For powered glide bombs that do not have prolusion systems, the propulsion system is expected to weigh 50 percent of the weight of the weapon, which was considered a conservative estimate that addresses the potential impact of the propulsion system on the weapon's form factor and ability to fit in the B-2 payload bay.

43 Courtney Albon, "AFSAB Penetrating Counterair Technology Study Already Informing AOA," *Inside Defense*, July 14, 2017, available at https://insidedefense.com/daily-news/afsab-penetrating-counterair-technology-study-already-informing-aoa; and Sydney J. Freedberg Jr., "Electronic Warfare 'Growing'; Joint Airborne EW Study Underway," *Breaking Defense*, June 23, 2017, available at http://breakingdefense.com/2017/06/electronic-warfare-growing-joint-airborne-ew-study-underway/.

The systems resulting from the PCA and PEA efforts do not need to be new aircraft programs. Some of the techniques described above using EMW unmanned aerial vehicles (UAV) or missiles to improve PGM Pa values could also be used to help penetrating aircraft avoid air defenses and more closely approach targets. These EMW systems could be deployed by a penetrating strike aircraft, or, as described for weapons salvos, they could be launched by another platform or system to maximize the penetrating aircraft's capacity to carry weapons.

Implementing New EMW Applications

U.S. forces could exploit EMW to shift the salvo competition in America's favor and restore U.S. escalation dominance. By raising the salvo sizes needed for Russian or Chinese attacks while enabling smaller U.S. strikes, American and allied forces can restore their ability to operate in contested areas and counter gray zone aggression. Enabling these approaches will require the development of new operational concepts and a shift of investment away from only strike weapons, toward a broad mix of EMW expendables and offboard systems that implement new approaches to great power competition and conflict. These concepts and capabilities are described in Chapter 3.

CHAPTER 3

New EMW Operational Concepts and Capabilities

The EMW approaches described in Chapter 2 may help create advantages for U.S. forces in the salvo competition and better enable them to defeat adversary sensor and weapon networks without highly escalatory strike campaigns. Chapter 3 assesses operational concepts and capabilities to carry out three types of EMW operations to support these approaches:

- Employing small expendable UAVs, missiles, and loitering munitions to improve the ability of U.S. weapons to reach targets and enable smaller, more precise, strike salvos;
- Using undersea platforms to launch EMW expendables to allow a smaller number of weapons platforms to conduct precise strike salvos; and
- Countering enemy search and targeting operations to increase the salvo size and level of escalation needed by an enemy to attack U.S. forces during a gray zone confrontation.

These could provide U.S. forces more options for operating in highly contested areas at acceptable risk and degrade enemy sensor and weapon networks. In some cases, EMW effects could enable U.S. or allied operations to be difficult for an adversary to detect or attribute.

Exploiting Small UAVs, Missiles, and Loitering Munitions

As described in Chapter 1, enemy ISR (intelligence, surveillance, and reconnaissance) countermeasures and air defenses will increase the salvo size needed for U.S. forces to mount a successful attack against Chinese or Russian sensor and weapon networks, increasing the level of escalation required to protect U.S. forces intervening in a gray zone confrontation.

Moreover, these larger salvo requirements could quickly deplete U.S. PGM inventories, the size of which is already a concern in today's conflicts in Iraq and Syria.[44]

Instead of simply using more strike platforms and weapons to overcome the effects of an enemy's precision defenses, U.S. forces could reduce the number of weapons needed in strike operations by increasing the likelihood that individual weapons will arrive at their intended aimpoints. One way to improve a PGM's probability of arrival is to increase its ability to penetrate and survive in defended environments, an approach DoD is pursuing with its new generation of strike and anti-ship weapons.[45] DoD could also pursue improved weapon seekers that are better able to detect targets despite jamming and camouflage, which would increase the number of weapons that strike actual targets. Improvements in survivability and sensors, however, will likely increase the complexity and cost of strike weapons, possibly reducing the number that can be procured by DoD.

The advent of autonomous vehicles and miniaturized, high-power EMW systems could offer a faster and more flexible approach to improving PGM Pa. Similar to how U.S. forces improve the ability of non-stealthy aircraft to penetrate contested areas with jamming and other measures, DoD could deploy small missiles, loitering munitions, and UAVs carrying EMW systems with strike salvos to improve the ability of today's weapons to reach their intended targets. For the sake of brevity, this report will refer to these small systems as "expendables."

Small expendables in development or use today include the Switchblade precision missile, which is in use with Special Operations Forces; small UAVs such as the Coyote UAV, used in the Navy's LOw-Cost UAV Swarming Technology (LOCUST) program;[46] and loitering munitions like the Lockheed Martin Fire Shadow.[47] Expendables have also been integrated with launch platforms. The Navy is developing a submarine-launched version of the Blackwing UAV, which is similar to the Switchblade.[48] Furthermore, the U.S. Air Force has deployed the Miniature Air-Launched Decoy (MALD) since the 1990s.[49]

44 Marcus Weisberger, "The US is Raiding its Global Bomb Stockpiles to Fight ISIS," *Defense One*, May 26, 2016, available at http://www.defenseone.com/threats/2016/05/us-raiding-its-global-bomb-stockpiles-fight-isis/128646/.

45 "AGM-158 JASSM: Lockheed's Family of Stealthy Cruise Missiles," *Defense Industry Daily*, July 21, 2017, available at http://www.defenseindustrydaily.com/agm-158-jassm-lockheeds-family-of-stealthy-cruise-missiles-014343/.

46 Eric Limer, "Watch the Navy's LOCUST Launcher Fire Off a Swarm of Autonomous Drones," *Popular Mechanics*, May 24, 2016, available at http://www.popularmechanics.com/military/weapons/a21008/navy-locust-launcher-test-2016/.

47 "Fire Shadow Loitering Munition," factsheet, Lockheed Martin, available at http://www.lockheedmartin.com/us/products/cdl-systems/about-us/projects/fire-shadow-loitering-munition.html.

48 Sam LaGrone, "UPDATED: AeroVironment to Supply Blackwing Mini UAVs for Navy Attack, Guided Missile Submarines," *USNI News,* May 16, 2016, available at https://news.usni.org/2016/05/16/aerovironment-to-supply-blackwing-mini-uavs-for-navy-attack-guided-missile-submarines.

49 Kevin McCaney, "Air Force looks to upgrade its EW jammers," *Defense Systems*, June 15, 2016, available at https://defensesystems.com/articles/2016/07/15/air-force-raytheon-mald-j-jammer-upgrades.aspx.

FIGURE 12: SWITCHBLADE MISSILE

Image courtesy of AeroVironment.

FIGURE 13: COYOTE UAV

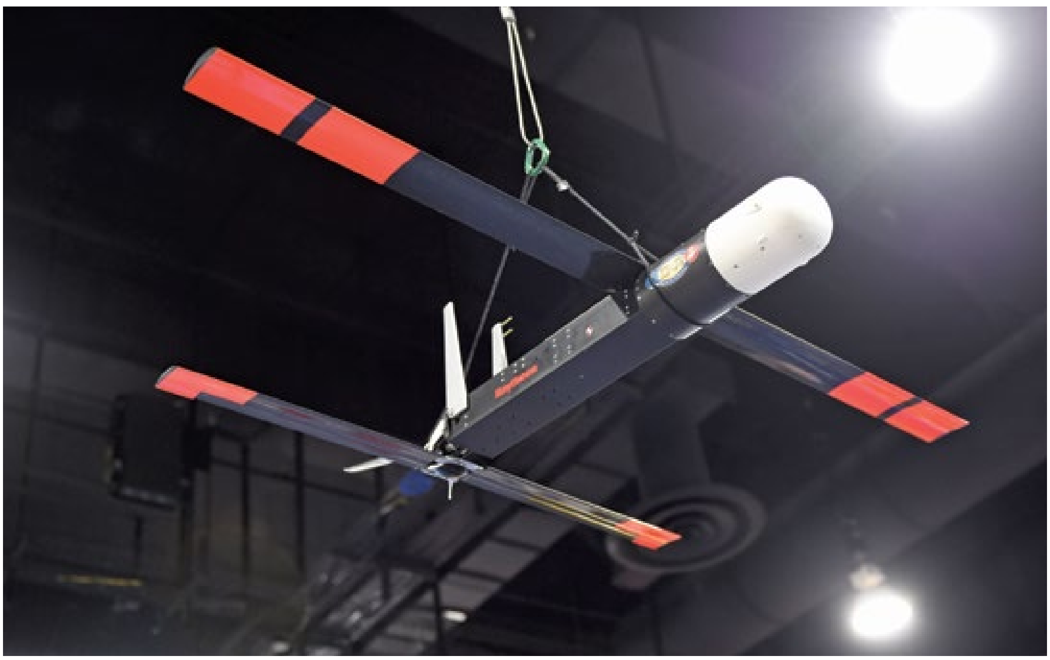


Photo courtesy of the Office of Naval Research.

DoD could gain more flexibility in designing its future strike salvos by incorporating sensors, jammers, or decoy systems into separate small expendables rather than enhancing PGMs themselves. This approach would also allow DoD to field new EMW technologies more rapidly and avoid the cost and time that would be needed to integrate these technologies into existing strike weapons.

FIGURE 14: MINIATURE AIR-LAUNCHED DECOY

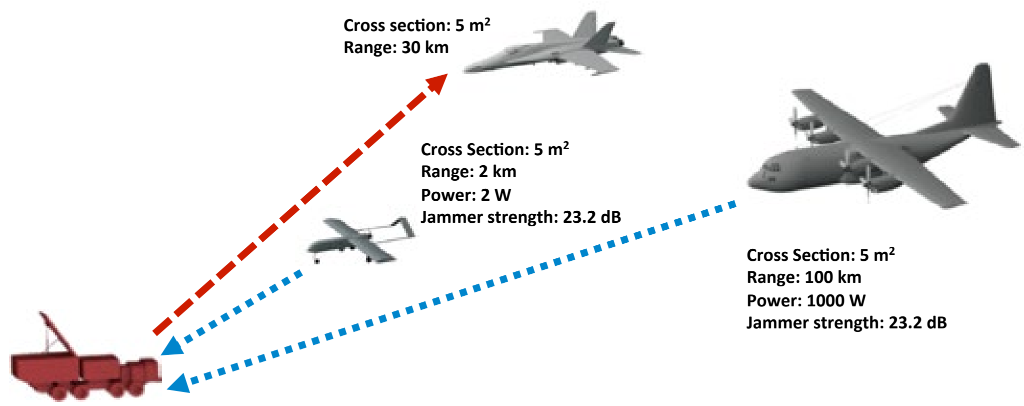
Photo courtesy of Raytheon.

Small Jammers and Decoys

Future U.S. strikes could include jammers that increase the RF noise level around salvos to reduce the ability of air defense radars to track incoming weapons. They could also include multiple small decoys that attract the focus of air defense radars and interceptors away from actual weapons or launch platforms. Both approaches would increase the probability that weapons will arrive at their intended aimpoints, reducing the salvo sizes needed to strike defended targets. Although weapons could also be modified to carry on-board jammers, this could be costlier and may increase the possibility the weapons will be counter-detected by the passive sensors that are increasingly part of advanced integrated air and missile defense systems.

Small UAVs, loitering munitions, or missiles will, by necessity, have small antennae and a limited power capacity. This will reduce their ability to jam high-power radars or mimic the emissions of much larger platforms or weapons. Expendables could mitigate these limitations by taking advantage of their ability to approach an enemy sensor more closely, and achieve the same EMW effects as a larger, standoff system. For example, a 2-watt (W) jammer on an expendable operating 2 km from a target radar could achieve the same jammer-to-signal ratio as a 1-kilowatt (kW) jammer operating 100 km from the same target radar (see Figure 15). Because the expendable would have a much smaller radar cross section and be much slower than an EW aircraft like an E/A-18G Growler or C-130 Compass Call, it would be more difficult for the adversary to track and engage with air defense systems, even if it is within 2 km. This is a challenge U.S. air defenses face today.[50]

FIGURE 15: JAM-TO-SIGNAL POWER POSSIBLE WITH DIFFERENT JAMMERS AT VARIOUS RANGES



Even at short range, the jamming power from a single expendable may not be sufficient to deceive or obscure an enemy air defense radar. The signals from multiple networked missiles, munitions, or UAVs could also be combined into a single synthetic beam to increase the effective power of small EMW systems. This approach, developed by programs such as DARPA's Retrodirective Arrays for Coherent Transmission (ReACT), can be used to jam a sensor or create a decoy signal by using a technique like digital radiofrequency memory (DRFM) to mimic returns that a threat radar would receive from a real weapon.[51] Using synthetic beamforming and collaboration, a group of small EMW expendables could degrade or deceive enemy sensors with effectiveness similar to today's large monolithic EMW systems. The Navy, for example, is pursuing these swarm techniques in programs like LOCUST.[52]

50 Ian Duncan, "U.S. Military Exploring Defense Methods Against Drones," *Government Technology*, June 22, 2015, available at http://www.govtech.com/products/US-Military-Exploring-Defense-Methods-Against-Drones.html.

