

# Future Warfare in the Western Pacific

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Chinese Antiaccess/Area Denial, U.S.  
AirSea Battle, and Command of the  
Commons in East Asia

The United States has long enjoyed what Barry Posen has termed “command of the commons”: worldwide freedom of movement on and under the seas and in the air above 15,000 feet, with the ability to deny this same freedom to enemies. This command has contributed to a remarkable era of military primacy for U.S. arms against potential state rivals.<sup>1</sup>

Many observers now fear that this era may be coming to an end in the Western Pacific. For more than a generation, China has been fielding a series of interrelated missile, sensor, guidance, and other technologies designed to deny freedom of movement to hostile powers in the air and waters off its coast. As this program has matured, China’s ability to restrict hostile access has improved, and its military reach has expanded. Many now believe that this “A2/AD” (antiaccess, area denial) capability will eventually be highly effective in excluding the United States from parts of the Western Pacific that it has traditionally controlled. Some even fear that China will ultimately be able to extend a zone of exclusion out to, or beyond, what is often called the “Second Island Chain”—a line that connects Japan, Guam, and Papua-New Guinea at distances of up to 3,000 kilometers from China. A Chinese A2/AD capability reaching anywhere near this far would pose major challenges for U.S. security policy.<sup>2</sup>

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1. Barry R. Posen, “Command of the Commons: The Military Foundation of U.S. Hegemony,” *International Security*, Vol. 28, No. 1 (Summer 2003), pp. 5–46.

2. Office of the Secretary of Defense, *Annual Report to Congress: Military Power of the People’s Republic of China* (Washington, D.C.: U.S. Department of Defense, 2006), pp. 21, 25; Jan Van Tol et al., *AirSea Battle: A Point-of-Departure Operational Concept* (Washington, D.C.: Center for Strategic and Budgetary Assessments, 2010), pp. x, 20, 39, 47; Evan Braden Montgomery, “Contested Primacy in the Western Pacific: China’s Rise and the Future of U.S. Power Projection,” *International Security*, Vol. 38, No. 4 (Spring 2014), pp. 115–149; Robert D. Kaplan, *Asia’s Cauldron: The South China Sea and the End of a Stable Pacific* (New York: Random House, 2014); Robert S. Ross, “U.S. Grand Strategy,

To avert this outcome, the United States has embarked on an approach often called AirSea Battle (ASB).<sup>3</sup> Named to suggest the Cold War continental doctrine of “AirLand Battle,” AirSea Battle is designed to preserve U.S. access to the Western Pacific by combining passive defenses against Chinese missile attack with an emphasis on offensive action to destroy or disable the forces that China would use to establish A2/AD. This offensive action would use “cross-domain synergy” among U.S. space, cyber, air, and maritime forces (hence the moniker “AirSea”) to blind or suppress Chinese sensors. The heart of the concept, however, lies in physically destroying the Chinese weapons and infrastructure that underpin A2/AD. As Chinese programs mature, achieving this objective will require U.S. air strikes against potentially thousands of Chinese missile launchers, command posts, sensors, supply networks, and communication systems deployed across the heart of mainland China—some as many as 2,000 kilometers inland. Accomplishing this mission will require a major improvement in the U.S. Air Force’s and Navy’s ability to find distant targets and penetrate heavily defended airspace from bases that are either hard enough or distant enough to survive Chinese attack, while hunting down mobile missile launchers and command posts spread over millions of square kilometers of the Chinese interior. The requirements for this mission are typically assumed to include a major restructuring of the Air Force to de-emphasize short-range fighters such as the F-35 or F-22 in favor of longer-range strike bombers; development of a follow-on stealthy long-range bomber to replace the B-2, and its procurement in far greater numbers than its predecessor; the development of unmanned long-range carrier strike aircraft; and heavy investment in missile defenses and information infrastructure. The result would be an ambitious modernization agenda in service of an extremely

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the Rise of China, and U.S. National Security Strategy for East Asia,” *Strategic Studies Quarterly*, Vol. 7, No. 2 (Summer 2013), pp. 32–33; Andrew Krepinevich, “China’s ‘Finlandization’ Strategy in the Pacific,” *Wall Street Journal*, September 11, 2010, <http://online.wsj.com/articles/SB10001424052748704164904575421753851404076>; Brendan P. Walsh, “Access Denied: Future Military Operations in an Anti-Access Environment” (Newport, R.I.: Naval War College, April 5, 2011); Robert Haddick, *Fire on the Water: China, America, and the Future of the Pacific* (Annapolis: Naval Institute Press, 2014); Andrew S. Erickson, “China’s Modernization of Its Naval and Air Power Capabilities,” in Ashley J. Tellis and Travis Tanner, eds., *China’s Military Challenge* (Washington, D.C.: National Bureau of Asian Research, 2012), pp. 61–125; and Andrew S. Erickson, *Chinese Anti-Ship Ballistic Missile (ASBM) Development: Drivers, Trajectories, and Strategic Implications* (Washington, D.C.: Jamestown Foundation, 2013).

3. The Department of Defense recently changed the name of these activities and research to Joint Concept for Access and Maneuver in the Global Commons. See Joint Chiefs of Staff, “Joint Concept for Access and Maneuver in the Global Commons,” Joint Staff memo, *USNI News*, January 8, 2015, <http://news.usni.org/2015/01/20/document-air-sea-battle-name-change-memo>. Following common usage in the public debate, however, we use “AirSea Battle” to refer to this program.

demanding military campaign to batter down A2/AD by striking targets deep in mainland China, far afield from the maritime domains to which the United States seeks access.<sup>4</sup>

ASB has thus proven highly controversial. Many observers object to its likely cost: a military program this ambitious will surely be very expensive in an era of increasingly restricted U.S. defense budgets.<sup>5</sup> Others cite its potential for escalation: U.S. air and missile strikes against targets deep in the Chinese mainland could easily spur retaliation against U.S. or allied homelands and a possible global war against a nuclear power.<sup>6</sup>

The need to incur any of these costs or any of these risks, however, turns on the underlying question of exactly how effective Chinese A2/AD can become.<sup>7</sup> Many mainstream arguments, on both sides of the debate, take for granted a substantial A2/AD threat: ASB advocates would respond to this threat by battering it down; many ASB opponents would avoid it via a distant blockade of China at straits beyond A2/AD's reach; both sides tend to grant A2/AD an ability to deny U.S. access to large parts of the Western Pacific absent a massive

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4. U.S. Department of Defense, *AirSea Battle: Service Collaboration to Address Anti-Access and Area Denial Challenges* (Washington, D.C.: U.S. Department of Defense, May 2013), <http://www.defense.gov/pubs/ASB-ConceptImplementation-Summary-May-2013.pdf>; and U.S. Department of Defense, *Joint Operational Access Concept* (Washington, D.C.: U.S. Department of Defense, January 17, 2012), [http://www.defense.gov/pubs/pdfs/joac\\_jan%202012\\_signed.pdf](http://www.defense.gov/pubs/pdfs/joac_jan%202012_signed.pdf). Official details on ASB remain sparse. Van Tol et al., *AirSea Battle*, is, however, widely considered a proxy for official views, and we treat it as such below. On target counts and distribution, see, for example, *ibid.*, pp. 59, 65; and Roger Cliff, *China's Military Power: Assessing Current and Future Capabilities* (New York: Cambridge University Press, 2015), pp. 100–101. Note that ASB is a general concept that could be implemented against any A2/AD threat—it could be employed in the Persian Gulf, for example, as well as the Western Pacific. Given our focus, however, we treat it in a Western Pacific context.

5. See, for example, T.X. Hammes, "Offshore Control: A Proposed Strategy for an Unlikely Conflict," *Strategic Forum*, June 2012, <http://www.dtic.mil/dtic/tr/fulltext/u2/a577602.pdf>; and Greg Jaffe, "U.S. Model for a Future War Fans Tensions with China and inside Pentagon," *Washington Post*, August 1, 2012.

6. See especially Caitlin Talmadge, "Preventing Nuclear Escalation in Conventional Conflict: The Case of the United States and China," paper prepared for the Carnegie Workshop on U.S. Nuclear Policy toward China, Washington, D.C., December 11–12, 2014. See also David Gompert and Terrence Kelly, "Escalation Cause: How the Pentagon's New Strategy Could Trigger War with China," *Foreign Policy*, August 2, 2013, <http://foreignpolicy.com/2013/08/03/escalation-cause/>; Amitai Etzioni, "The Air-Sea Battle 'Concept': A Critique," *International Politics*, Vol. 51, No. 5 (September 2014), pp. 577–596; Amitai Etzioni, "Who Authorized Preparations for War with China?" *Yale Journal of International Affairs*, Summer 2013, p. 37, <http://ssrn.com/abstract=2273837>; and Joshua Rovner, "Changing Military Dynamics in East Asia" (San Diego: University of California Institute on Global Conflict and Cooperation, January 2012).

7. It also depends, of course, on an assumption of U.S.-China competition that might yield war and for which U.S. defense planning must prepare. For the purposes of this analysis, we accept this commonplace assumption of the A2/AD/ASB debate, but we assume neither that conflict is inevitable nor that U.S.-China relations are doomed to military rivalry and aggressive arms racing.

U.S. offensive inland. Just how large a part of the Western Pacific the Chinese could close is often vague, however; many are skeptical that China can extend control all the way to the Second Island Chain, but few policy analyses have yet focused on the foundational military question of A2/AD's actual effectiveness and the range at which this capability can be expected to deny U.S. access or threaten allied shipping.<sup>8</sup>

This article thus provides a more systematic assessment of the potential military effectiveness of Chinese A2/AD. We ask not whether ASB would be escalatory, but whether it is necessary. That is, to what extent will ongoing technology trends allow either side to deny freedom of movement to the other, and over what area? Will China be able to push U.S. forces far enough from its shores to threaten U.S. alliances? If so, which ones, and how gravely? And what, given this, represents the best military strategy for the United States to adopt for the long term?

To answer these questions, we focus on the long-run potential of key technologies rather than on an assessment of existing or even programmed forces, equipment, and doctrine, and we do so in the context of an extended competition between mutually adaptive peer competitors, neither of which can simply outspend the other. The A2/AD debate is mostly about the future, not the present. For now, there is little real A2/AD threat to confront: most analysts still see U.S. naval and air superiority over the Pacific except for the immediate Chinese littoral and sometimes the airspace over Taiwan.<sup>9</sup> The Chinese today field only a handful of weapons with ranges anywhere near the Second Island Chain, and their military lacks experience in power projection beyond the vicinity of the Chinese coast. The chief reason for concern lies not in China's current arsenal, but in the trajectory of technical and acquisition trends whose maturation could take decades or even generations. Similarly, the ASB agenda for the United States is also mostly about the future: given the long service lives of warships, and the long lead times for developing new pro-

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8. Partial but important exceptions include Owen R. Coté Jr., "Assessing the Undersea Balance between the U.S. and China" (Cambridge, Mass.: Security Studies Program, Massachusetts Institute of Technology, February 2011); Montgomery, "Contested Primacy in the Western Pacific"; Thomas J. Christensen, "Posing Problems without Catching Up: China's Rise and Challenges for U.S. Security Policy," *International Security*, Vol. 25, No. 4 (Spring 2001), pp. 5–40; Michael O'Hanlon, "Why China Cannot Conquer Taiwan," *International Security*, Vol. 25, No. 2 (Fall 2000), pp. 51–86; Michael A. Glosny, "Strangulation from the Sea? A PRC Submarine Blockade of Taiwan," *International Security*, Vol. 28, No. 4 (Spring 2004), pp. 125–160; and Van Tol et al., *AirSea Battle*. None, however, treat the entire A2/AD challenge in the context of a long-term, two-sided competition wherein neither can outspend the other—the key scenario on which we focus below.

9. See, for example, James Dobbins et al., *Conflict with China: Prospects, Consequences, and Strategies for Deterrence* (Santa Monica, Calif.: RAND Corporation, 2011).

grams such as a stealthy long-range bomber to replace the B-2, the stakes in the A2/AD/ASB debate are mostly about the military prognosis for ten to twenty years from now, not tomorrow or next year. And by the time such major programs mature, faster-moving developments such as electronic countermeasures or tactical innovations may go through multiple rounds of adaptation, measure, and countermeasure, on both sides. The A2/AD debate is thus less about the military balance in 2016 or even 2020 than it is about the military future a generation from now, after an extended two-sided competition; below we use 2040 as a representative time frame for an environment with mature A2/AD technology on both sides.

Our focus on the long-term future motivates two critical framing assumptions. First, just as we cannot limit ourselves to today's Chinese arsenal, neither can we limit ourselves to today's Chinese military doctrine or current Chinese assumptions about the course of a war with the United States. Much can change in a generation. Perhaps Chinese doctrinal adaptation will be constrained by deep-seated cultural or historical factors, but twenty-five years of technological change will create strong incentives for doctrine to adapt, and it would be risky to assume that China will not respond.<sup>10</sup> We thus focus on what technology will make possible for either side, from which we infer strategies and operational concepts that would be advisable, but we leave to others whether China will act on the incentives these changes will create.<sup>11</sup>

Second, we assume that the United States cannot prevail by outspending China over this longer term. In the Cold War, the United States could do just that: a declining Soviet Union could not keep pace with Western economic growth, enabling the West to exhaust the Soviets in a protracted arms race. China, however, is not the Soviet Union: its gross domestic product is widely expected to exceed the United States' in coming years. A strategy that requires the United States to outspend a rising economic peer is unsustainable in the

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10. On Chinese strategic culture and the determinants of Chinese doctrinal choices, see, for example, Alastair Iain Johnston, *Cultural Realism: Strategic Culture and Grand Strategy in Chinese History* (Princeton, N.J.: Princeton University Press, 1989); Toshi Yoshihara, "Chinese Strategic Culture and Military Innovation," Ph.D. dissertation, Tufts University, 2004; and Andrew Scobell, *China and Strategic Culture* (Carlisle, Pa.: College Strategic Studies Institute, U.S. Army War College, 2002).

