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2035 Air Dominance Requirements for State-On-State Conflict

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The defensive form of warfare is intrinsically stronger than the offensive.

—Carl von Clausewitz

In 2035 some states' integrated air defense systems will be able to find, fix, track, target, and engage our current air dominance aircraft. US operations in this environment may prove costly and threaten heavy aircraft losses. Worse, decisive air operations, the hallmark of US military strategy for nearly 60 years, may not be possible in hyper-defended airspace.[1] As one commentator put it, "the US is confronted with a strategic choice: to risk loss of military access to areas vital to its national security or to explore options for preserving access."[2]

Unlike the 1970's stealth revolution, there is no "silver bullet" technological solution to the 2035 air dominance problem. The United States is unlikely to achieve unimpeded access using radio frequency, infrared, and electro-optical cloaking technologies alone.[3] Therefore, the United States needs to reevaluate its overall air dominance strategy to ensure it can gain initial access in this new, hyper-defended airspace to enable follow-on, high tempo US operations. Prevailing in this future environment requires holistic approaches using concepts of operations that integrate varied capabilities, capacities, and tactics to create a US advantage. The challenge (and the risk) lies in choosing among several available alternatives at a time when budgets are tight, the threat is still developing, and consensus is lacking on the best way to proceed.

To make these choices, senior policy makers need a framework and approach to evaluate the developing environment and assist in making investment choices. This paper's purpose is to develop such a framework through a five-part analysis. The first part provides a review of US technical challenges from potential enemy states. Future strategic, operational, and tactical challenges set the stage in this segment of the analysis. The second section examines competing air defense network models, breaking down how the United States might engage an opposing network to gain access. The next part defines a three-tiered approach (operations view, systems view, and acquisition view) to analyze alternative strategies against future adversary networks. Using this approach, the fourth section then examines three concepts of operations the United States may employ to gain access into hyper-defended enemy states. With these four steps completed, the final analysis outlines investment options and recommendations for technical opportunities to properly posture air dominance assets for 2035 decisive combat operations. The analysis begins by exploring the future strategic challenges the United States faces in 2035.

2035 Challenges

Strategic Challenge: Reaching the Battlespace

Since World War I, the United States has not been challenged in deploying its air dominance platforms to forward bases to execute combat operations.[4] This could change as modern states begin to level the formerly US-dominated, technological playing field. States use various collaboration methods through a global, web-enhanced platform to rapidly increase their technological capabilities.[5] One example is China's recent stealth fighter development. The J-20 appears to rival the F-22 in size, range, weapons load, and air defense capabilities. Although the J-20's status (prototype or technology demonstrator) is unknown, this aircraft could enter production in 8–10 years.[6] As a result, the United States must modify its widely held assumptions that "time is on our side, we have unfettered forward access with unhampered logistics and we can achieve air/sea superiority quickly."[7]

Regarding geophysical factors, China possesses strategic depth and layered interior defense lines which complicates reaching this potential battlespace. These defense systems include the DF-21D long range ballistic missile which has the capability to disrupt and/or deny US forward airbases and aircraft carrier capabilities.[8]

The South China Sea is divided into the first and second island chain (fig. 1). The DF-21D, if fully operational, could reach all current forward bases in the region except perhaps Guam. Therefore, the United

States must consider all current forward bases vulnerable to attack and powerless to enable decisive combat operations.