51 DRFM is a technique in which the jammer repeats back to the sensor the exact signal that was originally transmitted, modified to simulate a return from a larger target at a different range or even a different azimuth. See Kurt Vogel, "Retrodirective Arrays for Coherent Transmission (ReACT)," DARPA, available at http://www.darpa.mil/program/retrodirective-arrays-for-coherent-transmission.

52 Hope Hodge Seck, "Navy to Demo Swarming Drones at Sea in July," *Military.com*, June 24, 2016, available at http://www.military.com/daily-news/2016/06/24/navy-to-demo-swarming-drones-at-sea-in-july.html.

EMW UAVs, missiles, and munitions can also use high-power RF (HPRF) energy to damage enemy sensors and electronic systems. Weapons with HPRF expendables, also known as high-powered microwave weapons, could disrupt or damage specific electronic components inside a targeted system by inducing voltages or currents that exceed the capacity of one or more of the weapon's critical electronic circuits. Future HPRF weapons could also induce stray signals in a sensor or computer network that could disrupt its operation or create incorrect information such as false contacts.

One example of an HPRF weapon is the U.S. Air Force's developmental Counter-electronics HPM Advanced Missile Project (CHAMP) system. CHAMP incorporated an HPM generator into an existing cruise missile to allow the transmitter to be positioned close to targets and attack multiple locations in each flight. The Air Force is working now to incorporate CHAMP-like transmitters into other expendables and unmanned vehicles.[53] As in jamming or decoy operations, small expendables with HPRF generators could use proximity to compensate for their lower power levels (compared to a large cruise missile).

Conducting EMW operations close to a target and using synthetic beamforming will require precise emissions, particularly when they come from low-power systems that could be drowned out by other high-power radar and jamming signals. EMW missiles, UAVs, and munitions will need passive sensors to map the EM environment, avoid interfering signals, and precisely place their own transmissions. Passive EM sensors like those in the Advanced Anti-Radiation Guided Missile (AARGM) or Long-Range Anti-Ship Missile (LRASM) are small enough to be incorporated into most future EMW expendables.

Future EMW capabilities will also need cognitive control systems that anticipate the behavior of other emitters and determine the best location, waveform, and beam shape needed to create the desired EM effect. Cognitive EMW control systems under development, such as DARPA's Adaptive Radar Countermeasures (ARC) and Behavioral Learning for Adaptive Electronic Warfare (BLADE) programs, could evaluate the EM environment and develop and test courses of action (COA) to conduct EMW operations.[54] This will enable an operator to provide tasks to a group of EMW expendables before they deploy without knowing the exact details of the EMS environment in an objective area. In addition to assessing and developing a plan to conduct those tasks, cognitive EMW controls would enable EMW expendables to counter agile enemy radars and jammers; they are being designed to quickly develop and test countermeasures from pulse to pulse and communicate the results between themselves and with operators outside the objective area.

53 Katherine Owens, "Air Force Electronic Weapons to Get an Electromagnetic Power Boost," *Defense Systems*, May 15, 2017, available at https://defensesystems.com/articles/2017/05/15/electromagnetic.aspx.

54 Paul Tilghman, "Behavioral Learning for Adaptive Electronic Warfare (BLADE)," DARPA, available at http://www.darpa.mil/program/behavioral-learning-for-adaptive-electronic-warfare; and Paul Tilghman, "Adaptive Radar Countermeasures," DARPA, available at http://www.darpa.mil/program/adaptive-radar-countermeasures

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Small Sensors

Whereas jammers and decoys can improve a strike salvo's survivability, small UAVs, projectiles, or missiles equipped with sensors could help salvos circumvent or defeat enemy countermeasures. Expendables with EO/IR sensors would not be susceptible to Chinese or Russian RF jammers, and groups of expendables with a combination of EO/IR, passive RF, and radar sensors could help differentiate real Chinese or Russian targets from decoys. Against mobile or relocatable targets, sensor-equipped expendables preceding a salvo could provide updated targeting data to weapons just before they arrive in the target area. And following attacks, sensor-equipped UAVs, missiles, or munitions could conduct battle damage assessment (BDA) to improve the efficiency of follow-on attacks.

Sensors on small expendables will have less range and precision than those on larger platforms due to the limited power available on small UAVs, missiles, or projectiles. Furthermore, the achievable gain by transmitters and receivers also decreases with antenna or array size. These limitations could be partially mitigated by positioning small sensors closer to a target. Coherent beamforming, as described above for jammers and decoys, could also be used to compensate for low sensor power and gain. Multiple sensors that are networked together can form larger, more powerful virtual arrays or apertures, as developed in the ReACT program for RF sensing or DARPA's Military Imaging and Surveillance Technology (MIST) for visual imaging.[55]

Swarm Systems of Systems

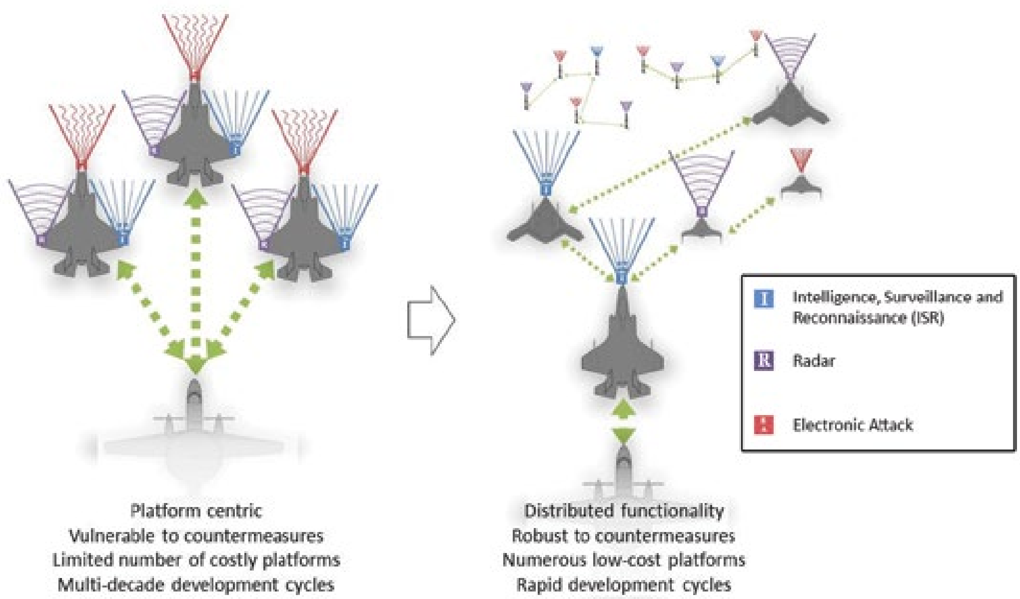
Contested areas near Chinese or Russian targets will host a large and diverse array of sensors and passive or active countermeasures intended to defeat U.S. strike weapons. U.S. strike salvos will need a similarly diverse set of EMW systems that can act over a wide area and from multiple directions. Expendables would enable a more heterogeneous SoS than monolithic sensor and EW platforms. Swarms of EMW expendables would assess the environment; evaluate potential threats; adapt friendly jamming, sensing, and communications to avoid counter-detection; develop and test jamming or decoy techniques to defeat adversary sensors and communications; and find, classify, and identify targets. Further contributing to the complexity of EMW operations, the increasing power and sensitivity of modern EMW systems causes each of these actions to be interrelated. For instance, jamming signals from EMW expendables need to be managed to avoid degrading sensors or networks connecting strike weapons, and active sensors on expendables should operate in a way to avoid counter-detection by enemy passive sensors.

To address the complexity and physical scope required in future EMW operations, expendables will need to incorporate cognitive processing and coordinate their actions through communication networks. These capabilities are in development through programs such

55 Stephen Griggs, "Military Imaging and Surveillance Technology (MIST)," DARPA, available at http://www.darpa.mil/program/military-imaging-and-surveillance-technology.

as the Office of Naval Research's Netted Emulation of Multi-Element Signatures Against Integrated Sensors (NEMESIS) and Electromagnetic Maneuver & Control Capability (EMC2) or DARPA's System of System Integration Technology and Experimentation (SoSITE),[56] depicted in Figure 16. Networking EMW expendables would allow them to share their sensor data, which can enable many small UAVs, missiles, or munitions to establish a common operational picture that would normally require large airborne or space-based sensor platforms. Networking can also enable a swarm of EMW expendables to share COAs they develop for tasked EMW operations; determine which expendables are best positioned to execute specific tasks; and then coordinate their jamming, decoy, or sensing operations.

FIGURE 16: SYSTEM OF SYSTEM INTEGRATION TECHNOLOGY AND EXPERIMENTATION (SOSITE) PROGRAM



Graphic courtesy of DARPA.

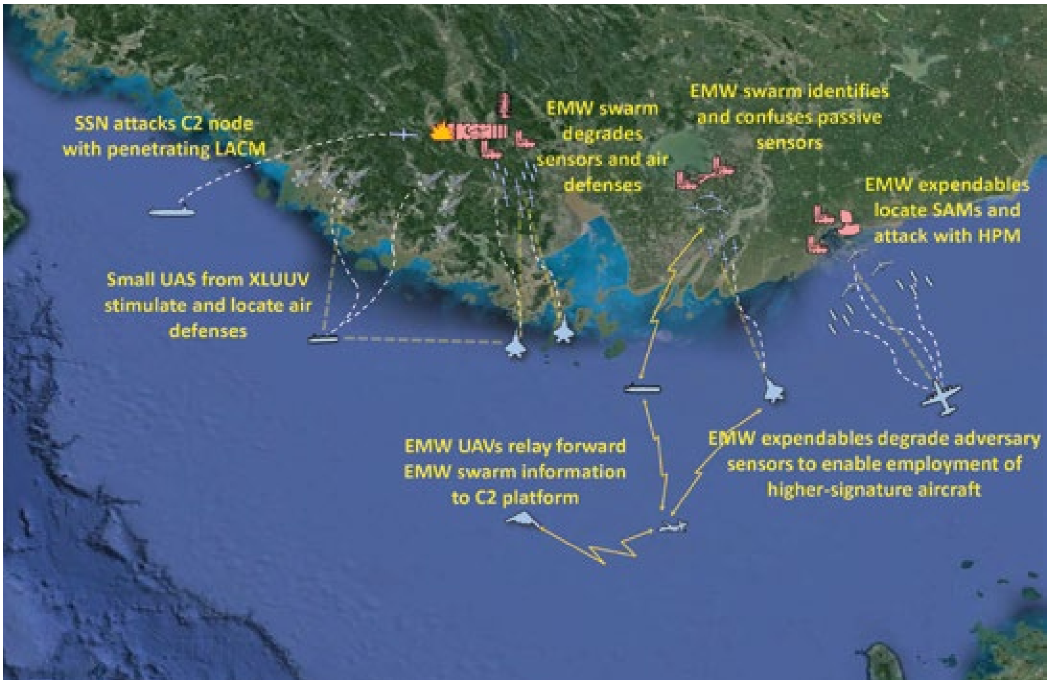
Swarms of EMW expendables operating as a SoS can conduct a range of operations to support smaller, less-escalatory, and more surgical power projection operations by U.S. forces against a gray zone aggressor. These missions, depicted in Figure 17, include:

Mapping passive and inactive defenses. The growing use of passive air defenses limits the ability of pre-strike surveillance to support accurate targeting of standoff strike weapons. To address these targets, EMW SoS could immediately precede a strike salvo with decoys and

56 Cheryl Pellerin, "DARPA Uses Open Systems, 'Plug and Fly' to Boost Air Power," *DoD News*, March 30, 2015, available at https://www.defense.gov/News/Article/Article/604383/darpa-uses-open-systems-plug-and-fly-to-boost-air-power/.

jammers to stimulate enemy air defenses and expendables equipped with passive or active sensors to monitor the enemy's reactions. The EMW swarm could then update targeting information and disseminate it to weapons salvos already in transit to the targets. In addition to mapping out the enemy air defense network, this could cause the enemy to waste some air defense weapons against the EMW SoS expendables before strike weapons arrive.