11. We thus treat technology as an exogenous systemic variable and examine its consequences. Of course technology is shaped by states and societies, which may try to redirect it strategically. We assume, however, that the technological trends underlying A2/AD and ASB are now sufficiently established to create objective systemic incentives that cut across societies. On variables that shape technology, see, for example, Wiebe E. Bijker, Thomas P. Hughes, and Trevor Pinch, eds., *The Social Construction of Technology: New Directions in the Sociology and History of Technology*, anniversary ed. (1987; Cambridge, Mass.: MIT Press, 2012).

long run: it would simply lead to faster relative economic decline and ever-greater difficulty over time in keeping up. Calls to overwhelm Chinese A2/AD with superior expenditure are self-defeating for the time horizon at the heart of this whole debate.<sup>12</sup>

Given such a long-run, two-sided assessment, we find that by 2040 China will not achieve military hegemony over the Western Pacific or anything close to it—even without ASB. A2/AD is giving air and maritime defenders increasing advantages, but those advantages are strongest over controlled landmasses and weaken over distance. As both sides deploy A2/AD, these capabilities will increasingly replace today's U.S. command of the global commons not with Chinese hegemony but with a more differentiated pattern of control, with a U.S. sphere of influence around allied landmasses, a Chinese sphere of influence over the Chinese mainland,<sup>13</sup> and contested battlespace covering much of the South and East China Seas, wherein neither power enjoys wartime freedom of surface or air movement.<sup>14</sup>

This finding derives from the physics of the key technologies coupled with inherent asymmetries in the operating environments of the land, air, and sea surface. Improvements in reconnaissance, surveillance, and target acquisition (RSTA) technology underlie much of A2/AD's defensive potential, but RSTA effectiveness varies widely with the complexity of the background against which it must detect targets. The sky and the surface of the sea present much simpler backgrounds than the land. Land-based missiles deployed amid a complex background thus enjoy systematic RSTA advantages against airborne or sea-surface foes. As RSTA improves, land-based mobile missile launchers are likely to remain much harder to target than more-exposed aerial or surface-

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12. Treating China as an equal may be unduly pessimistic. China could prove unable to employ complex military systems effectively; Chinese economic growth could falter; and China's scientists and engineers could prove less creative than the West's. The A2/AD/ASB debate, however, has tended to accept common projections of continued Chinese economic growth, and ASB advocates have typically assumed that China will use its equipment effectively. We thus accept these common assumptions, but we take seriously their implications for U.S. strategy: they make a strategy of outspending China unsustainable in a long-term competition. Our assessment can thus safely be considered an upper bound on Chinese A2/AD's real military utility, but a less slack upper bound than that of many ASB advocates.

13. Although "sphere of influence" often refers to areas beyond a state's shores, we use it here to denote the transition from China's current inability to control even its own airspace to a future in which it will be able to do so, emphasizing the parallels between the military dynamics of A2/AD on the two sides of a future conflict.

14. In this scenario, sea control or exclusion elsewhere will be determined by more traditional naval power projection (wherein the U.S. Navy is likely to enjoy important advantages for a long time to come).



naval combatants of comparable sophistication. This asymmetry will make it increasingly expensive to sustain air or sea-surface operations over or near hostile territory defended by such missiles. The same underlying asymmetry, however, makes effective A2/AD control of the air or sea surface harder the farther away from a controlled landmass it must reach. For long-range RSTA, radar is essential and is likely to remain the most robust solution to the demands of sensing mobile targets over wide areas in a long-term competition. Radar, however, is inherently vulnerable as an active emitter whose physics require an unobstructed line-of-sight to the target for location information precise enough to direct weapons. Whereas mobile missiles can launch from concealment amid complex terrain, radar must reveal its location through the act of sensing. Radar can be defended, but its defenders must themselves survive preemptive attack; the farther one must operate from a friendly shoreline, the more challenging this defensive requirement becomes and the more difficult it becomes to provide the RSTA needed for A2/AD to control the air or sea surface. A2/AD's achievable reach will vary over time, but it will be especially difficult for either China or the United States to extend A2/AD's reach beyond about 400–600 kilometers from a friendly coast, a limit defined by the Earth's curvature and the physical horizon this establishes for airborne radar operating over survivable land-based protectors. Reach on this scale, however, falls far short of what either side would need to dominate a theater the size of the Western Pacific.

These findings imply that, with astute U.S. policies, A2/AD is not a decisive long-term threat to most U.S. allies in the region. Japan, South Korea, and the Philippines are all either mostly or entirely beyond the likely reach of Chinese A2/AD given appropriate allied military choices. The threat to U.S. alliances often raised in the A2/AD literature can thus be mostly averted even without ASB.

Our analysis is not, however, a straightforward good-news story for the United States and its allies. Taiwan, for example, is much closer to the Chinese mainland than Japan, South Korea, or the Philippines, and it is much more exposed to a Chinese A2/AD threat that U.S. arms are unlikely to be able to preempt. Its proximity to China will not necessarily expose Taiwan to a credible invasion threat—the same technologies that enable Chinese A2/AD will enable Taiwan, with U.S. assistance, to extend its own A2/AD zone around the Taiwanese landmass in a way that would make a Chinese amphibious invasion prohibitively costly. But while Chinese military shipping would not be able to survive long enough to sustain an invasion, China could prevent

Taiwanese or neutral shipping from sustaining the Taiwanese economy. The fate of Taiwan in such a contest would rest on the threat of distant blockade by the United States against Chinese seaborne trade and the relative vulnerability of insular Taiwan and continental China to trade cutoffs. If AirSea Battle could preempt Chinese A2/AD, this scenario could be avoided—but it cannot. To do so would require sustained penetration of defended airspace on a scale that A2/AD will make cost-prohibitive by 2040; it is unlikely that ASB would be able to lift a Chinese blockade of Taiwan once China deploys mature A2/AD capability.

Second, our analysis does not indicate that Japan, South Korea, and the Philippines—or for that matter Vietnam, Singapore, or even Australia and the continental United States—will be wholly invulnerable to Chinese coercion. Technological change is progressively reducing the net cost of striking fixed targets such as power plants, cities, transportation hubs, or other civilian value targets with precision-guided ballistic missiles at ever-increasing ranges. This change will not enable A2/AD-like military control at great distances from China or the landmasses of U.S. allies, but it will make a form of coercive strategic bombardment available to any state that chooses to field the needed missiles, including China. Of course, China would be vulnerable to retaliation, either in kind or from distant blockade or other means. The outcome of such coercive campaigns would be shaped by the much-discussed dynamics of resolve and stakes. The ideal solution from the U.S. standpoint, however, would be an ASB-like preemptive capacity to destroy before launch the missiles that China would use for such missions, thus averting this threat altogether. This ideal solution, however, is at odds with the nature of the relevant technological trends.

To support these findings, we proceed in six steps. First, we establish an analytical context by sketching the political and geostrategic aims that the United States and China might pursue in potential future warfare in the Western Pacific and the role A2/AD and ASB might play in such a war. Next we describe A2/AD and its technological foundations in more detail, explaining why it constitutes a uniquely important issue for U.S. strategy in the Western Pacific. We then explore some critical weaknesses inherent in these technologies, especially the vulnerability of the long-range RSTA systems on which all else rests. This analysis implies a real but limited A2/AD ability to deny freedom of movement to an opponent. Next we consider the potential of ASB to deny China such a real-but-limited A2/AD capability; we reject this ambition as unachievable without sustained expenditures that would exceed



China's. We conclude by summarizing key points and developing in greater detail their implications for policy and scholarship.<sup>15</sup>

### *Strategic and Political Context of Warfare in the Western Pacific*

ASB advocates are sometimes criticized for proposing an operational concept devoid of any valid strategic purpose.<sup>16</sup> To what strategic end would either ASB or A2/AD be directed? And against what standard should they be judged?

The *casus belli* most often assumed to underlie a future U.S.-China war involve Chinese efforts to impose reunification on Taiwan or the escalation of territorial disputes with U.S. allies over island chains such as the Senkakus/Diaoyus, Paracels, or Spratleys. In this context, A2/AD is normally seen as a means for China to deny U.S. military assistance to its allies by excluding American military forces from the theater via attacks on U.S. forces, bases, and supporting infrastructure. Chinese attacks on such targets are means, not ends, however. The ultimate purpose for any of these putative campaigns is for China to secure a territorial stake by imposing its will on the U.S. ally that disputes that stake, not to destroy or exclude U.S. forces for its own sake. The proper standard for assessing either A2/AD or ASB is thus not whether U.S. forces can or cannot operate, but whether China can secure its political aim in the war, and how either A2/AD or ASB would affect this outcome.

China could secure these aims using any of three broad strategies. First, it could try to seize the disputed islands by brute-force invasion. This is the most straightforward method but will also become perhaps the most difficult by 2040, as proliferation of the same technologies that create A2/AD for China will empower its enemies to interdict the military shipping that China would require to sustain an invasion ashore. Amphibious invasion is notoriously difficult, with its extraordinary logistical demands straining most nations' limits under the best of conditions.<sup>17</sup> We assess A2/AD's effectiveness against military shipping in detail below, but in a future of increasingly wide-

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15. An online appendix that presents supporting calculations and technical details is available at <http://dx.doi.org/10.7910/DVN/GK6PR2>.

16. See, for example, T.X. Hammes, "Sorry, AirSea Battle Is No Strategy," *National Interest*, August 7, 2013, <http://nationalinterest.org/commentary/sorry-airsea-battle-no-strategy-8846>. Note that the Department of Defense has been careful to describe AirSea Battle as an operational concept, not a strategy. See U.S. Department of Defense, *AirSea Battle*, p. i.

17. See, for example, Joint Chiefs of Staff, *Joint Publication 3-02: Amphibious Operations* (Washington, D.C.: Government Printing Office, 2009), p. I-1.

spread A2/AD a successful invasion strategy will clearly be exceptionally demanding for China. Second, China could use coercive air or missile strikes against rival claimants' homelands to intimidate them into ceding a disputed stake; as we argue below, by 2040 long-range precision missile technology will give China what amounts to a substantial strategic bombing capability, even without the purchase of large fleets of traditional bombers. The empirical record of such bombing is lackluster, but China will be technically capable of employing this strategy if it chooses.<sup>18</sup> Third, China could use A2/AD to impose a coercive blockade of the disputed islands (or their claimants).

We consider all three strategies, but coercive blockade warrants particular attention as a strategy for China in a 2040 world with mature A2/AD. This is not the way blockade is typically treated in the ASB literature; in today's debate, blockade is normally treated as a U.S. method for countering Chinese threats by closing distant straits.<sup>19</sup> By 2040, however, technology will make this a natural mission for Chinese A2/AD—and a much easier mission than invasion given comparable technologies in U.S. and allied hands. A future A2/AD-enabled blockade of disputed islands or their claimants would enable China to exploit the area-denial advantages of A2/AD rather than overcoming them (as invasion would require); an A2/AD-enabled blockade would combine higher inflicted costs than many other coercive means with lower escalatory risks and potentially asymmetric effects.

As we argue below, by 2040 A2/AD will become a powerful means of interdicting aerial or sea-surface movement, which is the central military function of blockade. Whereas invasion in this time frame would compel China to sustain heavy logistical traffic through a Taiwanese A2/AD barrier facilitated by

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18. On strategic bombing's effectiveness, see, for example, Robert A. Pape, *Bombing to Win: Airpower and Coercion in War* (Ithaca, N.Y.: Cornell University Press, 1996); Michael Horowitz and Dan Reiter, "When Does Aerial Bombing Work? Quantitative Empirical Tests, 1917–1999," *Journal of Conflict Resolution*, Vol. 45, No. 2 (April 2001), pp. 147–173; and Aaron Belkin et al., "When Is Strategic Bombing Effective? Domestic Legitimacy and Aerial Denial," *Security Studies*, Vol. 11, No. 4 (Summer 2002), pp. 51–88.

19. See, for example, Jeffrey E. Kline and Wayne P. Hughes Jr., "Between Peace and the AirSea Battle: A War at Sea Strategy," *Naval War College Review*, Vol. 65, No. 4 (Autumn 2012), pp. 35–40; Aaron L. Friedberg, *Beyond Air-Sea Battle: The Debate over U.S. Military Strategy in Asia* (London: International Institute for Strategic Studies, 2014); Hammes, "Offshore Control"; Sean Mirski, "Stranglehold: The Context, Conduct, and Consequences of an American Naval Blockade of China," *Journal of Strategic Studies*, Vol. 36, No. 3 (June 2013), pp. 385–421; Gabriel B. Collins and William S. Murray, "No Oil for the Lamps of China?" *Naval War College Review*, Vol. 61, No. 2 (Spring 2008), pp. 79–95; Elbridge Colby, "Don't Sweat AirSea Battle," *National Interest*, July 31, 2013, <http://nationalinterest.org/commentary/dont-sweat-airsea-battle-8804?page=show>; and Llewelyn Hughes and Austin Long, "Is There an Oil Weapon? Security Implications of Changes in the Structure of the International Oil Market," *International Security*, Vol. 39, No. 3 (Winter 2014/15), pp. 152–189.

the Taiwan Strait's proximity to land-based Taiwanese or allied missiles (as we argue below, preempting such missiles will be very hard for any state), a Chinese A2/AD blockade of the commercial shipping that Taiwan needs to survive would compel Taiwan to overcome Chinese A2/AD. In fact, many U.S. allies—not just Taiwan—are inherently vulnerable to blockade.