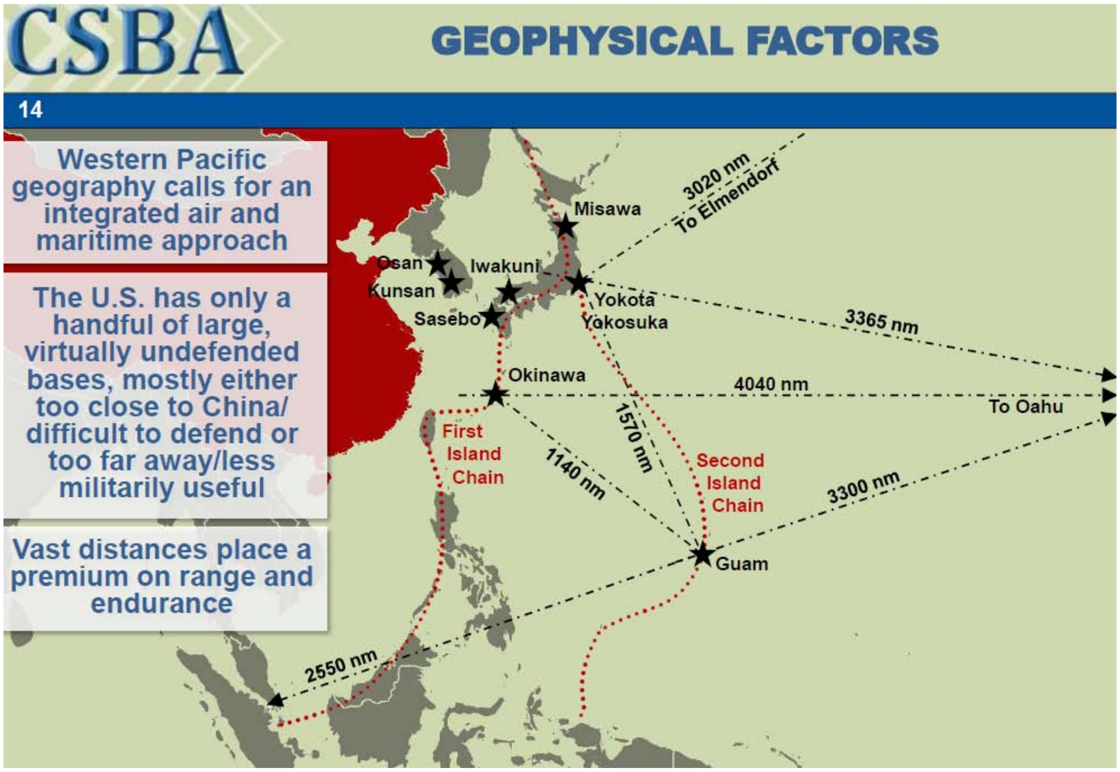

Figure 1. China's geophysical factors (*Reprinted from* Center for Strategic and Budgetary Assessments [CSBA], http://www.csbaonline.com/4Publications/PubLibrary/R.20100518.Slides_AirSea_Batt/R.20100518.Slides_AirSea_Batt.pdf).

In the absence of US theater missile defense capabilities and hardened sheltering at US forward bases, the United States is forced to operate from longer distances. Increased distances, such as missions from Guam, will drive increased sortie durations thus resulting in reduced available sorties over a given period of time. A nominal daily sortie rate for a 500 nautical mile (nm) combat radius is 3.94 sorties per aircraft per day. If the combat radius increases to 2250nm, the rate drops to 1.79 sorties per aircraft per day.[9] Therefore, US strategic planners must balance available long range air dominance platforms, their sortie requirements, and the time necessary to achieve combat objectives.

Summing up the strategic challenge, the increased threat to forward bases coupled with geophysical factors, reduces US air power projection capability. This challenges our traditional approach with its heavy reliance of forward basing and produces new requirements for increased range and improved survivability of all air-dominance platforms. Except the B-2 stealth bomber, air-dominance platforms may be unable to reach the battlespace without significant tanker support. This strategic "stiff arm" drives a requirement for more platforms due to fewer available sorties, amplifies air refueling requirements, and ultimately, slows the traditional tempo of US air operations.[10] This leads to the next hurdle: getting these limited number of air dominance platforms into the battlespace.

Operational Challenge: Penetrating the Battlespace

States with advanced defense networks could develop traditional and nontraditional means to detect and engage US air dominance platforms entering their battlespace. States possessing traditional, monostatic air defense networks, like Iran, may obtain more advanced air defense systems (i.e., Russian SA-20s) to significantly improve their air defense capabilities.[11] These systems with engagement ranges exceeding 100nm and advanced radar processing technology put current

US aircraft at risk. Advanced states may pursue more advanced means, such as bistatic radars, to improve their capabilities. Bistatic radar is the term used "to describe the orientation of the radar system in which the transmitting and receiving antennas are physically separated (fig. 2).[12] Therefore, US stealth platforms may find they are unexpectedly vulnerable in this new battlespace.