FIGURE 17: EMW SOS OPERATIONS



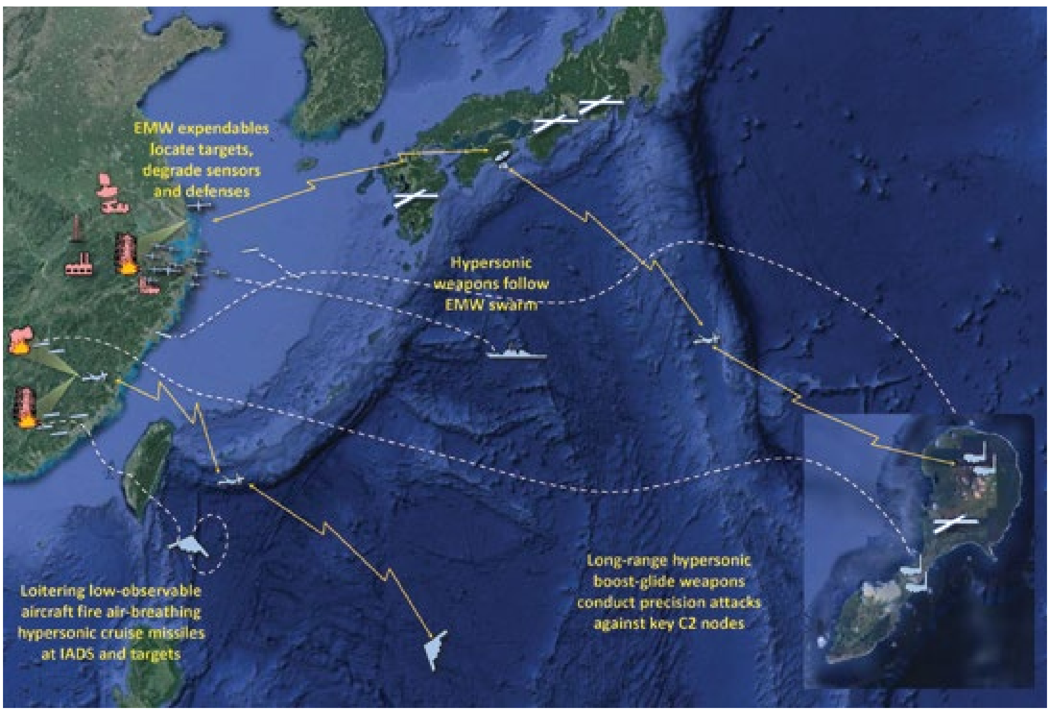
Sustaining resilient communications. Loitering EMW expendables equipped with communication systems could create LPI/LPD communication pathways into contested areas. This could enable operations in communications degraded or denied environments without the need for physical attacks against enemy communications jammers. It is likely that enemies will attempt to degrade or deny communications between networked EMW expendables. To conduct networked cognitive operations, a future EMW SoS will need capabilities like those being developed by DARPA's Communications in Extreme Environments (COMMEx) and Collaborative Operations in Denied Environment (CODE) programs, which enable communications between unmanned systems despite enemy jamming.

Extending sensor networks. Modern IADS can detect and attack current U.S. ISR aircraft such as the E-2 Hawkeye, E-3 Airborne Warning and Control System (AWACS), and E-8C Joint Surveillance Target Attack Radar System (JSTARS) at long range. Surveillance and targeting support in contested areas for penetrating platforms is a major capability shortfall. EMW expendables offer an alternative approach to find and target enemy aimpoints with both less probability of inciting escalation than a manned platform and less risk to U.S. forces. EMW SoS communicating via a mesh network of UAVs, projectiles, or missiles back to the controlling platform could also be used to extend the sensor range and coverage of a manned aircraft or ship operating at the edge of a contested area.

Tunneling. Jammer or decoy UAVs, missiles, or munitions at the leading edge of a salvo could confuse or obscure enemy air defense sensors and deplete air defense capacity before the bulk of the salvo arrives in defended areas. This initial wave of EMW expendables would essentially build a tunnel that would help follow-on weapons reach their targets.

Providing final targeting to salvos. As illustrated by Figure 18, EMW UAVs, missiles, and loitering munitions could form the leading edge of an autonomous salvo in which the sensor expendables verify targets and communicate them to weapons in the same salvo through short-range line-of-sight datalinks and a mesh network of EMW expendables. This approach would be useful against time-sensitive relocatable or mobile targets if the weapons in the salvo can loiter to wait for a positive identification of the target. It would also help hypersonic weapons that have a very short time-of-flight.

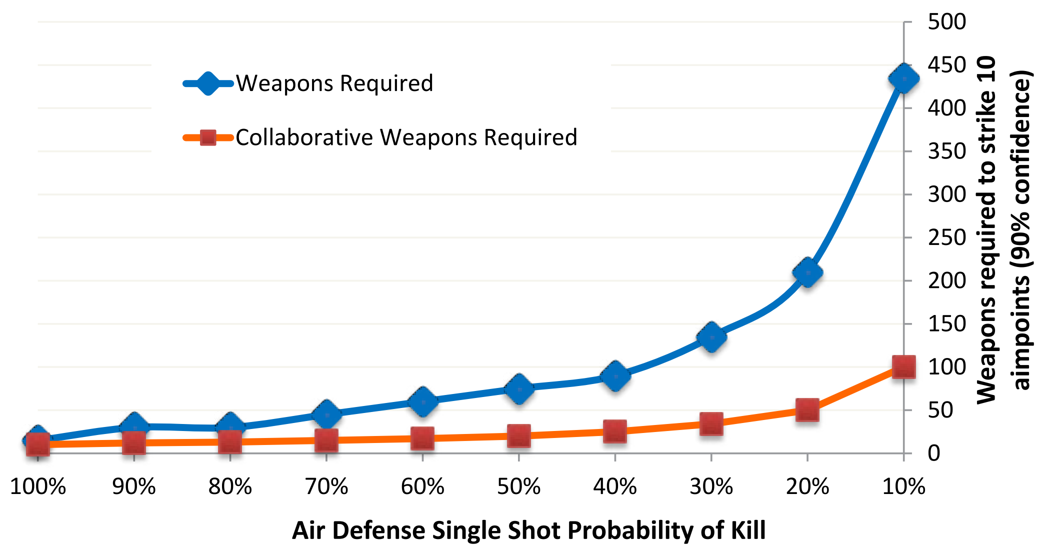
FIGURE 18: EMW SOS SUPPORTING LONG-RANGE HYPERSONIC WEAPON ATTACKS



Collaborative strike operations. EMW sensor expendables equipped with communication links and incorporated into a weapons salvo could coordinate attacks to ensure high-priority aimpoints are destroyed first, reassign targets when weapons are lost to enemy defenses, or attack higher-priority pop-up targets. These collaborative tactics would have the effect of improving a salvo's overall survivability and reducing the number of weapons needed for attacks in contested areas.

Figure 19 depicts the reduction in salvo size resulting from weapons collaboration. Without collaboration, a salvo needs enough weapons assigned to each aimpoint to ensure one survives enemy defenses. For example, if the air defense SSPk is 0.50, eight weapons would need to be launched at each aimpoint to ensure one of them reaches the target with 90 percent confidence (blue line). With collaboration, weapons could be retargeted in flight to make up for those lost in transit. As a result, a salvo only needs enough weapons to absorb the overall losses from enemy defenses. As shown by the orange line, a collaborative salvo may need only needs 20 weapons to hit 10 aimpoints with an air defense SSPk of 0.50.[57]

FIGURE 19: IMPACT OF WEAPONS COLLABORATION ON REQUIRED SALVO SIZE



Battle damage assessment. To assess the effects of attacks, strike weapons could be followed in a salvo by an EMW SoS consisting of sensor-equipped EMW UAVs, missiles, or munitions, complemented by expendables equipped with communication systems to act as a mesh network. This would enable the salvo to report whether the target was destroyed or

57 This chart assumes that ten aimpoints are being struck. With collaborative weapons, it assumes any weapon can be retargeted to any aimpoint, which may not be possible, depending on the distance between aimpoints and when retargeting occurs during weapon transit.

damaged. The EMW SoS could also use collaboration, as described above, to direct remaining weapons within the salvo to reattack targets that were not sufficiently degraded or cue attacks by a subsequent salvo.

Penetrating electronic attack. EMW SoS may be an effective approach to allow penetrating aircraft to approach targets more closely and persist in defended target areas (see Figure 20). As described in Chapter 2, an individual launch platform such as a strike aircraft can carry a larger number of smaller short-range weapons than it can larger, longer-range weapons. To support short-range air strikes, expendable UAVs, missiles, or munitions with sensors could precede penetrating aircraft to verify the locations of enemy air defenses and targets and communicate this information back to strike aircraft through a mesh network and line-of-sight communication links. These sensor systems could be followed by jammers and decoys that degrade enemy air defense sensors and distract their attention. Penetrating strike aircraft could then enter the target area to launch large, short-range weapon salvos designed to overwhelm the target's point defenses.

FIGURE 20: PENETRATING COUNTERAIR SOS

Delivery of EMW Expendables

EMW UAVs, missiles, and munitions can be delivered by a variety of methods. Because they are small, EMW expendables would not have long ranges or endurance and would need to be launched or delivered close to a target.

Large missiles could be used to penetrate contested areas and then disperse EMW expendables. Air-launched AIM-9, AIM-120, and Joint Air-to-Surface Standoff Missiles (JASSM); ship-launched SM-2, SM-6, and Tomahawk missiles; and surface-launched Army Tactical Missiles (ATACM) could each carry multiple small EMW loitering munitions or UAVs as submunitions.

Launching EMW expendables at higher altitudes is another approach to extending their ranges and endurance. Launching small EMW UAVs, missiles, or munitions from very high altitude (60,000 to 120,000 feet) balloons could be a less expensive option than using a missile. High altitude balloon technologies are very mature and may cost significantly less than other delivery methods. Furthermore, defeating balloon-delivered EMW expendables would likely require SAMs that can reach very high altitudes. Using these expensive SAMs to defeat large numbers of balloons—some which might be decoys—could be costly and operationally impractical for aggressors.

Another innovative delivery method for EMW expendables could be from undersea platforms, which may be the best use of undersea payload capacity in general. This approach to EMW expendable delivery is detailed in the next section.

Leveraging Undersea Platforms for EMW

Undersea platforms could be one of the most effective methods to deliver EMW expendables because they can closely approach enemy coastlines and targets. This allows shorter-range expendables to be employed, which are less expensive, smaller, and can be carried in higher numbers than larger payloads like cruise missiles. A submarine or unmanned undersea vehicle (UUV) with EMW expendables would also be able to stay on station longer than one carrying cruise missiles, because it could carry more payloads with fewer needed per salvo. As described in Chapter 1, an entire submarine's weapon capacity would likely be needed to attack any defended Russian or Chinese target.

U.S. military doctrine increasingly relies on submarines to conduct surveillance and targeting, surface warfare (SUW), anti-submarine warfare (ASW), and strike operations near enemy coasts. Nuclear attack submarines (SSN) can position themselves in a contested area before hostilities break out, then attack enemy sensors and platforms to reduce the threat to U.S. surface and air forces attempting to enter the region.

America's competitors recognize the importance of submarines to U.S. power projection and are pursuing new ASW approaches in response. These concepts and capabilities may suppress U.S. submarine operations near an adversary's coast, limiting the ability of SSNs to launch EMW expendables or strike weapons. Instead, using UUVs to deliver EMW payloads may better serve U.S. forces. The impact of new ASW approaches on submarine operations is described below, followed by discussion of methods U.S. forces could use to deploy EMW expendables from UUVs.

New ASW Approaches Could Change U.S. Submarine Operations

China's new ASW approaches include seabed sonar arrays and ocean observatories akin to the U.S. Sound Surveillance System (SOSUS); new maritime patrol aircraft; and surface combatants with new low frequency active (LFA) variable depth sonars (VDS) and long-range ASW rockets (ASROC).[58] Russia is a longstanding undersea competitor of the United States and is fielding a new generation of deep-sea surveillance submarines and SSNs that may carry effective sonar arrays.[59]

New Chinese or Russian ASW capabilities will not automatically translate into a highly lethal ASW network. Specialized personnel and extensive training and exercises are needed to gain and sustain the proficiency needed to successfully attack submarines in challenging acoustic environments such as the Baltic Sea or South and East China Seas. China's ASW investments suggest they are not necessarily designed to destroy U.S. submarines but instead marginalize and prevent them from being effective.