A number of U.S. allies in the region depend heavily on seaborne trade. Japan and the Philippines are island nations that must import both food and energy, and their economies are built on an exchange of goods with distant trading partners; South Korea is virtually an island, as its only land border is closed to most commerce. None is self-sufficient; the people of Japan and South Korea could starve if cut off from overseas foodstuffs, and their economies would collapse if suddenly isolated from world markets.<sup>20</sup> Additionally, none of the disputed islands in the Western Pacific could long sustain a population (or sometimes even a military garrison) without access to sea- and airborne supplies. Chinese blockade could thus impose enormous costs on such states.

Blockade is an act of war under international law, but it is inherently less escalatory than other ways of inflicting comparable costs. For strategic bombing to reduce South Korea's gross domestic product (GDP) by more than 50 percent, for example (as a complete blockade would do), would require a massive attack with heavy loss of Korean life.<sup>21</sup> By contrast, blockade could in principle halt seaborne commerce into Korean (or other) ports without a shot being fired: credible threats can dissuade merchant captains from running the blockade and risking their vessels or aircraft. Even large-scale sinkings of merchant ships would still kill relatively few people: a typical modern container ship has a crew of fewer than twenty; even if 100 such ships went down without a single survivor, fewer than 2,000 crewmembers would perish.<sup>22</sup> The ac-

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20. Japan and South Korea, for example, import more than 70 percent of the grain they consume. See "Daily Bread," *Economist*, October 26, 2013, <http://www.economist.com/news/china/21588436-china-globalises-some-still-think-it-should-be-self-sufficient-food-daily-bread>. On the Philippines, see Justin D. McKinley, Lanier Nalley, and Nate B. Lyman, "Food Security vs. Food Self-Sufficiency: The Case of the Philippine Goal of Self-Sufficient Rice Production," presentation prepared for the Western Agricultural Economics Association meetings, Monterey, California, June 26–28, 2013, <http://www.waeonline.org/UserFiles/file/McKinleyJustin-FoodSecurityvvsFoodSelfSufficiency.pdf>.

21. About 87 percent of South Korea's GDP is attributable to foreign trade. See World Bank, "Merchandise Trade (% of GDP)" (Washington, D.C.: World Bank, 2015), <http://data.worldbank.org/indicator/TG.VAL.TOTL.GD.ZS>.

22. In 2011, the average crew size for the world's 104,304 merchant vessels was less than fifteen crew members. See International Maritime Organization, "International Shipping Facts and Figures: Information Resources on Trade, Safety, Security, Environment" (London: Maritime Knowledge Center, 2012), sec. 3.2, <http://www.imo.org/en/KnowledgeCentre/ShipsAndShipping>

tual attacks, moreover, would come at sea, at a substantial remove from the civilian population. Further, a declared blockade puts the pressure of the next clear chance to avert bloodshed in the hands of the target state, which must choose whether to back down or escalate. None of this means that blockade is without escalatory risk—no act of war is. But in contrast with other means of imposing coercive costs on this scale, blockade's escalatory dangers are lower.<sup>23</sup>

By contrast, Chinese strategic bombing via missile strikes would require much more widespread destruction to impose comparable coercive pain. Unlike blockade, strategic bombing strikes targets inland amid the civilian population; it may kill many innocents depending on the weapons' targets and accuracy, and leadership targeting threatens decisionmakers' (and their families') personal survival.<sup>24</sup> Strategic bombing requires the bomber to make the first move, and unlike blockade the costs imposed are proportional to the assets destroyed. Strikes of this kind thus create escalatory pressures in ways that blockade may not, especially when the victims can respond in kind with similar missiles, which more and more states will have in coming years.

This analysis is not to suggest that blockade is now a preferred option for Chinese strategists or that China could impose one today. With current capabilities, it cannot; for now, coercive blockade is an option for the U.S. Navy but not for China.

Our focus, however, is 2040, not today. And as we argue below, in coming years technology will shift the relative attractiveness of blockade and invasion for China in favor of the former. In fact, by 2040 prevailing technology will make blockade China's most viable means of securing the political ends typi-

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FactsAndFigures/TheRoleandImportanceofInternationalShipping/Documents/International%20Shipping%20-%20Facts%20and%20Figures.pdf.

23. Some analysts assume that a U.S. counterblockade threat can deter a Chinese blockade of U.S. allies. China, however, is a massive continental economy with overland alternatives to seaborne trade. Of course, these alternatives would be more expensive, and the ultimate outcome would turn on a host of variables involving stakes and commitment, among other things. A complete analysis of the net coercive balance in a two-sided blockade is beyond our scope; we focus here on the military issues per se, rather than the political or economic dynamics of a potentially two-sided coercive blockade. On the blockade debate, see note 18.

24. This is true even for missile strikes on port facilities or related transportation systems. The port infrastructure of a modern trading economy comprises a sprawling array of facilities typically located in or near major urban areas: Japan, for example, has more than 250 commercial ports, with the port of Tokyo alone comprising more than 4.5 kilometers of container-ship berths, over 18 kilometers of other wharfs and piers, and 1,000 hectares of land area—all in a city of more than 13 million people. See "Port of Tokyo: Port Commerce," *World Port Source*, [http://www.worldportsource.com/ports/commerce/JPN\\_Port\\_of\\_Tokyo\\_1380.php](http://www.worldportsource.com/ports/commerce/JPN_Port_of_Tokyo_1380.php). Missile strikes sufficient to disable Japan's ports would kill far more people than an A2/AD-enabled blockade at sea.

cally assumed in the Western Pacific security debate. It is also a natural direction that any emerging great power's maritime strategists will inevitably consider: blockade is at the heart of the orthodox Mahanian maritime theory that Chinese strategists are already, and increasingly, consulting.<sup>25</sup>

We thus assume that a rational Chinese leadership will weigh blockade as well as invasion or strategic bombing given the changing incentives A2/AD technology will create by 2040. Therefore we consider it in detail below as one of the three broad strategies whose viability constitutes the crucial standard for assessing either A2/AD or ASB.

### *A2/AD and Its Strengths*

None of the three strategies described above is new; what makes A2/AD different from the past is the rapid improvement in sensor, guidance, and communication technology in recent decades, and the new ways of implementing these strategies that such technology creates. Together these have radically improved the lethality of long-range guided missiles and are increasingly enabling China to threaten distant targets, even without deploying a traditional power-projection navy or air force. To date, much attention has focused on Chinese use of such missiles to strike the bases and infrastructure the United States needs to operate in the Western Pacific; but in fact, the new missile, sensor, guidance, and communication technologies threaten a much wider target set including surface ships, airborne aircraft, factories, power plants, and armored ground vehicles.<sup>26</sup> These threats, moreover, are not symmetric or uniform in their effects: in the air and maritime domains they have systematically lowered the cost of defending airspace and excluding surface ships from nearby waters, giving rise to A2/AD.<sup>27</sup>

A2/AD's effects are asymmetric because attackers and defenders use these technologies in very different ways. Land-based air defenders look upward at airborne targets that are typically larger than themselves and silhouetted

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25. See, for example, James R. Holmes and Toshi Yoshihara, *Chinese Naval Strategy in the 21st Century: The Turn to Mahan* (London: Routledge, 2008).

26. R.J. Heaston and C.W. Smoots, "Introduction to Precision Guided Munitions" (Chicago: Guidance and Control Information Analysis Center, 1983), <http://www.dtic.mil/get-tr-doc/pdf?AD=ADA135619>, remains perhaps the best overview of the physical principles underlying these technologies.

27. Note that these technologies' effects on land warfare have been more muted, because of the more complex nature of the terrestrial environment. See Stephen Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, N.J.: Princeton University Press, 2004). On environmental complexity's effects on air and maritime warfare, see below.

against a mostly featureless sky; penetrating aircraft look downward at mobile land-based missiles and air-defense systems that are typically smaller than themselves in the middle of a complex background. Perhaps the central problem of modern sensor design is distinguishing the target's radar, infrared, or visible-light "signature" (or "signal") from the surrounding background noise; the more complex the background, the harder detection becomes. In this context, ground targets enjoy the great survival advantage of a vastly more complex background of hills, trees, houses, school buses, and tractor trailers. Low-flying aircraft can try to exploit this background complexity themselves, especially when their enemy is using airborne "look-down" air defense radars flying higher than their penetrating quarry. But because aircraft move rapidly, their speed can be used to filter out the background using Doppler techniques; slower-moving ground vehicles are much harder to distinguish than aircraft of comparable size. Nor are the target sizes comparable. Aircraft need large wings for lift and must carry enough fuel to reach distant targets, whereas ground systems are supported by the Earth and can be used without extensive pre-engagement travel—land-based missiles can thus deploy physically smaller, harder-to-spot equipment and still be effective while moving into and out of abundant cover. For any given technology, sensor effectiveness is thus normally higher against aerial targets than ground-based ones; because modern air defense systems can rely increasingly on ground-based surface-to-air missiles (SAMs) and other assets, they have a systematic advantage whose importance has grown as sensors have improved.

An important exception, however, is guidance for engaging stationary as opposed to moving targets. A runway or power plant can be located in peacetime by satellite photography or other means and its coordinates recorded for use in wartime. Guidance systems using fixed reference points such as navigation satellites, topographic features, or even stars can then direct weapons to those coordinates regardless of the target's surroundings and their complexity. And because such targets cannot move, attackers can strike them from great distances notwithstanding the long flight times such attacks may require: the target will still be there when the weapon arrives. Long-range precision weapons can thus be very effective against even well-defended fixed ground targets. Further, long-range surface-to-surface missiles (SSMs) have powerful defense-penetration advantages by virtue of their speed: modern A2/AD has little capability against incoming warheads moving as fast as Mach 12, and is unlikely to attain such capability any time soon.<sup>28</sup> Slower, shorter-range bal-

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28. Ballistic Missile Defense will improve over time, but so will long-range missile technology; fu-



listic missiles will be increasingly vulnerable to A2/AD missile defenses, but long-range high-speed SSMs will remain very likely to reach fixed targets for a long time to come. Such missiles' launchers, moreover, can be made independent of fixed, and hence vulnerable, infrastructure in ways that traditional bomber aircraft cannot. Whereas a B-2 requires a fixed concrete runway, China has already deployed missiles that can deliver a 600-kilogram payload to a range of over 1,400 kilometers from mobile transporter-erector-launchers, making them much harder to destroy preemptively.<sup>29</sup> New technology will thus create an increasingly lethal threat to fixed, but not mobile, ground targets over time.

The net effect of these changes has been to make penetration of defended airspace increasingly difficult for aircraft and moderate-speed missiles as microelectronic technology has improved.<sup>30</sup> And this effect is what has given

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ture missiles will increasingly add maneuverable warheads, decoys, and other countermeasures. On balance, there is little reason to expect a major net change in the performance of ballistic missile defense against long-range high-speed SSMs in the foreseeable future. See National Research Council, *Making Sense of Ballistic Missile Defense: An Assessment of Concepts and Systems for U.S. Boost-Phase Missile Defense in Comparison to Other Alternatives* (Washington, D.C.: National Academy Press, 2012); and Andrew M. Sessler et al., "Countermeasures: A Technical Evaluation of the Operational Effectiveness of the Planned U.S. National Missile Defense System" (Cambridge, Mass.: Union of Concerned Scientists and MIT Securities Study Program, April 2000), [http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/cm\\_all.pdf](http://www.ucsusa.org/sites/default/files/legacy/assets/documents/nwgs/cm_all.pdf). Note that slower but stealthy low-flying cruise missiles may also get through A2/AD defenses; their long flight times handicap them against mobile targets but not against fixed ones, reinforcing the latter's vulnerability. Note also that the U.S. missile defense systems based in both Europe and the United States are directed at very small nuclear attacks from North Korea and Iran. The U.S. government assures both China and Russia that these systems will not be effective against larger attacks from those countries and, thus, presumably not cost-effective against large conventional barrages.

29. Office of the Secretary of Defense, "Military and Security Developments Involving the People's Republic of China 2013" (Washington, D.C.: U.S. Department of Defense, 2000), p. 7. Note that the Chinese CSS-10 Mod 2 (DF-31A) is only partially free of fixed infrastructure: the missile is road-transportable, but requires dedicated concrete pads to launch. Fully mobile missiles with less dependence on fixed infrastructure are likely to appear in coming years.

30. The discussion above emphasizes air, as opposed to sea, defense. Many of the same trends, however, also apply to surface shipping. Surface ships are typically somewhat harder to detect than aircraft (as the sea surface is a somewhat noisier background than the air), but ships are much slower and larger. Thus, defenders have much more time to counterconcentrate force against surface ships trying to penetrate defended waters once detected. As sensors have improved, detection ranges against surface ships have increased to the point where airborne radars can locate even small commercial cargo vessels at ranges limited only by the curvature of the earth (see appendix). Further, guidance improvements have enabled very effective antiship attack, given detection. Warships can employ missile defenses against incoming antiship missiles. They face constraints, however, in shooting down incoming assailants that land-based SAMs do not—in particular, land-based SAMs operate amid a complex, noisy background, whereas ships operate on a sea surface that is much less complex. Modern warships are also extremely expensive and therefore scarce assets; it is cost effective for their assailants to spend lavishly on missile performance to destroy such high-value targets, whereas missiles designed to destroy inexpensive (and thus numerous) SAM transporter-erector-launchers must be kept fairly inexpensive themselves. Warships are thus likely

rise to a credible A2/AD threat. Some of the same technologies, however—especially improvements in missile guidance—have created an important exception in the form of long-range SSM attacks on fixed targets. A2/AD will be increasingly effective over time in denying access to aircraft and surface ships and in defending mobile land targets. Defending fixed targets from attack will be increasingly difficult, however, as these technologies spread.<sup>31</sup>

### *A2/AD Limitations*

A threat this formidable will not go unanswered, and A2/AD has important limitations that rivals can exploit to constrain its reach.

To destroy targets, A2/AD requires a complex “kill chain” starting with target detection and including munition delivery, weapon guidance, damage assessment, and potential restrike. Some links are more robust than others, and the first step—detecting distant targets—is particularly vulnerable.

#### RADAR VULNERABILITY AND A2/AD

A2/AD involves multiple target and sensor types, but we begin with the competition between detection and surface ship targets, which is critical both for blockade and for amphibious invasion. (In fact, for a circa 2040 amphibious invasion, surface ships’ vulnerability to hostile A2/AD is the limiting constraint on military viability. Even if an invader can land an overwhelming ground

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to be more vulnerable to air attack than land-based air defenses will be. Moreover, civilian merchantmen will be much more vulnerable still. Note that merchant ships cannot safely assume that they will not be targeted by expensive guided missiles—a medium-size container ship cost more than \$70 million in 2010, not counting its cargo, which would make such targeting cost-effective. See United Nations Conference on Trade and Development, *Review of Maritime Transport, 2010* (Geneva, Switzerland: United Nations Conference on Trade and Development Secretariat, 2010), p. 56. Merchant convoys escorted by warships would fare better, but inasmuch as the warships themselves will be hard-pressed, it is unlikely that practical escorts could protect civilian shipping in numbers large enough to lift a blockade. If submarines or mines are considered, too, then merchant ships’ ability to penetrate A2/AD is even more problematic. Modern technology is thus making A2/AD increasingly effective against both surface ships and aircraft.

31. These defensive trends have existed for decades, but were masked for many years by the United States’ advantages over its post-Cold War regional foes and the offensive capability these advantages enabled. States such as Baathist Iraq or 2001 Afghanistan could neither afford state-of-the-art defensive technology nor train their militaries to exploit fully the equipment they had. U.S. air offensives with modern technology thus appeared to signal an offense-dominant “revolution in military affairs,” but these one-sided offensive successes required radical capability imbalances that we do not assume for a future U.S.-China conflict. On airpower in post-Cold War regional conflicts, see, for example, Biddle, *Military Power*, chap. 7; H.R. McMaster, “On Warfare: Lessons to Be Learned,” *Survival*, Vol. 50, No. 1 (February/March 2008), pp. 19–30; John Stone, “Politics, Technology, and the Revolution in Military Affairs,” *Journal of Strategic Studies*, Vol. 27, No. 3 (September 2004), pp. 408–427; and Stephen D. Biddle, “Allies, Airpower, and Modern Warfare: The Afghan Model in Afghanistan and Iraq,” *International Security*, Vol. 30, No. 3 (Winter 2005/06), pp. 161–176.

force, its sustainability will turn on surface ships' continued ability to survive transit across miles of open ocean. We thus focus on this issue in our analysis of the invasion strategy.)

For A2/AD to deny access to surface ships, the critical detection function depends centrally on radar. Alternatives such as infrared or visible-light detection or interception of targets' electronic emissions can play useful roles (and we discuss these below), but only radar can provide the broad-area, day-night, long-range detection essential for A2/AD blockade or interdiction of invasion shipping. Aerial targets and submarine warfare obviously matter, too, and we treat them in detail below. But in the Western Pacific context these are chiefly means, not ends: the pivotal end is to sustain or deny ships' access to ports and invasion beaches, and for this, the first-order issue is radar's ability to detect surface targets at extended range.

Radar's detection range against surface ships is influenced by many variables, but the most important is the physical horizon. Warships and large cargo vessels present radar cross sections (RCSs) of thousands of square meters; even radars small enough to fit on aircraft can easily detect such large targets at ranges limited only by the curvature of the Earth.<sup>32</sup> ("Over the horizon," or OTH, radars can detect targets at ranges beyond the physical horizon, but require frequencies too low to provide the resolution needed for directing weapons to targets. They can be useful for early warning, but not targeting, and the enormous apertures needed even for early warning functions mandate fixed installations that are inherently vulnerable.<sup>33</sup>)

The only way to increase the distance to the horizon is to increase antenna altitude. Taking this to the extreme is to place ocean surveillance radars in space. The Soviet Union did this with its radar ocean reconnaissance satellites (RORSATs), four-ton, nuclear-powered radar satellites designed to scan the world's oceans for U.S. aircraft carrier battle groups, and China is now deploying space-based radars of its own.<sup>34</sup>

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32. For the authors' calculations of detection probabilities for a notional JSTARS-like airborne radar against ships operating in sea-surface clutter, see the technical appendix.

33. See, for example, Joseph F. Thomason, "Development of Over-the-Horizon [OTH] Radar in the United States," *IEEE [Institute of Electrical and Electronics Engineers] Proceedings of the International Radar Conference, 2003* (New York: IEEE, September 2003), pp. 599–601; and Bradley Perrett, "Long View," *Aviation Week and Space Technology*, September 22, 2014, pp. 42–45. James Barnum describes in more detail a particular OTH radar, the Wide Aperture Research Facility (WARF), which has an antenna 2.55 kilometers long and, at ranges from China to Japan's east coast, would have range resolution of 750 meters and azimuth resolution of 9.4 kilometers. See Barnum, "Ship Detection with High-Resolution HF Skywave Radar," *IEEE Journal of Oceanic Engineering*, April 1986, pp. 196–209.

34. Asif Siddiqi, "Staring at the Sea: The Soviet RORSAT and EOSAT Programmes," *Journal of the British Interplanetary Society*, Vol. 52, Nos. 11–12 (November/December 1999), pp. 397–416; and An-

Aircraft offer another means of increasing antenna altitude. The United States and other countries already deploy multiple types of airborne radar. The archetypes are the well-known U.S. airborne warning and control system (AWACS), for control of a tactical air battle, and joint surveillance and target attack radar system, for tracking surface targets such as tanks.<sup>35</sup> These radar carriers are usually modified commercial or cargo planes and operate at altitudes typical of such aircraft, about 13 kilometers, which yields a horizon about 400 kilometers away. The U.S. U-2, which can carry a search radar, operates at 20 kilometers, giving a horizon of about 500 kilometers. (The horizon increases only as the square root of the altitude; therefore a doubling of altitude yields only a 40 percent increase in horizon.) Payload constraints rise rapidly with increasing altitude and impose a sharpening trade-off between horizon and radar size and power above 13–20 kilometers. The now-retired U.S. SR-71 spy plane could cruise for a limited time at 23 kilometers with a small radar but at great expense in exchange for a minor increase in horizon to 540 kilometers; in practical terms, a horizon of 400–500 kilometers is the limit for airborne radar.

Radars are inherently vulnerable, however. As active emitters, they must radiate a signal that draws attention, reveals the transmitter's location, and can serve as a homing signal for anti-radiation missiles (ARMs) attacking it. Moreover, the physics of radar give its targets some inherent advantages in attacking radars. In particular, a target of comparable sophistication can detect a radar at ranges far greater than the radar can detect the target—and any radar with the resolution needed to direct a weapon requires a clear line-of-sight to the target, which exposes the radar to attack.<sup>36</sup>

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drew S. Erickson, "Chinese Air- and Space-Based ISR: Integrating Aerospace Combat Capabilities over the Near Seas," in Peter Dutton, Erickson, and Ryan Martinson, eds., *China's Near Seas Combat Capabilities* (Newport, R.I.: U.S. Naval War College, 2014), pp. 87–118.

35. Northrop Grumman, "AWACS Surveillance Radar: The Eyes of the Eagle" (Falls Church, Va.: Northrop Grumman, n.d.), <http://www.northropgrumman.com/Capabilities/AWACSAFY2/Documents/AWACS.pdf>; and U.S. Air Force, "E-8C Joint Stars," fact sheet (Washington, D.C.: U.S. Air Force, n.d.), <http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104507/e-8c-joint-stars.aspx>. China is deploying similar systems. See, for example, Erickson, "Chinese Air- and Space-Based ISR," pp. 90–95.

36. As noted above, OTH radars, which do not require line-of-sight to targets, must operate at frequencies unsuitable for targeting resolution; radars meant to direct weapons must thus have a clear line-of-sight to the target, which creates a reciprocal line-of-sight from the target to the radar. The target's detection-range advantage stems from the physics of waves: radar signals spread out and weaken as they travel; for the radar to detect a target, the signal must travel the distance to the target and then back again, but the target receives the radar signal after it travels about half that distance. The signal detected by the target is thus much stronger than it is by the time it returns to the radar antenna, enabling targets to detect radars at distances at which the signal would weaken

Radars in satellites have added vulnerabilities. They travel in predictable orbits, and carrying fuel into orbit for evasive maneuver is expensive, as is the weight of any defensive measures. About five times as much energy is required to place a kilogram into low earth orbit as it is to loft a kilogram to the same altitude; and at orbital speeds, even a tiny mass lofted into the path of an oncoming satellite will produce a collision with more than enough energy to destroy both objects without any explosive charge required. Antisatellite (ASAT) weapons thus possess a major structural advantage over satellites: the mass and energy differences alone suggest that a satellite killer will be two or three orders of magnitude cheaper than existing satellite targets.<sup>37</sup> Microsatellites weighing tens of kilograms carrying passive optical imaging sensors have demonstrated resolution that can identify large surface ships (but only in clear weather);<sup>38</sup> as the target satellite's mass diminishes the ASAT's advantage diminishes, but it does not disappear.

These inherent vulnerabilities mean that radars must be defended or otherwise protected if they are to survive. For satellites, however, defense is impractical in the long term if a sophisticated enemy is willing to attack them. The underlying energy and mass problems inherent in achieving orbit create large structural cost advantages for ASATs that satellite engineering improvements are unlikely to overcome in a long run, two-sided competition. Nor can redundancy or reconstitution solve the problem: one can replace lost satellites, but the enemy can always destroy the new ones, and the cost advantages of ASATs force the satellite owner to spend more than its rival with each iteration, making this a losing game in a sustained struggle between economic peers. (ASAT attacks create debris from the destroyed target that might damage friendly satellites, but this is unlikely to deter ASAT use in war. Such

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below its detection threshold for the radar (assuming equal signal-processing sophistication for the radar and the target).

37. For example, the Lightweight Exo-Atmospheric Projectile (the precursor to the warhead on the Aegis missiles), intended as an anti-ballistic missile interceptor but with proven ASAT capabilities, weighs only 6 kilograms. The interceptor's kinetic energy is so great that an explosive charge is superfluous even against satellites weighing tons. See Paul Baker and Anthony V. Funari, "Army Lightweight Exo-Atmospheric Projectile (LEAP)," *Proceedings of the American Institute of Aeronautics and Astronautics, 1992 Aerospace Design Conference*, 3–6 February 1992, Irvine California (Reston, Va.: American Institute of Aeronautics and Astronautics, 1992), <http://www.dtic.mil/dtic/tr/fulltext/u2/a345799.pdf>; and N.L. Johnson et al., "NASA's New Breakup Model of EVOLVE 4.0," *Advances in Space Research*, Vol. 28, No. 9 (2001), pp. 1377–1384. Currently, low Earth satellites are most threatened, but medium Earth orbits may become vulnerable to mobile antisatellite missiles. See Zachary Keck, "China Secretly Tested an Anti-Satellite Missile," *Diplomat*, March 19, 2014, <http://thediplomat.com/2014/03/china-secretly-tested-an-anti-satellite-missile/>.

38. Ranier Sandau, "Status and Trends of Small Satellite Missions for Earth Observation," *Acta Astronautica*, Vol. 66, Nos. 1–2 (February 2010), pp. 1–12.

damage is unlikely to exceed one additional satellite lost per decade per satellite attacked, and ocean surveillance satellites are likely to be in low orbits where debris is less persistent than elsewhere.<sup>39</sup>) Radar surveillance satellites are thus unlikely to survive long enough to be relied upon.

Airborne radars are more practical to defend. But in a long-term competition with an economic peer of comparable sophistication, defending an active emitter with a clear line-of-sight to the enemy poses important challenges—especially when pushing sustained wide-area surveillance as far forward as possible. For example, many tactical radars defend themselves via silence, turning off until cued by larger surveillance radars located well to the rear; such countermeasures are impractical when the surveillance radar must be pushed forward to maximize A2/AD's sustainable reach. Alternatively, forward-deployed airborne radar could shut off whenever it detected an approaching ARM; it could turn on pseudo-transmitters towed behind the aircraft to draw the homing missile away, or it could attempt other forms of spoofing or jamming or decoys. Attackers will counter by improving target-decoy discrimination, switching from passive to active searching for the final approach, or switching from homing on a radar signal to looking for the aircraft's infrared emissions. Given the uncertainties of such measure-countermeasure races, few planners will trust an expensive limited asset such as an airborne radar to such last-ditch methods. In all likelihood, active defense of such radars will be needed: incoming missiles—or the aircraft launching them—must be intercepted and destroyed before they can reach the radars they target. This interception problem is harder the farther ahead the radar must see.