Seabed sonar arrays and LFA VDS could quickly provide the approximate location of potential submarines, enabling them to be engaged by torpedoes deployed by maritime patrol aircraft and ship- or shore-launched ASROCs. This approach is not likely to provide a high Pk against U.S. submarines; the challenge for adversaries would be correctly placing torpedoes from rockets or airplanes on targets found using relatively inaccurate sensors. This approach might be effective, however, at suppressing U.S. submarine operations. It exploits three fundamental limitations of submarines:

- Compared to surface combatants and aircraft, submarines are slower, especially when trying to reduce their acoustic signature;
- Submarines have no or very limited self-defense capabilities; and
- Compared to surface combatants and aircraft, submarines have constrained situational awareness. Their sonars cannot detect threats as far away as radars and cannot determine whether a weapon is likely to hit the submarine as rapidly as a radar or missile warning receiver.

These vulnerabilities could compel a submarine to leave an area immediately when attacked or when its crew believed it had been counter-detected. Once it evades, a submarine will need to reposition itself at slow speed to regain its stealth. In this way, U.S. submarines might be kept on the move by frequent suppression attacks and unable to conduct effective strike or ISR missions in coastal areas.

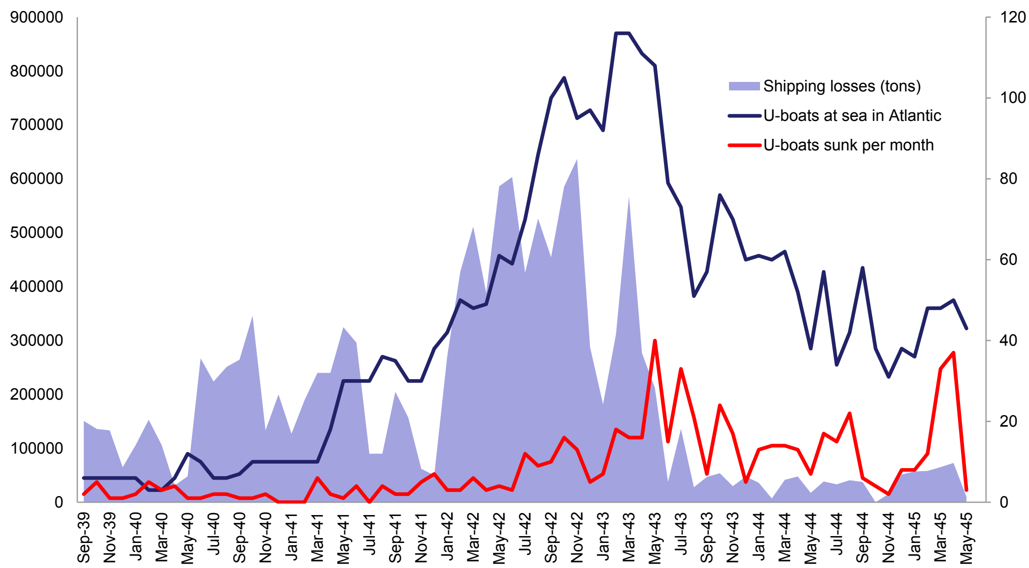
A strategy of suppressing rather than destroying submarines was a successful approach to ASW campaigns in previous conflicts. During the Battle of the Atlantic in the Second World

58 ONI, *The Russian Navy: A Historic Transition* (Washington, DC: ONI, December 2015), p. x, available at http://www.oni.navy.mil/Portals/12/Intel%20agencies/russia/Russia%202015print.pdf?ver=2015-12-14-082038-923; Lyle Goldstein, "China's Great Undersea Wall," *The National Interest*, February 22, 2016, available at http://nationalinterest.org/feature/chinas-undersea-great-wall-16222; and OSD, *Military and Security Developments Involving the People's Republic of China 2017*.

59 Kathleen H. Hicks, Andrew Metrick, Lisa Sawyer Samp, and Kathleen Weinberger, *Undersea Warfare in Northern Europe* (Washington, DC: Center for Strategic and International Studies, 2016), pp. 10–12, available at https://www.csis.org/analysis/undersea-warfare-northern-europe.

War, Allied forces faced a growing U-boat threat to ships carrying war material and supplies to England and later Continental Europe. As shown in Figure 21, overall shipping losses increased steadily in 1939 and 1940 as more U-boats deployed to the Atlantic. Losses dropped in mid-1941 despite continued increases in submarine presence and shipping traffic. This time corresponded with an increase in convoy escorts and ASW capabilities supplied by the United States. Notably, shipping losses decreased dramatically during 1941 despite U-boat losses remaining low.[60]

FIGURE 21: SHIPPING AND SUBMARINE LOSSES AND SUBMARINE PRESENCE DURING THE BATTLE OF THE ATLANTIC[61]



Shipping losses during the Battle of the Atlantic rose again in 1942 as the United States entered the war, with almost all the losses occurring off the American coast. At that time, the U.S. Navy did not have many ASW aircraft or ships for coastal shipping routes, having transferred all the available ones to convoy escort duty in the North Atlantic. As new escorts came into the fleet starting in late 1942, shipping losses decreased again and remained low for the remainder of the war (except for a brief spike in mid-1943). But, as was the case in 1941, lower shipping losses did not correlate with enough U-boat sinkings to significantly reduce deployed U-boat presence, which remained higher than in 1939–1941.[62]

60 This analysis and its conclusions are detailed in John Stillion and Bryan Clark, *What It Takes to Win: Succeeding in 21st Century Battle Network Competitions* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

61 Data for this chart was drawn from multiple sources, described in detail in Stillion and Clark, *What It Takes to Win*, p. 21.

62 The reduction in U-boat presence in 1943 resulted from a combination of a spike in losses and the redeployment of submarines from bases in Norway and France to Germany as Allied forces threatened to invade those areas.

These results suggest submarines were suppressed or marginalized in the Battle of the Atlantic without necessarily being destroyed. Allied ASW forces used overt sensors like radar or active sonar to find submarines, followed by attacks with depth charges or unguided torpedoes. Although these systems were not highly accurate or lethal, they conveyed to submarine crews that their U-boat had been counter-detected and would be pursued, which often led them to evade, not stand and fight. China may be pursuing such a strategy, and Russia or Iran may adopt a similar approach as they seek to reduce the threat from American submarines.

Increasing Salvo Sizes from Undersea Platforms

Even if a U.S. SSN can approach an enemy coast and conduct an attack before being detected and suppressed, its payload capacity may not significantly contribute to the salvo competition. As described in Chapter 1, more than 40 weapons may be needed to overcome the defensive capacity of even a small IADS complex. A strike of this size would require the entire payload capacity of a Block V *Virginia*-class SSN. Although this is nearly the same salvo capacity as a surface combatant or CVW sortie cycle (depending on the weapons used), the SSN must return to a relatively secure port to reload. Surface combatants can, in theory, reload weapons at sea using equipment that has been developed in various technology demonstrators.[63] A CVW can launch this number of weapons several times per day (depending on range and weapons used) for an indefinite period.[64]

The DoD can increase its undersea payload capacity and reduce the risk to manned submarines by shifting some submarine missions to UUVs. UUVs could also carry weapons and other payloads that are controlled by operators onboard a submarine. This would increase the number of undersea weapons available to commanders and enable submarines to remain somewhat removed from the highest threat areas located close to shore. UUVs could be considered more expendable than manned submarines and be programmed to not evade in the face of overt adversary sensor activities or even torpedo and depth charge attacks.

Using UUVs to deliver kinetic weapons autonomously would, however, require a significant change to current policy for the use of armed unmanned systems. According to DoD policy, "Autonomous weapon systems may be used to apply non-lethal, non-kinetic force, such as some forms of electronic attack, against materiel targets."[65] Today, UAVs such as the MQ-1 Predator and MQ-9 Reaper carry weapons, but they are in continuous communication with operators who retain positive control over weapons. A UUV would likely only have intermittent communication with operators and commanders.

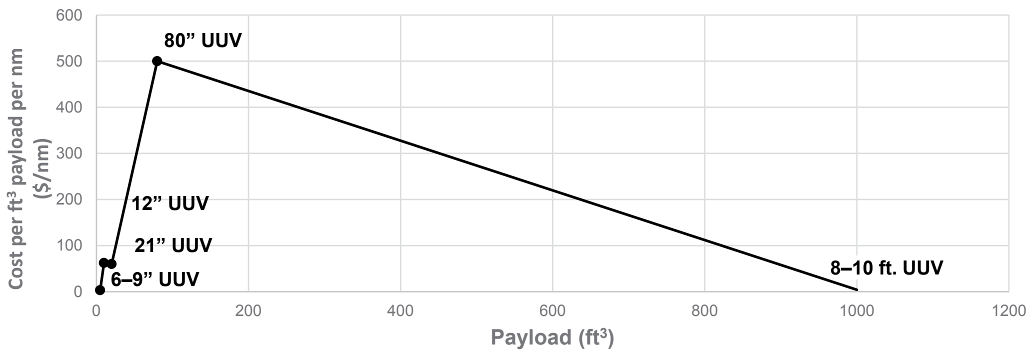
63 See footnote 27.

64 See footnote 28.
See Work, remarks at the CNAS Inaugural National Security Forum, December 14, 2015; Work, speech delivered at the McAleese/Credit Suisse Defense Conference, March 17, 2015; and Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*.

65 DoD, "Autonomy in Weapons Systems," DoD Directive 3000.09, November 21, 2017, p. 3, available at http://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodd/300009p.pdf.

The Navy is pursuing a family of UUVs to address a range of undersea warfare missions.[66] Smaller UUVs, such as micro UUVs of 6 to 9 inches in diameter and small-displacement UUVs of 12 inches in diameter, can act as weapons themselves. Larger UUVs such as medium-displacement UUVs of 21 inches in diameter and large displacement UUVs can carry weapons or other expendables. Figure 22 shows the relationship between cost and payload capacity for the Navy's current family of UUVs.[67]

FIGURE 22: COST EFFECTIVENESS OF U.S. NAVY UUVS



As the figure indicates, an extra-large UUV (XLUUV) of 8–10 feet in diameter would have the largest payload capacity and provide the most cost-effective option for carrying undersea payloads, including smaller UUVs. An XLUUV such as the Boeing Echo Voyager or Battelle Proteus would likely be able to carry three to six UGM-109 Tomahawk missiles, UGM-84 Harpoon missiles, or Long-Range Anti-Ship Missiles (LRASM) based on the dimensions of their payload bays.[68] These weapons are too long to be launched vertically from a UUV like they are on submarines or ships today, but could be launched horizontally in a similar manner to how TLAMs and Harpoons were launched from submarine torpedo tubes before submarines were equipped with vertical launch tubes. This approach would require a canting mechanism to tilt the launcher away from the XLUUV centerline, enabling it to eject the encapsulated missile around its bow as in submarine torpedo tubes. Figure 23 displays this configuration.[69]

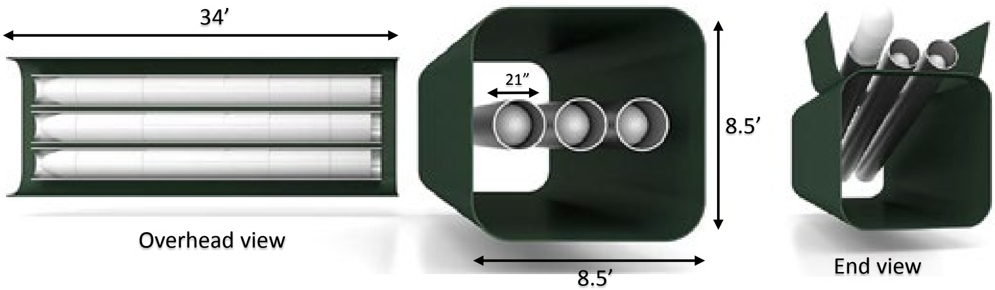
66 Chief of Naval Operations (CNO), Undersea Warfare Directorate, *Autonomous Undersea Vehicle Requirement for 2025*, Report to Congress (Washington, DC: DoD, February 2016), available at https://news.usni.org/wp-content/uploads/2016/03/18Feb16-Report-to-Congress-Autonomous-Undersea-Vehicle-Requirement-for-2025.pdf.

67 Cost and payload capacities are based on Navy budget exhibits for the LDUUV and MDUUV and manufacturer costs and specifications for the XLUUV and micro UUV.

68 "Proteus: A Dual Mode Underwater Vehicle," Battelle Memorial Institute factsheet, January, 2017, available at https://www.battelle.org/docs/default-source/government-offerings/national-security/undersea-systems-technologies/battelle-2016-undersea-proteus-underwater-vehicle.pdf?sfvrsn=8; and Dan Raley, "Under and Across the Oceans," *Boeing Innovation Quarterly,* February 2017, available at http://www.boeing.com/features/innovation-quarterly/feb2017/feature-across-oceans.page.

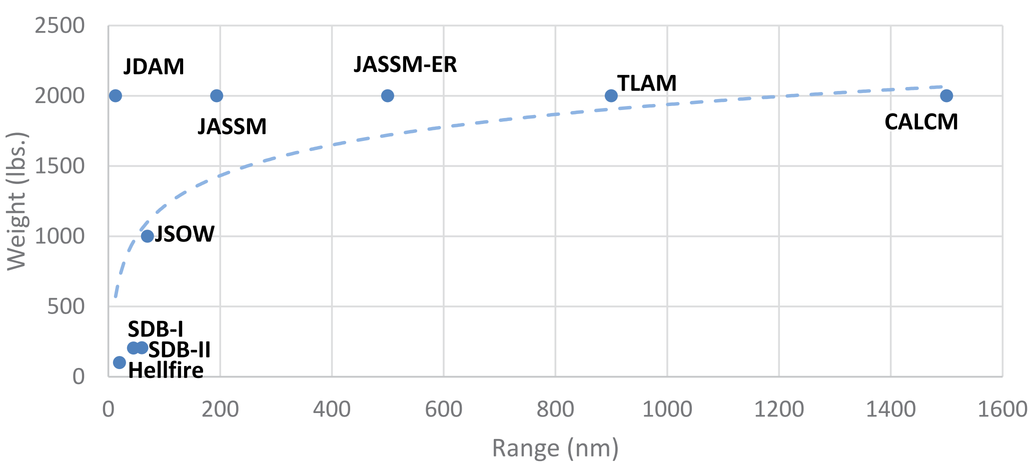
69 The XLUUV payload bay, based on the Boeing Echo Voyager, is about 35 feet long by 9 feet in diameter.

FIGURE 23: XLUUV CONFIGURATION WITH LONG-RANGE WEAPONS



An XLUUV could carry more weapons if the Navy exploited its ability to approach close to an adversary’s coast and loaded it with smaller, short-range weapons. Although submarines could also use smaller weapons to generate larger salvos, this would require that they approach closer to a target than today. This will place them at greater risk of being suppressed by adversary ASW efforts. XLUUVs, in contrast, are more expendable than submarines, and could be programmed to ignore suppression attacks. Figure 24 shows the relationship between size and range for common DoD weapons. In general, it shows longer-range weapons are larger than short-range weapons, resulting in fewer loaded on each weapons platform.

FIGURE 24: RELATIONSHIP BETWEEN WEAPON SIZE AND RANGE[70]



The impact of weapon size on XLUUV payload capacity is exacerbated by the constraints of the XLUUV hull form. Figure 25 illustrates the number of weapons that could be carried by an XLUUV, assuming weapons that are normally air-launched, such as the Small Diameter

70 This chart is derived from Gunzinger and Clark, *Sustaining America’s Precision Strike Advantage*, p. 32.

Bomb (SDB), would need boosters to get them to an equivalent altitude as when they are air-delivered.[71]

FIGURE 25: XLUUV PAYLOAD CAPACITY

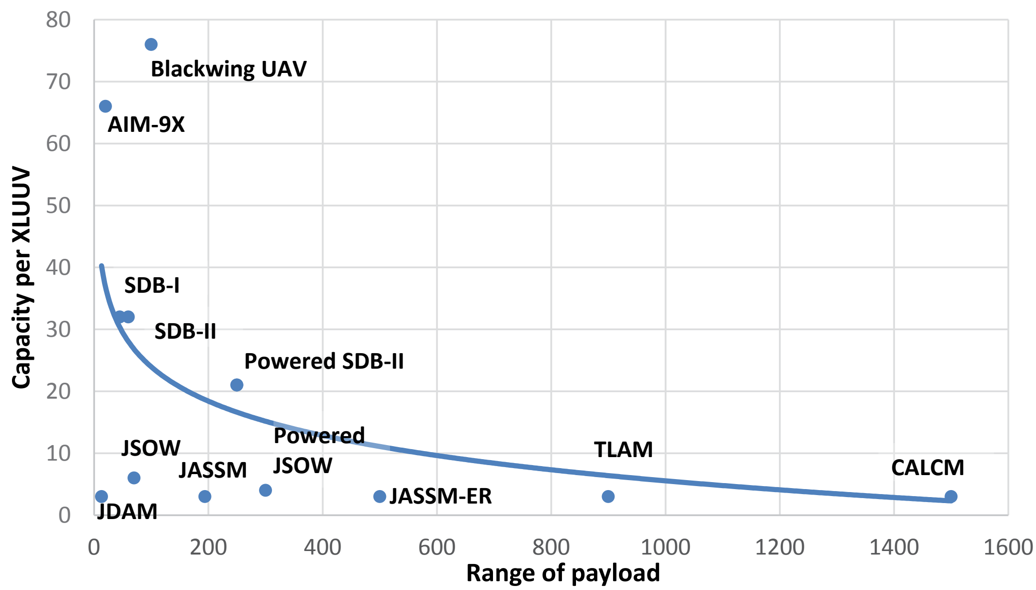
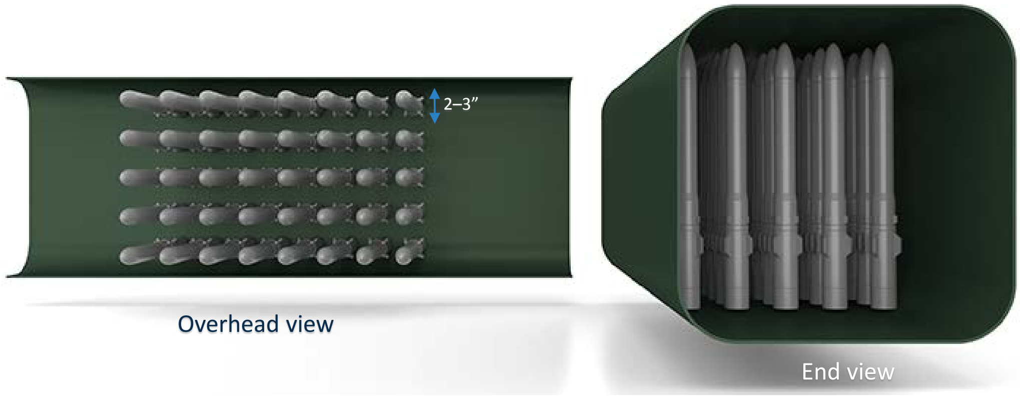


Figure 25 shows that smaller, shorter-range weapons such as a surface-launched SDB or AIM-9X could provide the largest number of weapons per XLUUV, even though they would incorporate a booster rocket. This results in part from their shorter length, which would allow them to be launched vertically from an XLUUV, rather than horizontally as with TLAMs or Harpoons. Weapons such as these could enable an XLUUV to contribute to higher salvo size by exploiting its ability to get close to targets. Figure 26 depicts the loadout of smaller weapons using vertical launchers in a XLUUV payload module.

71 Figure 22 assumes the total payload capacity of an XLUUV is 20,000 lbs., half of which is used for the framing and launch mechanisms for weapons or UAVs. Strike weapons are assumed to have a booster that weighs 50 percent of the total weight of the weapon, and UAVs are assumed to include a 100-lb. launch mechanism. This formula is consistent with current sea-launched weapons, but tends to result in heavier estimates for weapon configurations that already exist. This was deemed as acceptable because it would be more conservative than assuming lighter and more numerous weapons or other expendables.

FIGURE 26: XLUUV CONFIGURATION WITH SHORT-RANGE WEAPONS



DoD's current portfolio of smaller, shorter-range weapons, however, tends to have smaller warheads than its large strike weapons such as the TLAM or JASSM. This could preclude them from destroying hardened targets such as C2 (command and control) facilities or area targets such as large radar arrays or runways. They could, however, support attacks on these targets in combination with larger submarine- or air-launched strike weapons by overwhelming the capacity of an enemy's air defenses. In practice, U.S. forces could structure strike salvos with smaller weapons in the front of the salvo to deplete enemy air defense interceptors and launch larger weapons so they are in the rear of salvo attacks. Small weapons could also be effective against more fragile targets such as individual radar antennae, aircraft, and missile transporter erector launchers (TEL). For example, although a 20-pound Hellfire missile warhead will not necessarily destroy one of these targets, it could achieve a mission kill by inflicting enough damage to render it non-operational and in need of time-consuming repairs.

EMW May Be the Best Use of Undersea Payload Capacity

Even with greater weapons capacity, XLUUVs will only be able to support a limited range of strike operations. The small warheads in missiles like the Hellfire or AIM-9X will not be effective against all targets, and XLUUVs would require reliable, low-latency communications between the vehicle and its human operators to ensure positive control over attacks. Close to enemy territory, RF communications above the water are likely to be jammed or could reveal a vehicle's location, and undersea acoustic communications could be jammed or degraded by environmental factors. This would limit the locations from which XLUUVs could launch strikes.

A more versatile payload for undersea platforms would be EMW UAVs or missiles, which could support joint force surveillance, targeting, jamming, decoy, communications, or strike operations. Figure 27 depicts a strike operation using XLUUVs to launch EMW expendables in concert with large strike munitions fired from other platforms at standoff ranges.

FIGURE 27: XLUUV SUPPORT TO STRIKE OPERATIONS

EMW expendables deployed from XLUUVs would enable strike platforms to carry less of these expendables and more weapons. For instance, EMW missiles could be launched as part of a long-range salvo to improve weapons survivability. As suggested by Figure 24, a missile's size tends to increase with range until it becomes essentially a small unmanned aircraft like the TLAM or Conventional Air-Launched Cruise Missile (CALCM). These cruise missiles weigh about 2000 lbs., half of which is warhead. An EMW missile, therefore, would likely need to weigh approximately 1000 lbs. to reach the same maximum range. The EMW missile would take up at least half the space of a TLAM or CALCM; in practical terms, however, they may take up the same space because launch systems are not necessarily flexible enough to take advantage of the EMW missile's smaller size to carry more missiles. As a result, each EMW missile would likely reduce a launch platform's salvo size by one weapon.

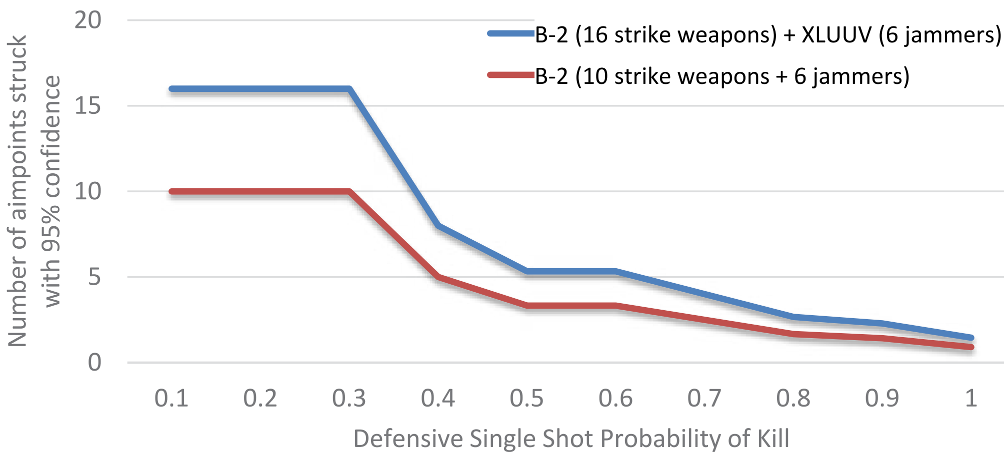
This effect is illustrated in Figure 28, which assumes that each jammer in a salvo launched by a B-2 or XLUUV reduces an enemy's air defense SSPk by 0.02.[72] It also shows that when a B-2 weapons payload includes both jammers and strike munitions, the benefit of adding jammers to its salvo is diminished by the resulting reduction of the B-2's strike capacity.

72 This is an assumed number for illustrative purposes only.

FIGURE 28: NUMBER OF WEAPONS REACHING AIMPOINTS FROM A B-2 SALVO

Figure 29 illustrates the potential *increase* in offensive capacity created by combining jamming expendables from an XLUUV with a full payload of strike weapons from a B-2.