This difficulty arises because the radar's defenders will themselves be targeted by the enemy, which will have comparable radars and missiles. In such contests, attackers enjoy the structural advantage of the initiative: they choose the time and place of their attack (in this case, against a radiating target whose location is known), and they can surge a concentrated force to overwhelm locally outnumbered defenders at that point. Defenders on land normally enjoy the offsetting advantages of cover and concealment. If the radar is defended by airborne fighters, however, no such offsets are available against the background of an open sky. Without this offset, airborne defenders face unfavorable cost ratios in maintaining continuous combat air patrols sized to meet the largest realistic surge attack by equally sophisticated assailants.<sup>40</sup>

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39. David Wright, "Space Debris," *Physics Today*, Vol. 60, No. 10 (October 2007), pp. 35–40. For a more detailed discussion, see the technical appendix.

40. In 1940–44, before the development of long-range escorts, air defenders could exact heavy tolls



To exploit the natural defensive advantage of cover and concealment, the radar's defenders would have to be ground-based SAMs that can operate amid the natural background complexity of the Earth's surface, affording them a structural RSTA advantage over the aircraft and missiles that would threaten airborne radar.<sup>41</sup> Modern SAMs can be highly effective against both fighter aircraft and even ramjet-speed ARMs; a network of mobile SAMs on cheap trucks rather than expensive aircraft, deployed amid cover and using a combination of their own and airborne radars for targeting, could provide a powerful defense of those airborne radars at a systematic cost advantage over the radar's airborne assailants.

Unlike airborne escort fighter aircraft, which could accompany an airborne radar out to sea, thus extending A2/AD's reach as necessary, land-based SAMs cannot. Shipborne SAMs could venture well beyond the coastline and would recover some of the cost advantages of land-based missiles against expensive airborne assailants; surface ships at sea, however, would sacrifice the defensive advantages of the land and its complex RSTA background. For a long-term competition against a comparably sophisticated economic peer, only a land-based defense that can exploit the systematic asymmetry in RSTA effectiveness of the land as a background can be expected to enjoy systematic cost advantages in defending the radar needed for effective A2/AD.

This long-run incentive for land-based air defense of airborne radars, however, will make effective RSTA increasingly difficult the farther from a defended coastline one tries to push A2/AD. The problem here is the tyranny of speed and distance. An effective defense must intercept incoming radar-assailants before those assailants reach the radar; such defense is relatively easy if the airborne radar flies well behind a dense belt of forward SAMs, which would then have ample opportunity to strike incoming ARMs before they could reach the rearward radars.<sup>42</sup> This would tether the airborne radar to the mainland interior, however, which in turn would limit the radar's effective

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on massed attackers even without exploiting cover and concealment, because they were defending against vulnerable bombers with slow penetration speeds. See, for example, Tami Davis Biddle, *Rhetoric and Reality in Air Warfare: The Evolution of British and American Ideas about Strategic Bombing, 1914–1945* (Princeton, N.J.: Princeton University Press, 2004). A 2040 air attack on A2/AD radars would follow very different dynamics.

41. This advantage would ordinarily be offset in turn by the aerial assailants' greater speed and ability to concentrate, leaving many SAMs stuck away from the critical point. Here, however, the SAMs are defending airborne radars that determine their own patrol patterns and can choose to fly where the deployed SAMs can defend them.

42. In the Cold War, NATO's airborne radars typically operated well to the rear, with multiple layers of air defenses between them and any significant threat. See, for example, Carlo Kopp, "AEW and AWACS," *Air Power Australia*, March/May 1989, <http://www.ausairpower.net/TE-AEW-AWACS.html>.

reach beyond the coastline. The farther forward one pushes the airborne radar, the less time and distance one allows for intercepting incoming radar-assailants, and the greater the risk that an ARM or other incoming missile gets through and destroys an expensive surveillance system.

In the limit, an aggressive attempt to push sustained surveillance by airborne radar as far forward as modern SAMs can protect might eventually enable such radars to be flown a few tens of kilometers out to sea beyond a SAM-defended coastline.<sup>43</sup> An aggressive effort to increase airborne radar's altitude as much as possible to increase its detection range might eventually give such radars a horizon of perhaps 400–500 kilometers. Together, these constraints would imply a limit of 400–600 kilometers reach for an A2/AD system premised on such a concept. Beyond this range, brief sallies could be mounted and recovered before an enemy could respond, but sustained surveillance would pose grave risks to the radars involved absent expenditures that would systematically exceed the opponent's.

Nor would sustained radar operations at or near this range be risk free. The less time and distance one allows for the radar's defenders, the greater the probability that assailants survive the defenses and destroy a scarce radar. To reach a 400–600-kilometer range would push the radar to its defenders' absolute limits.

Radar-driven A2/AD lethality, moreover, diminishes the farther away its targets are. Missiles lose energy and maneuverability at their range limits. Detection probabilities for radars diminish with range (especially against small or stealthy airborne targets as opposed to large-RCS surface ships). Fast-moving targets at extreme range may be able to enter and leave protected battlespace before effective engagement by distant A2/AD systems.

Of course, many different operational concepts for projecting long-range RSTA in support of A2/AD are possible. But in general, the vulnerability of satellites combined with the requirement to defend actively emitting radars against equally sophisticated assailants implies important limits on radar-enabled A2/AD's ability to extend its reach beyond controlled landmasses that can shield such radars' defenders. When radars can operate over fields of protective SAMs, the A2/AD they enable will be highly effective. But the greater the distance from a friendly coastline, the less viable A2/AD will be. And although exact operating ranges depend on the details of the systems deployed and their tactics, if the combatants are willing to destroy each

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43. The technical appendix presents a more detailed discussion of the dynamics of this defensive problem and the calculations behind this estimate.

other's satellites, then effective A2/AD will be especially difficult beyond the 400–600-kilometer limit implied by the physics of airborne radar and the dynamics of time and distance for its defense.

Could China escape these constraints with a preemptive first strike against the U.S. bases or platforms that would threaten its RSTA? China can eventually deploy a surprise-attack capability that could wipe out U.S. fixed infrastructure in the region, destroy aircraft parked on bases, sink much of any peacetime U.S. surface-naval presence forward deployed in nearby waters, and destroy U.S. satellites. Such an attack could certainly do great damage, especially if the United States places vulnerable ships and aircraft at risk nearby in peacetime. This damage would not, however, prevent the United States from destroying the satellites China would need for very-long-range RSTA, nor would it enable China to destroy Western mobile missiles not caught on fixed bases. Without satellite surveillance or preemption of Western missiles, China would still have to push mobile, presumably airborne, radars well beyond its shores and into the teeth of survivable, mobile Western sensors and missiles with A2/AD capabilities of their own; the farther beyond its coast China tries to push such systems, the more vulnerable they become to counter-attack by assailants operating from complex terrain and enjoying the survivability advantages that such terrain affords. Because the critical elements of a mature A2/AD system can all be made mobile (as we argue below), preemptive Chinese attack against fixed targets thus cannot destroy enough to clear the way for radar-based RSTA to enable theaterwide expansion of Chinese air or sea control.

#### PASSIVE ALTERNATIVES TO RADAR FOR A2/AD

If radar's vulnerability as an active emitter limits its ability to extend A2/AD's range, what about passive alternatives? Can any provide a longer reach?

In principle, drones, aircraft, or satellites can listen passively for ships' radio transmissions and triangulate their positions. Warships, however, can counter with low-probability-of-intercept techniques and strict electronic emissions control (EMCON) that substantially reduce detection rates and ranges. Commercial ships can resort to complete radio silence, a potentially costly constraint but one that substantially defeats passive listening efforts. Evasive maneuver by mobile targets using such techniques can greatly complicate passive signals intelligence (SIGINT) targeting at the extended ranges needed to exceed active radar's reach.

Given perfect visibility, high-flying drones with passive sensors detecting visible and infrared light can scan large ocean areas, but range drops dramati-

cally under less-than-perfect weather conditions. In a mutual A2/AD environment, such drones would also be subject to attack just as airborne radars are; their passive sensors could make such drones harder to detect than airborne active radars (especially if the drones were small and stealthy), but their shorter sensor ranges under typical conditions would require them to fly closer to their quarry, complicating their defense if attacked. Their surface-ship quarries, moreover, would be dangerous attackers in convoys escorted by warships with A2/AD radars and missiles and operating beyond the reach of the drones' land-tethered defenders. It is far from clear that passive drones could survive in such a high-threat environment long enough to extend China's A2/AD reach significantly beyond what airborne radar could do.

China could still use drones or scattered passive sonars backed up by long-range missiles (or, equivalently, mines) to harass shipping and even sink some ships. Maintaining a blockade, however, requires persistent monitoring of wide ocean areas day and night in all weather to support an ability to at least threaten virtually all shipping and inflict meaningful attrition on ships trying to run the blockade in defended convoys. Only radar can do this.

#### SUBMARINES, MINES, AND A2/AD

Submarines and mines are also natural options for enforcing blockades or countering invasion shipping, and both have played a role in the A2/AD/ASB debate.<sup>44</sup> Neither of these, however, could enable a longer A2/AD reach than radar-directed aerial weapons.

Submarines substitute sonar for the role radar plays in air warfare. In deep waters, a sonar can potentially hear surface ships hundreds of kilometers away.<sup>45</sup> To achieve such ranges with accuracy sufficient for targeting, however, requires triangulation by networks of precisely located underwater hydrophones with the ability to communicate huge volumes of data to large, shore-based or submarine-based processing centers that can untangle the complex effects of varying salinity and temperature and the way these affect sound transmission over such distances. This communication function is very challenging for navies that do not control the surface or airspace and thus cannot

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44. See especially Coté, "Assessing the Undersea Balance between the U.S. and China"; Lyle Goldstein and William Murray, "Undersea Dragons: China's Maturing Submarine Force," *International Security*, Vol. 28, No. 4 (Spring 2004), pp. 161–196; and Andrew Erickson, Lyle J. Goldstein, and William S. Murray, "Chinese Mine Warfare: A PLA Navy 'Assassin's Mace' Capability" (Newport, R.I.: U.S. Naval War College, 2009).

45. Robert J. Urick, *Principles of Underwater Sound*, 3rd ed. (Los Altos, Calif.: Peninsula, 1983), p. 164.

rely on chains of secure short-range aerial or surface relays. Radio communication could transmit the data directly to shore, but long-range transmissions can be intercepted and jammed or used to empower attacks on the transmitting antennas or the hydrophones themselves. China could rely on underwater cable, but a survivable system would require it to lay and maintain hundreds of kilometers of underwater cable secretly and sustain this fixed cable system against attack in wartime or compromise during peacetime, which would be extremely difficult.<sup>46</sup>

To operate in distant waters under hostile control, submarines must thus use onboard sonars and operate near the targets they would engage. These requirements create vulnerabilities of their own.

Submarines are formidable not because they are particularly difficult to destroy, but because they are hard to find. U.S. ballistic missile submarines are considered invulnerable at sea because their missiles' range allows them to roam randomly through vast expanses of ocean. Tactical submarines working as commerce raiders, by contrast, cannot stay in the vastness of the ocean simply to stay hidden; they must go to their targets. Antisubmarine warfare (ASW) is always difficult but less so when the submarines must come to the target. Getting within detection and weapon range forces hunter-killer submarines into a much smaller box where searchers can focus or submarine hunters can set up detection barriers that submarines must cross.

Avoiding detection in a defined area is a challenge for submarines where the hunters control both the surface and the air. ASW aircraft are a particular threat; submarines cannot maintain stealth while firing missiles at threatening aircraft. Self-defense is thus an extreme last resort, enabling airborne searchers to linger, seeding critical areas with hydrophones, and quickly engaging detected submarines with homing torpedoes while facing little meaningful risk of retaliation. Surface forces, being less dependent on stealth than their submarine quarries, can more fully exploit short-range active sonar, which is effective against even the quietest submarines.

Intense ASW in a restricted area can thus be effective,<sup>47</sup> but to exploit this advantage may require that cargo ships move only in convoys. Convoying would distort normal commercial traffic even if Chinese submarines sink few

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46. In the Cold War, for example, U.S. submarines located and tapped Soviet underwater naval communications cables. See, for example, Mel Mandell, "120,000 Leagues under the Sea," *IEEE Spectrum*, Vol. 37, No. 4 (April 2000), pp. 50–54, at p. 52.

47. James Broadmeadow et al., *Improved Anti-Submarine Warfare (ASW) Effectiveness: MSSE Capstone Project* (Monterey, Calif.: Naval Postgraduate School, June 2008), <http://www.dtic.mil/dtic/tr/fulltext/u2/a483343.pdf>.

ships. But by enabling focused ASW, it could let cargo ships run a submarine blockade at tolerable cost. Submarines are thus important combatants and might allow a defender to impose unacceptable costs on an invasion fleet, but they are unlikely to enable true Chinese blockade beyond airborne radar range in the time period considered here.

Like submarines, mines were key weapons of blockade in both world wars and could still impose important costs on invaders. Modern mines are extremely sophisticated. Sensitive sensors, often used in combination, can detect the sound of passing ships, distortions in the Earth's magnetic field caused by the passing of a large metal object such as a ship, or tiny pressure increases resulting from the water displaced by a large passing ship. Computers on the mine can analyze these data and be programmed to explode only in the presence of particular types of ships—for example, ignoring small ships to wait for larger, presumably more lucrative, targets. The screw noises of a surface ship and submarine are distinguishable, so the mine can be programmed to explode only near submarines. The computer can also tell the mine to ignore the first ship passing by, assuming that it is most likely a minesweeper, or simply lie dormant for weeks. Such smart mines that lie on the bottom are very difficult to clear or “sweep.” Some “mines” are actually torpedoes lying in ambush. The U.S. CAPTOR, for example, was a homing torpedo that activated when a passing ship was detected. The torpedo had its own homing guidance, so the lethal radius of such “mines” could be kilometers under favorable detection conditions.<sup>48</sup>

The main weakness of mines is that they are fixed in place and their range (even if kilometers long) is short relative to the size of the ocean. And although mines are cheap compared to their intended targets, no navy can afford to scatter them at random in the open ocean. They are, rather, laid at harbor entrances or in bands along coasts or across straits. Even with such focused application, mines are area weapons and must be used in large numbers to be effective. Thus, laying minefields is not a simple task.