FIGURE 29: NUMBER OF WEAPONS REACHING AIMPOINTS FROM A B-2 SALVO SUPPORTED BY EMW EXPENDABLES FROM AN XLUUV



Shifting decoys and jammers to XLUUVs could reduce costs by exploiting the XLUUV's ability to approach an enemy's coastline closely. XLUUVs operating close to an enemy's coastline may be able to carry small, short-range UAVs like the Coyote that are less expensive than long-range EMW missiles.[73] And because they would travel shorter distances in highly contested environments, small EMW expendables may not need the survivability enhancements of longer-range missiles like MALD.

Another advantage of using XLUUVs to launch EMW expendables, rather than weapons, is its ability to remain on station. An XLUUV that generates a salvo large enough to overcome advanced air defenses will most likely have to rearm before a subsequent attack could be launched. Since XLUUVs would not be able to rearm at sea, they would need to undertake a time-consuming and hazardous transit out of a combat zone to a rear area to reload. Launching small EMW expendables from undersea platforms would help make the most of their limited magazine capacity. Small UAVs with long loiter times may even be able to provide ISR or EW for multiple strikes. For example, a Coyote UAV can operate for 1.5 to 3 hours.[74] In the case depicted by Figure 26, the XLUUV will have only used up 38 percent of its payload and can remain on station to support further strikes.

Finally, launching EW expendables, rather than weapons, from XLUUVs would reduce command and control complexity. Due to salvo size constraints of XLUUVs, strikes against defended targets would require several XLUUVs with larger weapons or an XLUUV in support of manned strike platforms carrying large weapons. The need to coordinate the launch of strike salvos, particularly collaborative ones, from multiple XLUUVs would be a very difficult command and control challenge unless the XLUUVs are positioned near an established communications node such as the Forward Deployed Energy and Communications Outpost (FDECO) or a manned platform such as a submarine. Moreover, current policy may preclude using XLUUVs to launch weapons.

Countering Enemy Search and Targeting Operations

EMW expendables delivered by undersea platforms can improve the ability of U.S. forces to conduct small, precise strikes against Russian or Chinese sensor and weapon networks during gray zone confrontations. This will provide U.S. forces another rung on the escalation ladder, as shown in Figure 8. These approaches must be complemented by EMW concepts and capabilities to degrade the ability of Chinese and Russian sensor networks to find, target, and engage U.S. forces. As described in Chapter 2, although these efforts will not completely hide U.S. forces, they could increase the salvo size needed for an enemy to ensure a successful attack, removing their possibility of conducting a limited strike.

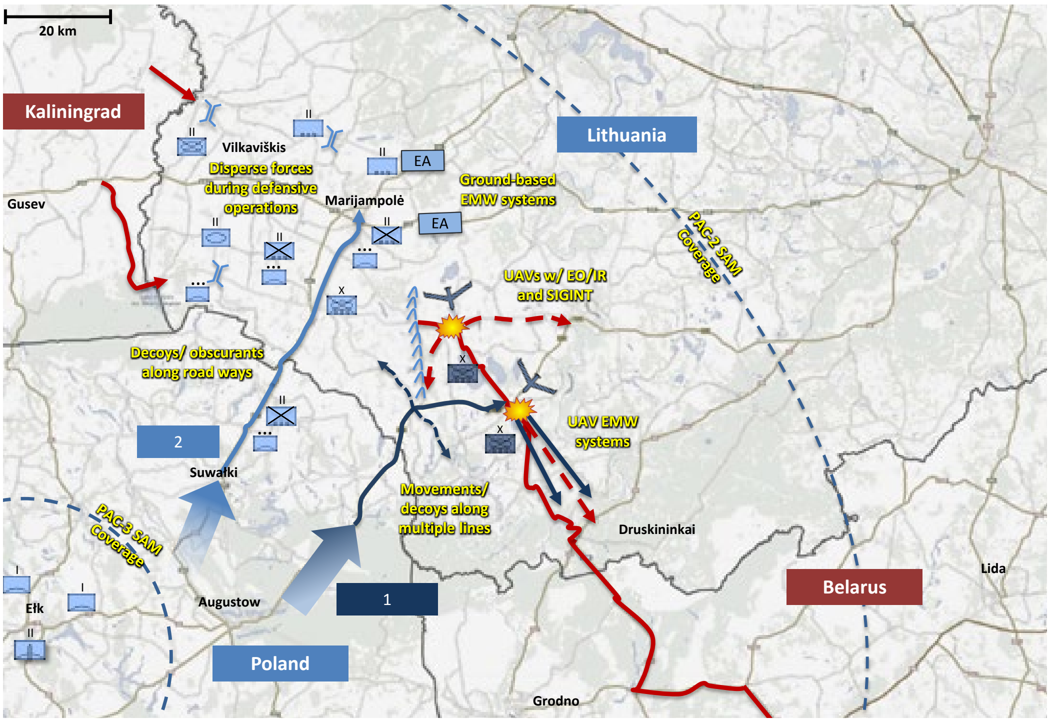
The most challenging counter-ISR scenarios are likely for ground operations. As shown in Figure 2, Russian sensor coverage is very dense in Eastern Europe; this includes active and

73 A single MALD-J cost over $366,000 in 2015. A Coyote UAV costs $15,000, and an engine-less loitering munition with a booster rocket and sufficient power to support a miniature EW system could likely be purchased for less than $150,000 per unit.

74 "BAE Systems/Sensintel Coyote," UAVGlobal factsheet, available at http://www.uavglobal.com/sensintel-coyote/.

passive EM sensors associated with Russian military and paramilitary units. Figure 30 depicts an operation in this environment to defeat Russian forces in the Suwalki Gap, the 60 nm-wide border territory between Lithuania and Poland that separates Russia's ally Belarus from Russian Kaliningrad. In the depicted scenario, NATO forces 1 and 2 are attempting to defend the gap and interdict Russian forces crossing from Belarus to Kaliningrad.

FIGURE 30: EMW SOS OPERATIONS IN BALTIC GROUND COMBAT SCENARIO



To protect ground units in this scenario, U.S. forces would need to use EMW SoS that combine countermeasures to reduce friendly force signatures with decoys to create viable false targets. Using countermeasures and decoys in concert allows them to reinforce each other, reducing the effectiveness needed in each individual system and lowering the cost and complexity of the overall SoS. Specific elements of an EMW SoS, which could also be used to protect naval forces in contested maritime areas, are described in more detail below.[75]

75 The use of these approaches and technologies is described expertly in Jonathan F. Solomon, "Maritime Deception and Concealment: Concepts for Defeating Wide-Area Oceanic Surveillance-Reconnaissance-Strike Networks," *Naval War College Review* 66, no. 4, Autumn 2013.

Reduce Friendly Force Signatures

The following are operational approaches and capabilities that, in combination, would reduce the signatures of friendly forces and hence degrade the ability of an adversary to find and target U.S. and allied forces. More importantly, reducing signatures degrades the enemy's ability to classify and identify targets, and therefore differentiate them from decoys, which will slow its targeting efforts or require larger salvos to quickly attack all the viable targets.

Dispersal and movement. U.S. and allied forces would need to disperse around staging and movement areas to increase the number of potential targets and slow enemy classification and identification. Dispersal will also shrink the size of individual ground force concentrations, which reduces their EM signature, enables them to more easily hide in terrain and foliage, and can help decoys to look more genuine. Once ordered to advance, friendly forces would move along multiple routes to sustain their dispersal and enable decoys to be employed away from concentrations of actual forces. Dispersal will incur a cost in the form of more complex and expensive logistics support.

Camouflage. Multi-spectral camouflage is improving, mostly through research and development by American allies and partners. They could be a viable source of new camouflage technologies for DoD.[76] New materials, such as those used in Saab Barracuda's Mobile Camouflage System, can obscure a target from EO, medium-wave IR (MWIR), and long-wave IR (LWIR) sensors. Camouflage can also incorporate metallic fibers to help defeat radar. Figure 31 shows a typical standard camouflaged shelter. Figure 32 depicts a MWIR image of an armored vehicle that is covered with IR camouflage (circled on the left) and a second armored vehicle covered with standard visual camouflage (circled on the right).

Maneuver forces could be equipped with malleable mobile camouflage systems that do not inhibit the operation of vehicles even while the vehicles are in motion. Relocatable systems such as artillery pieces could be covered with multi-spectral camouflage netting. As described in Chapter 2, camouflage should not be expected to completely hide a real vehicle or system. Instead, camouflage should be used on both real and decoy systems to make differentiating between them difficult. Adversaries could then be compelled to attack both real and decoy targets or delay attacks to further assess the operational picture. This technique would also allow forces to use decoys and camouflage that are less sophisticated and less expensive.

76 "MCS Mobile Camouflage System: Protection on the Move," Saab Barracuda factsheet, available at http://saab.com/land/signature-management/platform-integrated-systems/mcs_mobile_camouflage_system/; and "Welcome to the World of Camouflaging," Raksha Supreme Inc. homepage, available at http://www.rakshasupreme.com.

FIGURE 31: TYPICAL CAMOUFLAGE SHELTER

U.S. Army photo by Sgt. Michael J. MacLeod.

FIGURE 32: IR CAMOUFLAGE (LEFT IMAGE)

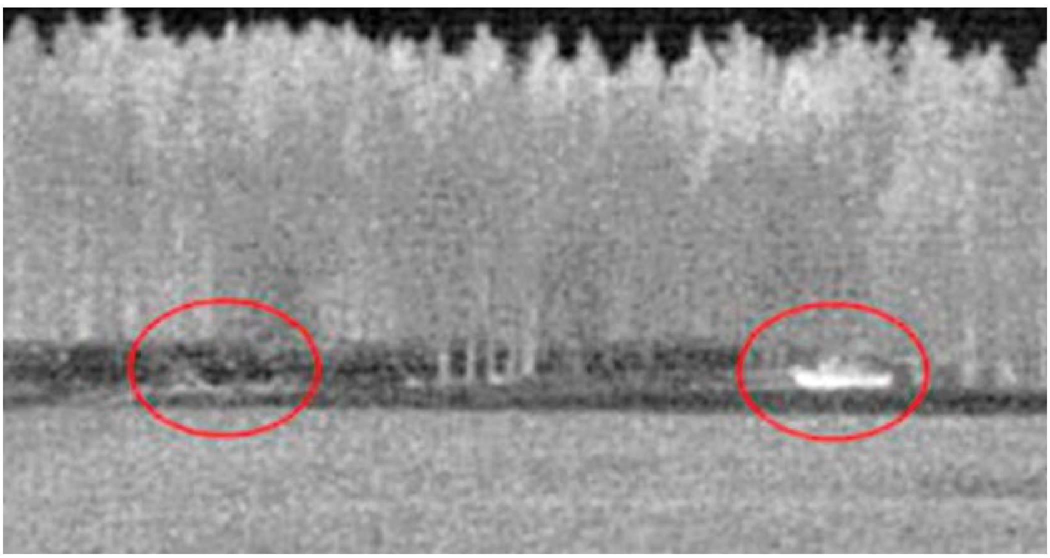


Image courtesy Saab Barracuda.

Obscurants. Camouflage may be impractical or too expensive to use on large, mobile platforms such as ships or larger ground formations. Smoke and other obscurants could be used to reduce the signature of a vehicle, ship, or formation by reflecting or absorbing EM energy emanating from the target or being used by the enemy to find the target (such as IR energy and radar, respectively). New obscurants are improving their capability by incorporating new particles with higher extinction coefficients and materials that can reflect MWIR, LWIR, UV (ultraviolet), and MMW (millimeter wave) RF energy.[77] In addition to obscuring the signature of the real or decoy system being protected, obscurants may also compel attackers to shift from passive EO/IR sensors to active RF seekers that would be easier for friendly forces to detect and deceive through jamming. Figure 33 shows the U.S. Navy testing a carbon fiber-based obscurant fog that could be effective in defensing against anti-ship missiles.[78]

FIGURE 33: OBSCURANT TESTING

U.S. Navy photo by Timothy Wilson.

77 Frank D. Chapman and Andrew Reichert, "Obscurants and Electronic Warfare," *Chemical Review,* Winter 2011, available at http://www.wood.army.mil/chmdsd/images/pdfs/Winter%202011/Chapman-Reichert.pdf.

78 Eric Slavin, "Navy Looks to Advancements in 'Fog of War' for Missile Defense," *Stars and Stripes*, July 3, 2014, available at https://www.stripes.com/news/navy-looks-to-advancements-in-fog-of-war-for-missile-defense-1.291850#.WcAH09VSyUm. For more on obscurants developed by the U.S. Army, see "ECBC Demonstrates First Prototype of Multi-Colored Smoke Grenade," news release, Edgewood Chemical Biological Center, U.S. Army, September 3, 2014, available at https://www.ecbc.army.mil/news/2014/ECBC-Demonstrates-First-Prototype-Multi-Colored-Smoke-Grenade.html.