Sweeping or hunting mines is also technically challenging, expensive, time-consuming, and dangerous. The sweeper, however, has the advantage of geometry: whereas the minefield should cover all possible approaches to, say, a harbor, the sweeper needs to open only linear corridors through it. The mine-layer must then return to lay more mines, in inshore waters where the surface and air are likely to be enemy controlled. Missiles could deliver a few mines in

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48. Scott C. Truver, “Taking Mines Seriously: Mine Warfare in China’s Near Seas,” *Naval War College Review*, Vol. 65, No. 2 (Spring 2012), pp. 30–66, <https://www.usnwc.edu/getattachment/19669a3b-6795-406c-8924-106d7a5adb93/Taking-Mines-Seriously—Mine-Warfare-in-China-s-Ne>.



critical places through such defended airspace, but at costs per ton that exclude maintenance of large minefields. Submarines can lay mines in such areas. But as noted above, submarines will have trouble operating routinely where submarine hunters can focus their efforts and control both the surface and the air; submarine minelayers could thus pose a harassment threat, but they are unlikely to enable a sustained blockade.

These shortcomings do not mean that mines or submarines can be ignored. China would probably be unable to sustain a submarine or mine blockade against determined opposition, but it could threaten shippers with occasional sinkings. Although this could be important in a contest of mutual coercion, it falls short of the kind of sustained blockade that airborne A2/AD technologies can threaten—within the range limits of radar-driven A2/AD. Consequently, radar's ultimate limits will make it very difficult to extend A2/AD's effective reach beyond about 400–600 kilometers from a controlled landmass.

### *AirSea Battle and A2/AD Preemption*

A2/AD is thus a geographically limited threat; the less grave the A2/AD threat, the less need there will be to employ AirSea Battle to dismantle it. But while the A2/AD threat is more limited than often supposed, it is real nonetheless, and by 2040 it could still restrict U.S. military freedom of movement significantly relative to today's command of the global commons. ASB promises a return to the pre-A2/AD condition of full access by U.S. forces to Chinese airspace and adjoining waters, with the ability to destroy Chinese power projection and long-range coercive missile forces and apply whatever pressure is required to force a U.S.-favorable resolution to any conflict. If achievable such an outcome would surely be preferable to accepting even a limited Chinese A2/AD capability. It is not achievable, however, without sustained U.S. expenditures that would substantially exceed China's.

The first and greatest challenge ASB would face in this mission is the same as China's in A2/AD: finding targets, especially the large numbers of mobile land-based missiles that underwrite Chinese A2/AD. Of course the United States, like China, could destroy fixed targets that might have been mapped out years in advance. Every essential component of A2/AD can, however, be executed without fixed assets. Missiles and command centers can be made mobile—perhaps tapping into nonradiating landlines when available. Airborne radar carried by modified commercial or cargo aircraft can operate from austere airfields or even long stretches of highway,<sup>49</sup> perhaps with depots deep

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49. There is ample Cold War precedent for this. See, for example, *Abandoned, Forgotten, and Little*

in the interior for major maintenance needs, all defended by mobile SAMs directed by powerful but mobile radars. As noted above, mobile targets are much harder than fixed sites to find and strike from great distances; China thus has an incentive over time to shift more and more of its A2/AD assets to mobile platforms. In the long run, one should expect all critical components to be land mobile.

Given the challenges of striking mobile targets from great distances, ASB relies heavily on penetrating stealthy aircraft for this role. Penetrating aircraft can bring sensors closer to their targets, improving detection performance against small vehicles in complex backgrounds; they can overfly intervening obstacles, improving line of sight; and they can bring ground-attack weapons to closer range before launch, reducing the targets' ability to find cover during the weapon's time of flight. Such penetration, however, would take the bomber into the very teeth of China's A2/AD air defenses; thus, penetrating aircraft would require stealth to survive while hunting Chinese mobile missiles, radars, and supporting infrastructure.

The central issue for ASB bomber penetration is therefore the competition between stealthy bombers and their mobile land-based air defense and other targets. This competition would turn on each side's ability to find the other. Targets on the surface or in the air will be detected through electromagnetic radiation, whether visible light, infrared, or radar. Light and infrared have the advantage of passive detection: in contrast to radar, the sensor sends out no signal of its own to alert the target and attract attack. Radar can be used at night and in all weather, and will be the heart of any search capability. Many of the general principles shaping the ASB competition between stealth and air defense, however, can be illustrated with passive sensors and our discussion starts there, then returning to radar.

A long-range bomber is bigger and heavier than a missile transporter, which gives the latter important advantages in the visual and infrared regimes. Bigger targets are easier to see: the B-2's size and long contrails at high altitude largely restrict it to nighttime operations even against enemies far less challenging than China. Any vehicle's infrared signature, moreover, is roughly proportional to the heat produced; here the airplane's fantastic mobility comes at a cost: prodigious energy use. An F-22 in most-efficient cruise burns 4 tons of fuel per hour, whereas a heavy missile transporter burns about 25 kilograms per hour traveling on level roads.<sup>50</sup> Moreover, aircraft must expend consider-

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*Known Airfields in Europe* (website), <http://www.forgottenairfields.com/germany/lower-saxony/oldenburg/ahlhorn-highway-strip-s356.html>.

50. This calculation takes the F-22 ferry range as 1,850 miles with 11.9 tons of fuel and most-

able power simply to stay airborne. Trucks are supported by tires, not wings, and their engines can be turned off, removing that heat source.

Stealth aircraft devote much effort to suppressing such infrared signatures, but so can ground vehicles: trucks can use many of the same techniques with equal or greater effectiveness. As threats to key ground vehicles increase, their designers will increasingly exploit stealth, and their energy-expenditure fundamentals make this easier than for aircraft. For example, the stealthy B-2 exhausts its engines above the wing to mask the hottest gas from ground observers. Trucks can use the same tricks, such as running exhaust under the vehicle to cool before release, or mixing hot engine gases with cooler air before exhausting it, or placing insulation over hotspots, or using infrared suppressive paint. Moreover, the surfaces on an airplane that emit heat are also aerodynamic structures critical to flight, which compels costly performance compromises, including severe restraints on design and recourse to expensive materials. Ground vehicle designers have a far easier job: they can, for example, add panels that shield hotspots but have no structural or motive function. If an aircraft burning tons of fuel per hour can be infrared stealthy, then a truck burning less than 1 percent as much fuel can be, too—and much more easily. Furthermore, ground vehicles must be detected against a far more complex background than aircraft; the signature reduction needed to make an aircraft indistinguishable from the sky is far more demanding than that needed to make a truck indistinguishable from its surrounding rocks, roads, trees, and buildings at a wide range of temperatures.

Radars will be the most important means of finding targets on the surface and in the air. Reducing radar signatures is the primary focus of stealth. What stealth accomplishes, however, is to reduce radar detection range—no aircraft, even if very stealthy, is literally invisible to radar at any distance. Yet there are important limits on stealth's ability to reduce detection range that derive from the basic physics of radar.

The strength of the echo that a radar receives from a given target weakens with range.<sup>51</sup> Like any radiated signal, the radio wave heading toward the target spreads out, and its intensity decreases with the square of the distance. The

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efficient cruise speed as Mach 0.9. See U.S. Air Force, "F-22 Raptor," fact sheet (Washington, D.C.: U.S. Air Force, September 6, 2005), <http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104506/f-22-raptor.aspx>. It assumes that large trucks will get 5 miles per gallon at 40 miles per hour, or 25 kilograms per hour. If we consider fuel per kilometer, the aircraft may be less disadvantaged, as it travels quickly and spreads its infrared signal over a longer trail than a truck. Airplanes, however, still produce an order of magnitude more heat per kilometer than trucks.

51. On the underlying physics, see, for example, Merrill L. Skolnik, *Introduction to Radar Systems*, 3rd ed. (New York: McGraw-Hill, 2001); and J.C. Toomay and Paul J. Hannen, *Radar Principles for the Non-specialist*, 3rd ed. (Raleigh: SciTech, 2004).

returning echo does the same. Therefore, combining the two effects, the signal the radar receives weakens as the fourth power of the distance to the target. Double the distance and the return is one-sixteenth as strong, three times as far and the return signal is weaker by a factor of eighty-one, and so on.

This rapid drop-off in the radar echo strength puts severe restraints on the range of any radar, but it also means that large reductions in RCS have only limited effect on reducing detection range. The converse of a rapid drop in echo strength with increasing range is a rapid increase in echo strength with decreasing range. If one target can be seen at a certain range, then another target, with an RCS reduced by a factor of ten, will still be visible to the same radar if the range is reduced by not even half. The strength of the radar echo, moreover, and hence the detection range, depends on the power of the radar and the amount of that echo that is picked up, which depends on the size of its antenna. Surface radars, even mobile radars, can pump out large amounts of power and have large antennas. So a stealthy fighter such as the F-22 might be effectively invisible to the smaller, less-powerful radar that would be found in another fighter jet but not to a powerful, but still mobile, surface radar.

Details of military radar and stealth performance are classified, but the range dependence derives from physics and can be used for rough extrapolation from published information. Let us assume a stealthy aircraft RCS of between 0.01 and 0.0001 square meters.<sup>52</sup> The unclassified version of the National Academy of Sciences report on ballistic missile defense presents a map of radar ranges suggesting that a “doubled” TPY truck-mobile radar, basically two current antennas, one atop another, could detect a ballistic missile reentry vehicle almost 3,000 kilometers away.<sup>53</sup> The report does not give the RCS assumed for nuclear warheads, but even if it were a square meter (which is certainly too large, probably by at least a factor of ten),<sup>54</sup> then the rule of range raised to the fourth power implies that a target with an RCS of 0.0001 m<sup>2</sup>

52. John P. Fielding reports an RCS of 0.025 m<sup>2</sup> for the F-117 and 0.1 m<sup>2</sup> for the B-2. See Fielding, *Introduction to Aircraft Design* (Cambridge: Cambridge University Press, 1999), p. 42. One can infer an RCS of 0.0001 m<sup>2</sup> for the F-22. See Lockheed Martin Aeronautics Company, “Stealth Capabilities—First and Only 24/7/365 All-Weather Stealth Fighter” (Fort Worth, Tex.: Lockheed Martin Aeronautics Company, April 11, 2012), <http://www.f22-raptor.com/technology/stealth.html>, which describes the F-22’s radar signature as “approximately the size of a bumblebee.” We take that somewhat elliptical construction as a careful attempt at precision, referring to the technical definition of RCS: the apparent size of a conducting sphere that would give the equivalent radar return. Lockheed Martin specifies not “an insect,” but specifically a bumblebee. The yellow-faced bumblebee, the most common in Southern California, home of Lockheed Martin, has a lateral cross section of about one ten-thousandth of a square meter.

53. National Research Council, *Making Sense of Ballistic Missile Defense*, p. 154, fig. 5.8.

54. George Lewis and Theodore Postol estimate the reentry vehicle RCS to be 0.01 m<sup>2</sup>. See Lewis and Postol, “Ballistic Missile Defense: Radar Range Calculations for the AN/TPY-2 X-Band

would give the same radar return at a range one-tenth as far, or 300 kilometers. The Academy report map shows that the current TPY-2 radar,<sup>55</sup> now used to detect missile warheads as part of the terminal high altitude air defense system, has a range of about 1,500 kilometers so that radar could see the smaller target at 150 kilometers. Other calculations derive a range of 550 kilometers for the Aegis radar against a missile warhead target with an RCS of 300 square centimeters,<sup>56</sup> which implies that the same radar could detect a 1-square-centimeter target at 132 kilometers. No one should claim both that radars can see nuclear-armed missile warheads at hundreds, even thousands, of kilometers, and that stealthy aircraft are simply invisible to large, powerful ground-based radars. These calculations imply that patrolling over China searching for surface targets will be dangerous and potentially costly. This finding does not mean stealth is useless; it is better to have a smaller RCS, and in fighter-against-fighter duels the F-22 will be formidable. Even advanced stealth aircraft, however, cannot roam over mainland China with impunity; they will still need to exploit survival tactics such as terrain masking, jamming, and suppression of enemy radar through active attack when entering areas covered by large ground radars.

Moreover, as with infrared, ground vehicles can adopt stealth techniques of their own against penetrating aircraft radars—and often more easily and cheaply than aircraft can. As with infrared, aircraft surfaces that deflect radar signals must also serve as aerodynamic surfaces, so performance compromises and increased costs are inevitable with stealth. In contrast, a truck that is towing missiles can separate the function of transport and low RCS. For example, coverings that deflect or absorb radar energy can be added that need serve no additional function. Surface targets must be resolved against a complex radar background unlike aircraft, which are seen by surface radar against the blackness of outer space, so trucks can add nonstructural coverings not simply to reduce signatures but to create patterns that will confuse automatic pattern recognition.

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and NAS Proposed GBX Radars,” *mostlymissiledefense* blog, September 21, 2012, <http://mostlymissiledefense.com/2012/09/21/ballistic-missile-defense-radar-range-calculations-for-the-antpy-2-x-band-and-nas-proposed-gbx-radars-september-21-2012/>. Lewis and Postol calculate a range half as great as that in the National Academy of Sciences report; our treatment above is thus conservative.

55. Missile Defense Agency, “Navy/Transportable Radar Surveillance (AN/TPY-2),” fact sheet (Fort Belvoir, Va.: Missile Defense Agency, U.S. Department of Defense, July 2014), [http://www.mda.mil/global/documents/pdf/an\\_tpy2.pdf](http://www.mda.mil/global/documents/pdf/an_tpy2.pdf).

56. George Lewis and Theodore Postol, “Ballistic Missile Defense: Estimating the Range of an Aegis Radar against a Missile Warhead Target,” *mostlymissiledefense* blog, October 23, 2012, <http://mostlymissiledefense.com/2012/10/23/438/>.

Mobile surface targets have other deception options unavailable to aircraft. If missile-towing trucks can add panels to reduce radar signatures, similar panels can be added to other trucks to make them resemble missile launchers. Trucks can hide in forests or among buildings, even staying on the far side of a searching radar, whose position will be revealed by its own emissions.<sup>57</sup> Large numbers of cheap Quonset-hut-like structures, opaque to radar, could provide occasional concealment but would almost always be unoccupied and thus inefficient to attack. Other decoys are easy and cheap; for example, a private Russian firm has developed entire inflatable decoy S-300 anti-aircraft missile batteries,<sup>58</sup> and the majority of "tanks" that were destroyed during the NATO air campaign against Serbia were almost certainly decoys.<sup>59</sup> Both air and surface combatants can exploit jamming, but the surface vehicles carrying jammers will be far cheaper. Finally, high-value ground targets can protect themselves with short-range terminal defenses, including radar-controlled guns.

Aircraft can also exploit radio signals emitted by mobile targets. Being mobile is probably essential for survival on the modern battlefield, but mobility creates new demands for wireless communication. Militaries always try to intercept each other's communications to glean intelligence. Communications intelligence typically requires code-breaking, which cannot be guaranteed. But even without the reading of messages, much is revealed just by analysis of the signals (i.e., SIGINT). In particular, mobile assets must communicate with higher commands and each other, risking intercept and identification of the target's location. Something as routine as rendezvous with a fuel truck requires either very rigid procedures that themselves can be exploited by an attacker or communication among mobile units that an attacker might detect.

Cold War U.S. SIGINT against Soviet mobile missiles was highly successful to an extent that has only recently been documented.<sup>60</sup> This record raises hopes

57. In the 1991 Iraq War, Iraqi Scud missile crews used similar techniques to prevent U.S. searchers from finding and killing even a single confirmed launcher. See Elliot A. Cohen, *Gulf War Air Power Survey*, Vol. 2: *Operations, Effects, and Effectiveness* (Washington, D.C.: Government Printing Office, 1993), pp. 330–340, <http://www.afhso.af.mil/shared/media/document/AFD-100927-067.pdf>.

58. Alexander Marquardt, "Russia's High-Tech Military Turns to Inflatable Weapons," *ABC News*, October 12, 2010, <http://abcnews.go.com/Technology/International/russias-inflatable-military/story?id=11856527>.

59. Paul Beaver, "How Yugoslavia Hid Its Tanks," *BBC News*, June 25, 1999, <http://news.bbc.co.uk/2/hi/europe/377943.stm>.

60. Austin Long and Brendan Rittenhouse Green, "Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy," *Journal of Strategic Studies*, Vol. 38, Nos. 1–2 (2015), pp. 38–73. Long and Green argue, however, that locating conventional launchers is more challenging than locating nuclear missiles.



that SIGINT could be used to find and destroy Chinese mobile missiles.<sup>61</sup> Yet there is no fundamental physical basis for a searcher's advantage. The Soviets were sloppy in their communication systems' design and procedures and grossly underestimated U.S. capability to intercept messages.<sup>62</sup> That, combined with highly proficient U.S. intelligence, made it possible to deduce Soviet missile locations. Perhaps China will repeat well-documented Soviet mistakes or make new ones of its own, and perhaps U.S. intelligence will continue to find ways to exploit those mistakes; tight communications security across a sprawling system of moving platforms is a challenge for any organization. Yet the United States cannot guarantee that China will make such errors. Iraqi Scud missile units in 1991, by contrast with similar Soviet units, proved able to maintain communications security to a degree that protected them from American detection and attack: there were no confirmed Scud kills by U.S. searchers in 1991.<sup>63</sup> Certainly the physical fundamentals are such that a proficient superpower can substantially protect itself if it makes the effort. Low-probability-of-intercept communications technologies, for example, can require SIGINT searchers to loiter for extended periods near their quarry to detect its signals; loitering airborne searchers large enough to kill targets will be vulnerable for the reasons noted above. Very small stealthy drones might be more survivable in this role, but would be unable to carry weapons sufficient to kill their targets; for them to transmit data sufficient to track and kill mobile targets from distant platforms in safe locations creates communications intercept vulnerabilities for the drones (or the shooters).<sup>64</sup> Ground-based mobile

61. Paul Bracken, "The Cyber Threat to Nuclear Stability," *Orbis*, Vol. 60, No. 2 (Spring 2016), pp. 188–203.

62. A. Andronov, "The U.S. Navy's "White Cloud Spaceborne ELINT System," *Zarubezhnoye Voyennoye Obozreniye* [Foreign Military Review], No. 7 (1993), pp. 57–60. Translation by Allen Thomson.

63. Cohen, *Gulf War Air Power Survey*, Vol. 2, pp. 330–340.

64. U.S. submarines could play an important ASB role as missile delivery platforms in such a concept, using their stealthiness to approach close to the Chinese shoreline to reduce flight times for missiles attacking Chinese mobile land-based targets. See, for example, Owen R. Coté Jr., *The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines*, Newport Paper No. 16 (Newport, R.I.: Naval War College, 2003), pp. 86–87; and Van Tol et al., *AirSea Battle*, pp. xv, 64. In particular, Coté proposes an approach for integrating such submarine missile platforms with small drones to detect radar signals and locate the emitters using time-of-arrival analysis. See Owen R. Coté Jr., "Submarines in the AirSea Battle," paper presented at the Submarine Technology Symposium, Johns Hopkins Applied Physics Laboratory, Baltimore, Maryland, 2010; and Owen R. Coté Jr., "How Will New Submarine Sensors and Payloads Influence Naval Warfare in the 21st Century?" interview, *Information Dissemination* blog, <http://www.informationdissemination.net/2012/06/how-will-new-submarine-sensors-and.html>. In our context, this concept faces several challenges, however. The drones' low-resolution antennas make them susceptible to jamming and spoofing, and they must survive in a challenging air-defense environment. The submarines, moreover, would reveal their positions when launching missiles.

systems also have options that airborne searchers do not. For example, mobile ground systems could broadcast only far enough to be picked up by fixed repeaters or terminals connected to landlines. Moreover, a multitude of cargo trucks, even cars, could be fitted with cheap decoy transmitters that would occasionally mimic actual launchers. Very-short-range ground communication could exploit extremely high radio frequencies absorbed by the air, making long-range intercept virtually impossible, a tactic not available to aircraft operating hundreds of kilometers from the nearest friendly radio receiver.

Instead of aircraft, the United States could use satellites for surveillance to find mobile surface targets. Like aircraft, satellites could be passive, looking at visible or infrared light, or use active radar. A satellite has a minimum orbital altitude and therefore a minimum distance to the surface, which requires the sensor aperture to be larger to achieve the same resolution as a comparable airborne sensor. The satellites would therefore be large, probably weighing a ton or more. As noted above, such satellites are extremely vulnerable to ASATs deployable at a fraction of the satellite's cost and well within China's technical grasp.

None of these ASB limitations mean that A2/AD will be perfect or impenetrable, or that China will have an easy time keeping stealthy aircraft from intruding into its airspace. Effective A2/AD will be very demanding to maintain against skilled attackers. And as the Prussian military theorist Carl von Clausewitz teaches us, war is inherently uncertain, probabilistic, and subject to friction.<sup>65</sup> Helmuth von Moltke was famously uncomfortable risking all on a single throw of the dice in 1914, but given war's uncertainties a bold leader willing to take such gambles might succeed even if the odds are against this, and a defender whom the odds favor might nevertheless fail through error or misfortune.<sup>66</sup> Even a failed offensive by a proficient attacker, moreover, will surely inflict damage in spite of the best A2/AD defense—even well-defended mobile targets will take losses (and fixed targets will be highly vulnerable, as noted above). Our analysis does not imply that A2/AD will offer an impenetrable defense against a determined ASB attack.

What our analysis does show, however, is that, on balance, technological

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When close to shore, they would be exposed to counterfire from surface-to-surface missiles armed with homing torpedoes. This tactic would thus be high risk for assets as valuable as submarines in a mature A2/AD environment: the great cost of submarine launchers requires almost a hundred-to-one exchange ratio against surface radars to be cost-effective.

65. Carl von Clausewitz, *On War*, trans. Michael Howard and Peter Paret (1976; Princeton, N.J.: Princeton University Press, 1989), especially bk. 1, chaps. 3, 7.

66. Geoffrey Wawro, *Warfare and Society in Europe, 1792–1914* (New York: Routledge, 2000), p. 192.

change is progressively making defense relatively easier and offense relatively harder for skilled combatants in a long-term competition between economic peers in the Western Pacific. By 2040 this competition is likely to make it much more difficult to sustain air or surface-naval operations near enemy-controlled landmasses without systematically outspending one's enemy. The difficulty of projecting effective A2/AD over distances far beyond friendly coastlines, however, will make it very hard for China to use A2/AD to underwrite true military hegemony in the region.

This conclusion holds even if the United States does not incur the cost or risk of AirSea Battle, which is unlikely on balance to enable successful preemption of a mature Chinese A2/AD capability at a sustainable cost. ASB is both less necessary than its advocates believe and less likely to succeed without sustained expenditures that would exceed China's. In a long-term competition with a rising economic peer, ASB would thus worsen, not improve, the United States' strategic position in the region.

## *Conclusion*

Chinese A2/AD is thus a real threat to U.S. interests in the Western Pacific that cannot be averted at a sustainable cost. But this threat's magnitude is smaller than often assumed, and it will be very difficult for China to extend A2/AD's effects over distances great enough to threaten most U.S. allies if China's opponents take reasonable precautions.

The entirety of the Japanese home islands, for example, will likely remain beyond A2/AD's reach, as well as the entirety of the Philippines, the Spratleys, and the southeast coast of South Korea including the port city of Pusan. The Second Island Chain will remain well beyond China's ability to interdict sea or air traffic. All are well beyond the likely 400–600-kilometer limit on A2/AD's future reach, and thus A2/AD-imposed Finlandization is not a realistic danger for them if the West responds appropriately, even without ASB.

Taiwan, on the other hand, is only 160 kilometers from the Chinese coast; the port of Taipei is just 200 kilometers from China, and the most distant point on Taiwan is no more than 390 kilometers away. Taiwan is thus much more exposed than are other U.S. allies. This does not mean China could conquer Taiwan by invasion: a Taiwanese A2/AD system could deny China a credible invasion threat by sinking Chinese military shipping. But while Taiwan could sink Chinese invasion shipping, China can probably also sink the civilian merchant shipping Taiwan depends upon for survival: the approaches to all

Taiwanese ports are dangerously close to the Chinese mainland, and certainly well within the outer physical limits on Chinese A2/AD range.<sup>67</sup> Perhaps China would be deterred from blockading Taiwan by a U.S. threat of counter-blockade against China; perhaps not. But without such deterrence, Taiwan cannot rely on an AirSea Battle-style preemption campaign to lift a Chinese blockade by force. Unlike Japan, South Korea, or the Philippines, Taiwan thus faces a serious threat of A2/AD blockade in coming decades, and one the United States cannot easily lift.<sup>68</sup>

The Senkaku/Diaoyu Islands similarly lie within the potential range of both sides' future A2/AD capabilities. The islands lie about 340 kilometers from the Chinese coast; though they are harder for China to reach than Taiwan, it is possible that Chinese A2/AD could threaten civilian or military traffic into or out of the archipelago by 2040. But the islands also lie 425 kilometers from Okinawa, 180 kilometers from Taiwan, and 160 kilometers from the small outlying Japanese island of Ishigaki. This proximity could enable U.S. and allied missiles based on these landmasses to reciprocally threaten any Chinese traffic bound to or from the islands.

Taiwan and the Senkaku/Diaoyu thus lie within a zone in which neither side can confidently assume freedom of movement by 2040. In fact, much of the South and East China Seas share this property: they are within 400–600 kilometers of both the Chinese coast and U.S. allied controlled landmasses in Japan, South Korea, the Philippines, and indeed Taiwan itself. An allied blockade of China thus need not necessarily be limited to distant straits: allied long-range missiles targeted by survivable airborne radars may, if all allies participate, be able to close the Chinese coast to traffic directly. Far from becoming a Chinese lake, the air and ocean surface within the First Island Chain is more likely to become a wartime no-man's-land (or no-man's-sea), wherein neither side enjoys assured freedom of movement.

Large defended sanctuaries in the Chinese mainland, by contrast, can be brought solidly within Chinese control. A2/AD there will make persistent target searching and repeated attack sorties by U.S. or allied aircraft prohibitively

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67. Taiwan's eastern ports are masked from direct Chinese radar surveillance by the Chungyang Mountains, but airborne radars flying over the Chinese coast north and south of the island can track ships bound for such ports until they get within tens of kilometers from harbor.

68. On the dilemmas of defending Taiwan, see especially Charles L. Glaser, "A U.S.-China Grand Bargain? The Hard Choice between Military Competition and Accommodation," *International Security*, Vol. 39, No. 4 (Spring 2015), pp. 49–90. On the challenges facing a Chinese invasion or blockade, see O'Hanlon, "Why China Cannot Conquer Taiwan"; and Glosny, "Strangulation from the Sea?"

costly, whereas China's own air traffic will enjoy largely unmolested freedom of movement as long as it does not stray far beyond the coast.