Emerging UV sensors are a challenge for active countermeasures like jammers or lasers, because they look for areas of reduced UV energy that would indicate a target's presence rather than looking for UV energy reflected from the target. Obscurants could be used instead of lasers against UV sensors to create areas of low UV energy that would act as decoys, resulting in a larger number of potential targets for the enemy to assess and engage.[79]

In general, an obscurant becomes more effective as the amount of obscurant between a target and a sensor increases. Although obscurants can be dispensed by each platform that needs protection, dispensing them from a separate vehicle could help compensate for wind and weather effects. An obscurant cloud could be positioned where it can best protect multiple vehicles that could be targeted by an enemy. Unmanned ground vehicles (UGV) or unmanned surface vehicles (USV) would be well suited to this role because they could carry large amounts of obscurants and their dispensing systems. A few artillery-launched smoke and obscurant rounds could also provide protection from standoff ranges for friendly sensors or air defense system emplacements.[80] Like camouflage, obscurants would need to be deployed around both actual and decoy forces to increase the number of targets the enemy must prosecute or investigate.

Counter-EO/IR lasers. As described in Chapter 2, EO/IR sensors on satellites, UAVs, and manned aircraft are likely to provide enemy forces with persistent surveillance coverage over large areas of interest such as Eastern Europe or the South and East China Seas. Relying on temporary obscurants and camouflage to protect every U.S. vehicle, system, and decoy in these areas may be infeasible.

To complement these passive countermeasures, U.S. ground or naval forces could employ lasers to degrade or damage the focal plane arrays or charged coupled devices (CCD) used as detectors in EO/IR sensors. These lasers, also called dazzlers, could be relatively low power and carried by UGVs or USVs.

EO/IR sensor dazzlers could be modeled after the laser-based systems used today to protect aircraft from EO/IR missiles such as the Directional Infrared Countermeasures (DIRCM) or Common Infrared Countermeasures (CIRCM) programs.[81] Furthermore, systems like DIRCM and CIRCM will need to be added to force packages to protect ships, vehicles, and dismounted troops as militaries expand the use of EO/IR missiles to circumvent improving RF countermeasures.

79 David Axe, "Navy Wants Ultraviolet Cloaking Device for Jet Fighters," *Wired*, May 9, 2012, available at https://www.wired.com/2012/05/navy-uv-cloak/.

80 Chapman and Reichert, "Obscurants and Electronic Warfare," p. 22.

81 "AN/AAQ-24(V) DIRCM (Directional Infrared Countermeasure)," Northrop Grumman Corporation factsheet, available at http://www.northropgrumman.com/Capabilities/DIRCM/Pages/default.aspx?utm_source=PrintAd&utm_medium=Redirect&utm_campaign=LaserDIRCM_Redirect.

Radar jammers. Overhead airborne or space-based radars, such as synthetic aperture radars (SAR), are used to image features and potential targets on the ground or in the water. Jammers, including those using DRFM technology, could obscure the signatures of real and decoy systems. The developmental Army's Multifunction EW (MFEW) program is repurposing jammers used to defeat radio-controlled improvised explosive devices (RCIED) to jam a wide range of frequencies used by overhead radars. MFEW systems could be mounted on UGVs to displace the jamming source from actual units, reducing the risk from enemy passive sensors and weapons attacking the jammer.[82]

Jammers could also be useful against individual RF-guided weapons launched at U.S. ground or naval forces. EW systems like the Navy SLQ-32 Surface Warfare EW Improvement Program (SEWIP) confuse or blind an RF-guided missile's seeker to cause it to miss the target.[83] This reduces the likelihood an enemy achieves a hit and increases the salvo size it needs to launch to ensure it overcomes U.S. kinetic and non-kinetic defenses. Today, most anti-armor and counter-personnel weapons are GPS or EO/IR-guided. One of the additional benefits of camouflage and obscurants would be to compel adversaries to shift to RF-guided weapons that are susceptible to jammers.

Communication jammers. Human intelligence and third-party targeting is already a threat to U.S. ground forces and increasingly to naval forces. U.S. EMW SoS could include SIGINT and communications intelligence (COMINT) systems to monitor enemy communications and identify potential cueing or targeting operations. Systems such as the Navy's Ship's Signal Exploitation Equipment (SSEE) or the Army's future MFEW could conduct COMINT and jam voice or data signals.[84] Systems like SSEE installed on ships today are relatively low power and could also be carried by UGVs, USVs, or UAVs to operate closer to targets areas and enable communications jamming without exposing friendly forces to counter-detection.

Emission controls. Since the Cold War, U.S. forces have operated with little regard for enemy SIGINT and ELINT satellites, aircraft, and ground sensors. Even if an enemy had sensors that could detect RF emissions, U.S. forces assumed they would not be capable of geolocating the source of the signals with quality targeting accuracy or link that information to long-range precision weapon systems.[85]

As described in Chapter 1, the situation has clearly changed. U.S. naval and ground forces deploying to the Western Pacific or Eastern Europe routinely operate with EMCON measures

82 Sydney J. Freedberg Jr., "Army's New Rapid Capabilities Office Studies Electronic Warfare Boost," *Breaking Defense*, July 1, 2016, available at http://breakingdefense.com/tag/mfew-multi-function-electronic-warfare/.

83 "Surface Electronic Warfare Improvement Program (SEWIP)," U.S. Navy Fact File, January 30, 2017, available at http://www.navy.mil/navydata/fact_display.asp?cid=2100&tid=475&ct=2.

84 "New Cryptology Training Readies Sailors for Fleet Missions," news release, Center for Information Dominance Public Affairs, U.S. Navy, April 14, 2016, available at http://www.navy.mil/submit/display.asp?story_id=94173.

85 Sydney J. Freedberg Jr., "Invisible Bullets: The Navy's Big Problem in Future War," *Breaking Defense*, January 27, 2016, available at http://breakingdefense.com/2016/01/invisible-bullets-the-navys-big-problem-in-future-war/.

that reduce their vulnerability to detection and geolocation by Chinese and Russian passive RF sensors, respectively. EMCON would be an essential component of a future EMW SoS.[86]

Acoustic jammers. Sonar is increasingly the most important sensor for naval forces. EMCON can prevent ELINT and SIGINT detection, and jammers can defeat radar, but ships cannot completely stop making sound underwater. Their movement causes flow noise, their propellers cause cavitation, and discrete tonals will come from rotating equipment such as pumps and motors. Sound also travels over the horizon as it refracts through the water column and bounces off the ocean surface and bottom.

Although sound is not EM energy, U.S. counter-ISR approaches will need to address adversary seabed sonar arrays as well as sonars deployed by enemy ships, submarines, and helicopters. For this reason, the PLA considers hydro-acoustic confrontation to be an element of electronic warfare and addresses it as part of the PLA's electronic warfare and cyber warfare doctrine and organizations.[87]

U.S. EMW SoS could use acoustic jammers to raise the noise level in the water to mask friendly forces from passive sonar. It could also confuse an enemy's active sonars, as RF jammers confuse radar. Jammers would be best deployed on UUVs to maintain the geometry between enemy sonars, jammers, and U.S. ships and submarines that is needed to mask friendly forces without inadvertently illuminating them like an active sonar would.

Resilient and LPI/LPD communications. To coordinate operations while in EMCON, ground, air, and naval forces can use mission-type orders—in which individual units pursue objectives based on the intent of the overall operational commander—and pre-plan deconfliction and responses with one another. U.S. forces could also use LPI/LPD line-of-sight (LOS) datalinks such as Multifunction Advanced Datalink (MADL), Tactical Targeting Network Technology (TTNT), or optical laser or LED communication systems.

LOS communication systems are less vulnerable to detection and jamming by enemy forces seeking to disrupt the coordination of U.S. and coalition operations. Because of their low power and directionality, their signals are short range and unable to reach receivers that are over the horizon or obscured by terrain. The U.S. military could use several relay approaches to enable LOS voice and datalink communications between its dispersed forces.

High-altitude long endurance UAVs such as the MQ-4A Global Hawk or MQ-4C Triton that have a field of view of more than 250 nm in each direction[88] would enable them to relay LOS communications across an entire theater such as the Baltic Sea region or the South China Sea. These UAVs could, however, be vulnerable to enemy air defenses.

86 Robinson Harris and Andrew Kerr, "It's Déjà vu All Over Again," *U.S. Naval Institute Blog*, June 7, 2017, available at https://blog.usni.org/posts/2017/06/07/distributed-lethality-and-sea-control-its-deja-vu-all-over-again.

87 Ye Zheng, *Lectures on the Science of Information Operations* [Chinese] (Beijing: Military Science Press, 2013), pp. 7–8.

88 This is assuming an altitude of 60,000 feet, resulting in a distance to the horizon of about 280 nm.

Mobile ground-based HF radios and tropospheric scatter microwave systems could be used, as they were in the Cold War, to broadcast to deployed forces located hundreds of miles over the horizon. Because these systems use atmospheric reflection and scattering to propagate over the horizon, their signals are diffuse and difficult for an enemy to either jam or use to geolocate transmitters. Figure 34 shows a typical troposcatter system, the Raytheon Tactical Extension of Line-of-Sight (TELOS).

FIGURE 34: TELOS TROPOSCATTER COMMUNICATION SYSTEM

Photo courtesy of Raytheon.

Offset airborne transmitters could reduce the likelihood that the source of long distance communications would be accurately localized. A small, low-altitude UAV could be launched by a C2 platform, fly a kilometer or two away, and relay communications sent from the C2 platform to other vehicles, aircraft, or ships in a formation. Communications could be transmitted from the C2 platform to the UAV through an LPI/LPD optical or RF signal before being re-transmitted by a UAV using an RF signal. This system would increase the likelihood that if enemy forces localized the source of the transmissions (i.e., the UAV), they would attack the area below the UAV instead of the originated C2 platform.

Creating Viable False Targets

Because signature reduction efforts and countermeasures will not be perfect, EMW SoS will also need to include decoys to create viable false targets. This will increase the number of potential targets Russian or Chinese forces would need to engage, as well as the number of weapons required. As a result, their strikes would need to be larger and more escalatory.

Visual and IR decoys. Lightweight rigid and inflatable decoys can simulate ground vehicles, artillery pieces, or aircraft. Figure 35, shows a decoy F-16 Viper strike-fighter (bottom of the picture) next to a real F-16. With a clear photographic-quality visual and time to carefully inspect the image, it is apparent which image is a decoy and which is a real aircraft. If *both* were covered with camouflage or an obscurant, or if an enemy sensor was degraded by jamming or dazzling, the two platforms may look sufficiently alike to require detailed measurement and signature intelligence (MASINT) to distinguish the real aircraft from the decoy. If the attacker does not have time for MASINT analysis before a strike, it would be compelled to use enough weapons to destroy both aircraft as well as defeat the defenses expected to protect them. The resulting geometric increase in required salvo size could exceed what the enemy is willing to expend on that attack.

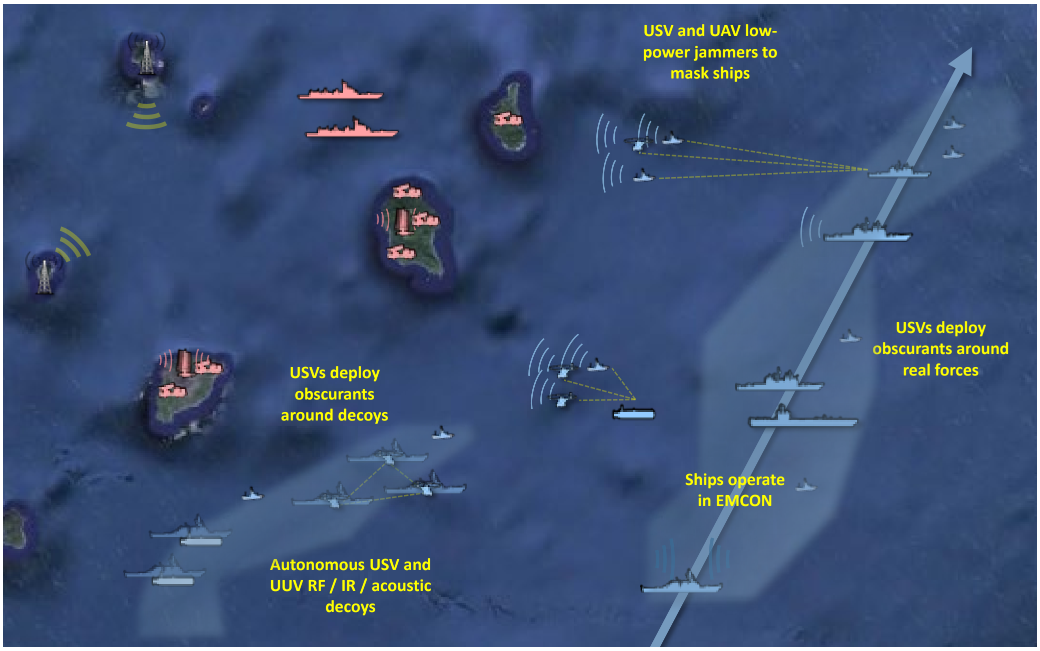
FIGURE 35: REAL (UPPER) AND DECOY (LOWER) F-16

U.S. Air Force photo.