The net result will thus be a system of competing spheres of influence in the Western Pacific: a Chinese sphere over its mainland; a U.S. sphere over most of its allies' landmasses and including most of the region's disputed island chains; and a zone of mutual exclusion in between in which neither side enjoys freedom of movement.

None of these spheres of influence, however, will be able to protect its inhabitants against the threat of coercive bombing of fixed targets via one-way trips by long-range, high-speed, guided SSMs. In fact, such missiles will eventually achieve true intercontinental range from mobile launchers beyond the reach of effective preemption. Neither side will be able to control waters or airspace in the other's sphere, but all will increasingly be able to strike discrete fixed targets for coercive effect. The balance of leverage achievable by such strikes will be shaped by a host of situational variables, and mutual vulnerability could create either mutual restraint or rapid escalation; to assess such campaigns is beyond our scope. But A2/AD technologies will make such strikes possible for an increasingly wide range of parties over time, and ASB will be unable to prevent China from being among these.

These projections, however, are based on two key conditions. First, they assume that each side can use advanced technology to its full potential. Many recent U.S. opponents have not been able to employ complex technology effectively, and even the Soviet Union failed to maintain the security needed to protect mobile missiles from U.S. SIGINT during the Cold War.<sup>69</sup> In continental warfare, many great powers failed to master complicated modern-system force employment, and variations in such behavior have been more important than technology per se for observed outcomes.<sup>70</sup> A2/AD's air and maritime warfare involves fewer combatants and simpler military environments than continental land combat, but that does not make A2/AD simple. If China proves unable to master the complexity of A2/AD from mobile platforms, then U.S. airpower might be able to contest airspace even over mainland China.

Second, the projections above assume that each side adopts the critical A2/AD technologies. If China does so, what must the United States do to limit their A2/AD threat to the projection above?

The answer is a combination of policy decisions and acquisition of a handful of modernization programs that are technologically feasible and affordable by

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69. Long and Green, "Stalking the Secure Second Strike."

70. This is the central finding of Biddle, *Military Power*.

comparison with ASB, but which are not now under way. As for the latter, the United States will need a new long-range, high-speed, anti-radiation missile designed to destroy airborne radars from launch points beyond the radar's acquisition limit. Today's AGM-88 HARM has a reported effective range of about 150 kilometers;<sup>71</sup> a range of at least 600 kilometers would be preferred to defeat improved Chinese airborne target acquisition. To achieve this range will require a larger, heavier missile, which will increase its cost and reduce the number that can be carried by available launch platforms; ramjet propulsion may be necessary to attain the needed combination of speed and range. But none of these requirements are beyond today's state of the art, and none would produce a missile whose cost would exceed its target's.

The United States must also be able to neutralize any satellite-based sea surveillance systems China may deploy. Neutralization may be possible with cyber or other soft-kill approaches, but it will probably be necessary to maintain a hard-kill ASAT capability for this purpose. If Chinese space-based radars are allowed to function, continued growth of Chinese long-range missile capabilities will eventually enable an A2/AD system that really could threaten targets out to the Second Island Chain. A U.S. capability to deny this is thus critical if Chinese A2/AD range is to be constrained to the limits presented above.

This ASAT capability may not require any new equipment: the United States' existing Patriot PAC-3 is reportedly sufficient to threaten any Chinese sea-surveillance radar satellite, and the U.S. military demonstrated an air-delivered ASAT system with the needed performance as early as the 1970s.<sup>72</sup> More efficient or less destructive options may be desirable and possible, but are not strictly necessary.

Instead, the key requirement could be to avoid policy decisions that would preclude U.S. use of existing systems against Chinese satellites in wartime. Many analysts now believe that mutual ASAT bans would benefit the United States, given its heavy reliance on space. ASAT limitations raise larger questions of the value of international cooperation. But in strictly military terms, it is unclear that mutual sanctuary for military satellites favors the United States. In fact, it could enable a far more extensive Chinese military reach in the future

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71. Carlo Kopp, "Texas Instruments (Raytheon) AGM-88 HARM," *Air Power International*, Vol. 4, No. 1 (December 1998; updated January 27, 2014), <http://www.ausairpower.net/API-AGM-88-HARM.html>.

72. See, for example, Peter Grier, "The Flying Tomato Can," *Air Force Magazine*, Vol. 92, No. 2 (February 2009), <http://www.airforcemag.com/MagazineArchive/Pages/2009/February%202009/0209tomato.aspx>.



Western Pacific than it could possibly achieve without space access. Access to space makes U.S. military operations cheaper and more efficient, but as we note below, the United States enjoys a variety of alternatives to military satellites that could allow operations even without it. For the Chinese, by contrast, survivable sea-surveillance radar satellites would make the difference between accepting a U.S. sphere of influence covering much of the Western Pacific and the opportunity to threaten U.S.-allied commerce out to or beyond the Second Island Chain. For China, the military difference between satellites and their absence is thus important in ways that go far beyond efficiency.

The United States must also take steps to establish its own A2/AD zone against China. In particular, new antiship missiles will be needed with the range to exploit U.S. RSTA potential. Today's AGM-84 Harpoon has a maximum range in excess of 125 kilometers, but likely well short of the 600 kilometers that might take full advantage of modern airborne radars.<sup>73</sup> The Harpoon is also subsonic; a higher-speed, stealthy, longer-range missile would be preferable. Here, too, the resulting missile will be larger, heavier, and more expensive than today's Harpoon, but the resulting weapon would still be far less expensive than its targets.

Such missiles will require launch platforms not tied to fixed bases, which will be increasingly vulnerable to Chinese missile attack at ranges well beyond A2/AD's 400–600 kilometer limit against mobile targets. Many candidate platforms are available for this role, ranging from surface naval combatants to submarines to carrier-based aircraft to land-based aircraft operating from field-expedient runways, or others. The very-long-range bombers often favored by ASB proponents are thus not required for this role—nor is the stealth such large aircraft would need to penetrate defended airspace.

It would also be militarily advantageous for U.S. allies to consider deploying A2/AD capabilities of their own, including long-range mobile SSMs to parallel China's.<sup>74</sup> The latter in particular could be helpful in deterring Chinese fixed-target coercive strikes that ASB is unlikely to be able to preempt.

Given U.S. treaty constraints, allies seeking such long-range SSMs will have to develop them as indigenous programs. The 1987 Intermediate-range

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73. For Harpoon range, see Boeing, "Harpoon Block II" (St. Louis, Mo.: Boeing, March 2013), <http://www.boeing.com/assets/pdf/defense-space/missiles/harpoon/docs/HarpoonBlockIIBackgrounder.pdf>.

74. For similar proposals, see, for example, Toshi Yoshihara, "Going Anti-access at Sea: How Japan Can Turn the Tables on China" (Washington, D.C.: Center for a New American Security, 2014); and Terrence Kelly et al., *Employing Land-Based Anti-Ship Missiles in the Western Pacific* (Santa Monica, Calif.: RAND Corporation, 2013), [http://www.rand.org/pubs/technical\\_reports/TR1321.html](http://www.rand.org/pubs/technical_reports/TR1321.html).

Nuclear Forces Treaty prohibits U.S. deployment of ground-launched cruise and ballistic missiles with ranges of 500 kilometers to 5,500 kilometers.<sup>75</sup> Nor can the United States assist its allies in deploying such weapons themselves without violating its obligations under the 1987 Missile Technology Control Regime, an agreement that precludes transfer of technology needed to develop missiles with a payload of 500 kilograms or more and a range of 300 kilometers or more.<sup>76</sup> Although the net utility of these agreements is beyond our scope, it is worth noting that the United States can meet both its military requirements and its obligations under these agreements if it chooses air- or sea-basing for modernized U.S. missiles (or if it restricts their range to 500 kilometers), and if American allies with the technical capacity to do so (such as Japan or South Korea) deploy such missiles as indigenous programs.

It will also be important, as noted above, to limit U.S. military vulnerability to Chinese antisatellite systems. Preemption of Chinese ASAT capability will not be a viable option, as this can be made mobile and survivable. Hardening or signature reduction for key satellites should be explored but is unlikely to succeed. Redundancy and reconstitution are a losing game in a long-term competition: the United States could replace lost satellites, but the Chinese could always destroy the new ones, spending less with each iteration than the United States. Reduced dependence is thus probably the better long-term strategy. All the truly critical mission requirements of establishing U.S. A2/AD and constraining China's can be accomplished without space: surveillance, target acquisition, and guidance can all be provided by airborne platforms that can be made independent of fixed bases; communications can be provided by airborne relays and links; and navigation can be accomplished via natural celestial or terrestrial reference points. Of course, any of these alternatives would be more expensive than today's reliance on space-based capabilities. And in many scenarios, today's satellites will not be attacked. The United States should certainly not stop using space; but in a high-stakes confrontation with China, it cannot assume that its satellites will survive. Hence the United States will eventually need to build survivable airborne alternatives sufficient to enable continued operations after mutual ASAT use has destroyed both sides' military satellites. This will require important investments, but far less than a thoroughgoing ASB capability would demand.

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75. "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, <http://www.state.gov/t/avc/trty/102360.htm>.

76. U.S. Department of State, "Missile Technology Control Regime," fact sheet (Washington, D.C.: U.S. Department of State, March 4, 2009), <http://www.state.gov/t/isn/rls/fs/120017.htm>.

It will also be increasingly important for U.S. forces to practice aggressive electronic emissions control (to reduce U.S. vulnerability to Chinese SIGINT). Strict EMCON has always been important, but against a mature A2/AD threat it will be especially vital. By some accounts the U.S. Navy has grown careless in this discipline through years of operations in benign environments;<sup>77</sup> by 2040, however, poor U.S. EMCON could underwrite a major expansion in China's A2/AD reach with grave consequences for U.S. security.

It is just as important, though, to be clear on what is not needed: the analysis above implies that AirSea Battle is not required for U.S. security in the Western Pacific, nor must the United States accept the costs and risks associated with its requirement for massive preemptive attack against Chinese land-based missiles and infrastructure located deep in mainland China. Our analysis implies no need to redesign or fundamentally restructure the U.S. Navy and Air Force to cope with Chinese A2/AD. A number of more limited changes are needed, but the analysis above does not imply a case for transformational change to meet the threat of A2/AD in the Western Pacific—incremental updating on the margins of existing U.S. capabilities and programs is sufficient.

Our analysis also has implications for scholarship in strategic studies and international relations. For offense-defense theorists, for example, our analysis suggests that the offense-defense balance (ODB) in the Western Pacific may be shifting toward defense—but only if both the United States and China continue to modernize. A defense-favorable ODB may dampen arms race incentives, but failure to modernize would undermine any stabilizing effects and some of the needed policies (e.g., a U.S. ASAT capability) are often considered provocative. An offense-defense balance that could underlie a less competitive political relationship with China might thus require a more competitive military relationship than some analysts would prefer. More broadly, the political effects of the military requirements for a more defense-oriented Pacific ODB warrant further consideration.

Perhaps most important, our findings show the critical need for further research on the determinants of skilled force employment and the prospects for effective Chinese use of the technologies considered above. Following the A2/AD/ASB debate, we have assumed that a Chinese superpower (unlike Iraq or Afghanistan) will be able to develop and use complex technologies to their full potential. This assumption may or may not be sound, however,

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77. See, for example, Jonathan Greenert quoted in Sydney J. Freedberg Jr., "CNO Adm. Greenert Emphasizes Navy's Bright Future, Not Budget Crisis," *Breaking Defense*, March 12, 2013, <http://breakingdefense.com/2013/03/cno-adm-greenert-emphasizes-fleets-bright-future-not-budget-c/>.

and for now the needed social science on the determinants of force employment is seriously underdeveloped relative to the physics on which the projections above are mostly built. Given China's importance for U.S. security, reducing these uncertainties through further research must be a high priority for scholarship.

There are also some important limitations to the technical analysis above. We have not considered cyber capabilities in any detail, for example; this is an important priority for further research.

Nor are the findings above a conclusive case for or against any particular acquisition program or force structure. We assess one theater and one prospective opponent in the context of political stakes now typically assumed for that theater and the campaign dynamics these imply. The U.S. military must prepare for many theaters and many opponents, however. Defense planning must thus account for a wider range of possibilities than just future warfare in the Western Pacific; programs such as a future stealth bomber that our analysis suggests may be less cost-effective for the future Western Pacific than many now assume may nevertheless be justifiable in light of other opponents and other scenarios not assessed here. Of course, the future Western Pacific has been an unusually important scenario in the debate over U.S. acquisition programs and force structure; given this, the case for a future stealth bomber or other such programs may be weakened at the margin if their utility in an oft-cited scenario is lower than sometimes claimed. This is not a dispositive finding for such programs, however, in the absence of a broader analysis. Nor do we argue that all elements of ASB are unwise—above we argue for longer-range U.S. HARMs and antiship missiles, a recommendation consistent with many ASB proponents' calls for increasing U.S. forces' reach.

What we can establish, however, is that the A2/AD threat at the heart of this debate is real, but limited. Broad trends in technology will make it possible for China to bring the recent era of U.S. command of the global commons to an end in coming decades if the Chinese pursue the required technologies and use them to their full potential. AirSea Battle will not prevent this. Yet the result need not be a new era of Chinese regional hegemony—with astute choices, the long-term military prognosis in the Western Pacific is neither U.S. nor Chinese dominance but a future of competing spheres of influence in a system where most U.S. allies will find themselves imperfectly, but substantially, secure.