Decoys are improving in their visual accuracy and ability to emulate RF and IR signatures. They are not, however, highly mobile. Decoys that are able to keep up with the maneuver force and maintain their signatures could be too expensive to be expendable or use in large numbers. Instead, maneuver units could use less capable physical decoys that can be quickly deployed and rapidly broken down when they need to move.

Naval visual or IR decoys are more challenging, since ships are much larger and are normally always in motion. Instead of using visual or IR decoys, U.S. forces could create viable false naval targets using RF emulators as well as radar and acoustic decoys, then cover them with sensor jamming and obscurants to hide the absence of a visual or IR decoy. Figure 36 shows a naval application of an EMW SoS near the Spratly Islands in the South China Sea.

FIGURE 36: NAVAL EMW SOS OPERATIONS IN THE SOUTH CHINA SEA



RF decoys. Jammers and obscurants can degrade the ability of radars to detect ships, vehicles, or other surface platforms. Their use is also likely to attract an enemy's attention to the defended area. To complicate enemy search and targeting and increase the number of targets to be engaged or investigated, U.S. forces must also deploy unmanned decoys that will mimic the RF emissions and radar returns of real platforms—and cover them with jammers and obscurants.

EMW SoS could include decoy systems like those on the Nulka ship-launched decoy, or the Office of Naval Research's Advanced Offboard EW (AOEW) UAV that provides a radar return consistent with a simulated target. These could be combined on USVs, UGVs, or UUVs carrying the Navy's Integrated Cover and Deception System (ICADS) and other capabilities that emulate the radar and radio signals from a real ship, aircraft or ground unit.[89]

Acoustic decoys. Similar to EMW operations above water, acoustic jammers undersea need to be complemented by high-fidelity acoustic decoys to create additional targets for the enemy to investigate or attack. Compared to RF and visual decoys, acoustic decoys could achieve higher levels of fidelity because they do not need to simulate the physical dimensions of a target. Acoustic decoys for surface ships could be used on USVs or UUVs in concert with RF decoys and radio emulators to prevent enemies using radar or ELINT sensors to quickly differentiate real targets from decoys.

89 Jonathan F. Solomon, *Defending the Fleet from China's Anti-Ship Ballistic Missile: Naval Deception's Roles in Sea-Based Missile Defense*, thesis (Washington, DC: Georgetown University, 2011), p. 56.

An XLUUV or USV using an electronic sound generator or a physical propulsion system could mimic the broadband flow noise or propeller cavitation noise a surface warship makes. Electronic sound generators could also be used to generate narrowband sounds coming from specific equipment on a surface ship or submarine, similar to decoys that are now used to train submarine crews and test torpedo operations.[90] Against active sonars, an acoustic decoy could use signal processing that mimics the active sonar return from a real ship or submarine.

Computer network emulators. Capable adversaries such as the PLA and Russian military would be expected to gain access to and monitor U.S. unclassified and possibly classified computer networks. This access could enable them to monitor C2 systems such as the Distributed Common Ground System (DCGS) or Blue Force Tracker and determine the true disposition of U.S. and allied forces. To prevent an enemy from using these systems to quickly circumvent signature reduction and decoy operations, U.S. forces will need to employ concepts and capabilities to simulate the computer network activity of deployed forces. This may include simulating false targets in DCGS and Blue Force Tracker, as well as placing emulators in operating areas to mimic the use of local telecommunication networks by simulated U.S. and allied forces.

90 "Mk-30 Expendable Mobile Anti-Submarine Warfare Training Target (EMATT)," U.S. Navy Fact File, June 15, 2016, available at http://www.navy.mil/navydata/fact_display.asp?cid=50&tid=300&ct=2.

CHAPTER 4

Conclusion

The advent of Informationized Warfare, New Generation Warfare, and gray zone operations create new challenges for the U.S. military. Most significantly, these approaches are designed to pursue military objectives against American allies and partners incrementally without reaching a level of violence that would justify a large-scale U.S. military response. As evidenced by Russia's efforts in Ukraine and Georgia or China's actions in the South and East China Sea, the combination of modest military goals and low-intensity warfare can leave the United States few options to assist a friendly state under pressure from a more-powerful neighbor.

An essential element of new Chinese and Russian warfighting strategies is their ability to protect low-intensity military and paramilitary operations with networks of long-range sensors and weapons that would enable precise, small-scale attacks against U.S. and allied forces attempting to intervene on behalf of a beleaguered ally. To protect a response under this threat, U.S. forces would need to suppress or roll back adversary A2/AD capabilities, which could escalate what had been a small-scale confrontation. Otherwise, U.S. forces would need to deploy in large formations that are able to defend themselves, which could also be escalatory. Due in part to this risk, American leaders have thus far been reluctant to intervene directly in Russian or Chinese low-intensity aggression against their neighbors.

To restore U.S. escalation dominance, U.S. leaders need the option of degrading Chinese or Russian sensor and weapon networks with small, less-escalatory attacks and denying Russia or China the option of conducting scalable precision strikes against U.S. forces. DoD could accomplish this by implementing new EMW concepts and capabilities.

Small EMW expendables, individually and in swarms, could be used by U.S. forces to increase the survivability of strike platforms and munitions, improving the ability of weapons to reach their intended targets. As a result, attacks against Russian or Chinese sensors and weapon networks could be smaller and less escalatory than air defense suppression or roll-back campaigns that rely on widespread destruction of enemy systems. If U.S. attacks are small enough or use only EMW effects, they may be difficult for an adversary to attribute, as well.

EMW SoS could drive up the salvo size an aggressor must use to successfully attack U.S. forces, which would remove the option for China or Russia to threaten or conduct small, precise attacks against U.S. forces intervening in gray zone aggression. Reducing the signatures of U.S. air, naval, and ground units and creating viable false targets would increase the number of targets an adversary would need to engage. EMW systems could also defeat individual weapons launched against U.S. ships, aircraft, troops, or vehicles, increasing the number of weapons needed to destroy each target. Together, these EMW SoS would increase the required salvo size for a successful attack against U.S. forces beyond what the aggressor is willing to expend. Moreover, an attack of that scope would not be consistent with the warfighting approaches China or Russia are pursuing, as they would likely provide justification for a wider and more robust response by the United States and its coalition partners.

In summary, DoD should pursue the following actions to counter new forms of warfare adopted by China and Russia:

- Develop planning scenarios and overall strategies to address Informationized Warfare, New Generation Warfare, and gray zone warfare;
- Build operational concepts focused on the use of EMW capabilities for these forms of warfare;
- Establish technical concepts and capability requirements for offensive and defensive EMW SoS rather than individual capabilities;
- Use impact on salvo size as a metric for EMW SoS rather than the probability that targeted sensors will be defeated. For example, an offensive EMW SoS should reduce the needed salvo size for strikes, whereas a defensive EMW SoS should increase the salvo size needed for enemy attacks;
- Increase investment in EMW SoS components that create advantages for U.S. forces in salvo competitions and support operational concepts that respond to new forms of warfare;
- Use changes in DoD governance such as the EW Executive Committee and Chief Information Warfare Officer to accelerate development of new concepts and requirements as well as prioritize investments in the right EMW capabilities.

The U.S. military needs to be prepared for a wide range of potential future operations and contingencies. The advent of new forms of low-intensity aggression does not imply that high-end warfare will never happen. In the current period of great power competition, however, DoD must address the approaches its adversaries are pursuing and will continue to use unless America can develop a more effective response. The electromagnetic spectrum is where that response should largely occur.

LIST OF ACRONYMS

AARGM	Advanced Anti-Radiation Guided Missile
AOEW	Advanced Offboard EW
ARC	Adaptive Radar Countermeasures
ARM	anti-radiation missile
ASCM	anti-ship cruise missile
ASROC	anti-submarine rocket
ASW	anti-submarine warfare
ATACM	Army Tactical Missile
BDA	battle damage assessment
BLADE	Behavioral Learning for Adaptive Electronic Warfare
C2	command and control
C3ISR	command, control, communications, intelligence, surveillance, and reconnaissance
CALCM	Conventional Air-Launched Cruise Missile
CAP	combat air patrol
CCD	camouflage, concealment, and deception
CCD	charged coupled devices
CG	aircraft carrier
CHAMP	Counter-electronics HPM Advanced Missile Project
CIRCM	Common Infrared Countermeasures
COA	courses of action
CODE	Collaborative Operations in Denied Environment
COMINT	communications intelligence
COMMEx	Communications in Extreme Environments
CSBA	Center for Strategic and Budgetary Assessments
CVW	carrier air wing
DCGS	Distributed Common Ground System
DDG	guided missile destroyer
DIRCM	Directional Infrared Countermeasures
DoD	Department of Defense
DRFM	digital radiofrequency memory
EEZ	Exclusive Economic Zone
ELINT	electronic intelligence
EMC2	Electromagnetic Maneuver & Control Capability
EMCON	emissions control

LIST OF ACRONYMS

EMS	electromagnetic spectrum
EMW	electromagnetic warfare
EO	electro-optical
EO/IR	electro-optical/infrared
EW	electronic warfare
FDECO	Forward Deployed Energy and Communications Outpost
GPS	Global Positioning System
HF	high frequency
HPM	high-powered microwave
HPRF	high-power radio frequency
IADS	integrated air defense system
ICADS	Integrated Cover and Deception System
INF Treaty	Intermediate-Range Nuclear Forces Treaty
IR	infrared
ISR	intelligence, surveillance, and reconnaissance
JASSM	Joint Air-to-Surface Standoff Missile
JDAM	Joint Direct Attack Munition
JSTARS	Joint Surveillance Target Attack Radar System
kW	kilowatt
LACM	land attack cruise missile
LED	Light-Emitting Diode
LFA	low frequency active
LOCUST	Low-Cost UAV Swarming Technology
LOS	line-of-sight
LPI/LPD	low probability of intercept/low probability of detection
LRASM	Long-Range Anti-Ship Missile
LWIR	long-wave infrared
MADL	Multifunction Advanced Datalink
MALD	Miniature Air-Launched Decoy
MASINT	measurement and signature intelligence
MFEW	Multifunction EW
MIST	Military Imaging and Surveillance Technology
MLRS	multiple launch rocket system
MMW	millimeter wave

LIST OF ACRONYMS

MWIR	medium-wave Infrared
NATO	North Atlantic Treaty Organization
NEMESIS	Netted Emulation of Multi-Element Signatures Against Integrated Sensors
OTH	over-the-horizon
Pa	probability of arrival
PCA	Penetrating Counterair
PEA	Penetrating Electronic Attack
PGM	precision-guided munition
Pk	probability of kill
PLA	People's Liberation Army
Pn	probability of negating
RCIED	radio-controlled improvised explosive device
ReACT	Retrodirective Arrays for Coherent Transmission
RF	radio frequency
SAM	surface-to-air missile
SAR	synthetic aperture radar
SDB	Small Diameter Bomb
SEAD	Suppression of Enemy Air Defense
SEWIP	Surface Warfare EW Improvement Program
SIGINT	signals intelligence
SoS	system of systems
SoSITE	System of System Integration Technology and Experimentation
SOSUS	U.S. Sound Surveillance System
SRBM	short-range ballistic missile
SSEE	Ship's Signal Exploitation Equipment
SSN	nuclear attack submarine
SSPk	single shot probability of kill
SUW	surface warfare
TEL	transporter erector launcher
TELOS	Tactical Extension of Line-of-Sight
TLAM	Tomahawk Land Attack Missile
TTNT	Tactical Targeting Network Technology
UAV	unmanned aerial vehicle
UGV	unmanned ground vehicles

LIST OF ACRONYMS

UHF	ultra high frequency
USV	unmanned surface vehicle
UUV	unmanned undersea vehicle
UV	ultraviolet
VDS	variable depth sonar
VHF	very high frequency
VLS	vertical launch system
W	watt
XLUUV	extra-large unmanned undersea vehicle

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