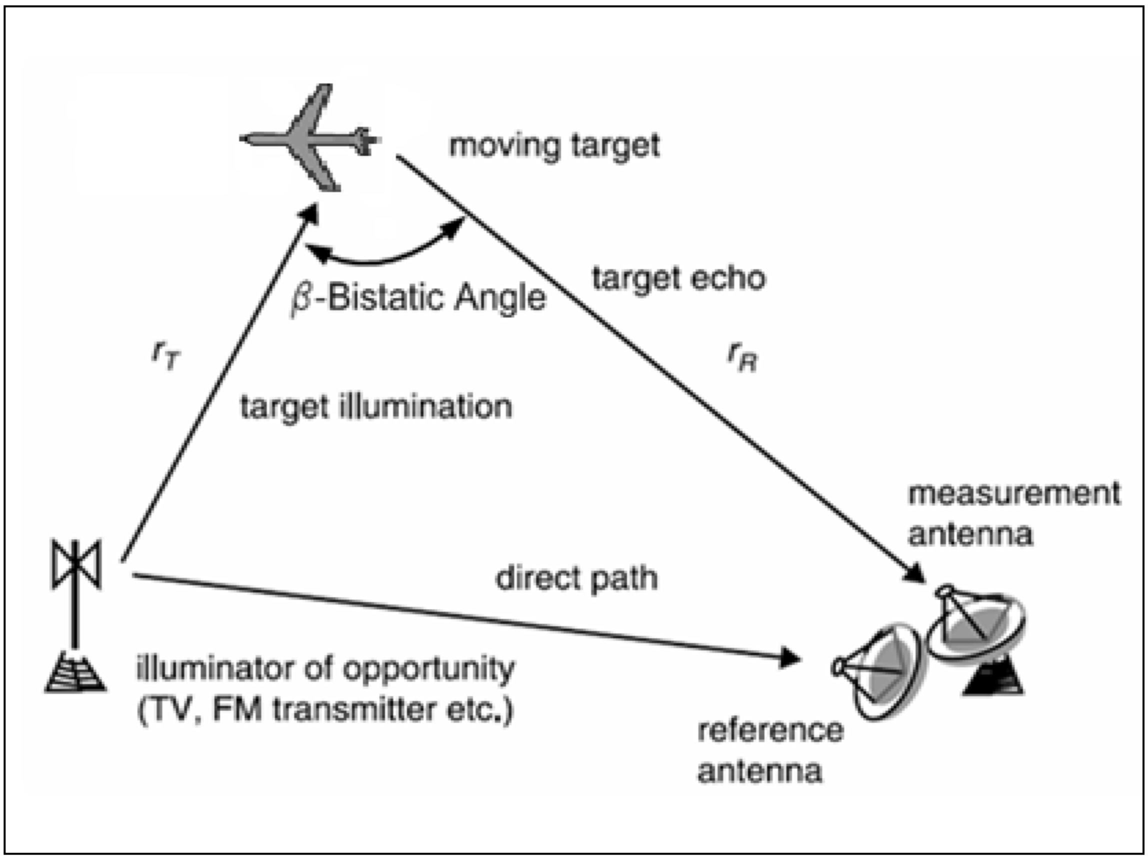

Figure 2. Bistatic radar operation (*Reprinted from* John Franklin, "Passive Bistatic Radar," www.cse.unt.edu/~rakl/john-proposal.ppt [accessed 3 January 2011]).

Bistatic radars do not have to be military acquisition and target tracking radars. Transmitters, or illuminators of opportunity, can take the form of television, radio, or mobile phone antennas and can be modified into a bistatic configuration. These "passive coherent locations .

. . coupled with sensitive receivers could track stealth aircraft."[13] If these radar configurations come to fruition, US tactical planners would have difficulties distinguishing traditional military radar systems from civilian systems. This would, in turn, make targeting problematic.

As software and processing technology continue to improve, bistatic radar systems could quickly render current stealth technology obsolete. Current stealth aircraft shape and design help minimize detection from traditional, monostatic configurations.[14] However, bistatic configurations with advanced signal processing capability could "exploit radio signals already plentiful in the atmosphere rather than generating its own target beams."[15] In response, the United States may need to use cyber attack against signals processing centers to support air dominance platforms.

Summing up the operational challenge, traditional monostatic surface-to-air missiles and more advanced bistatic radars could prevent US air dominance platforms from penetrating the battlespace. Increased computer signal processing is required to reach this level of access denial. Difficulties in targeting threat transmitters and passive receivers further complicate the problem. US planners may need cross-domain alternatives for air dominance platforms to aid in their survival. This leads to the next hurdle in future air dominance: completing mission objectives in hyper-defended airspace.

Tactical Challenge: Employing in the Battlespace

Given the developments in directed energy technologies, hyper-defended battlespaces challenge not only aircraft survivability, but also weapon survivability. Laser weapons provide an affordable point defense against aircraft and their weapons.[16] This is why the entire enemy kill chain, not just the parts, must be analyzed against US capabilities. If air dominance platforms launch weapons that never survive to the target, then the capabilities to reach and penetrate the battlespace become negated.

In future hyper-defended airspace, surface-to-air missile systems will function to kill delivery platforms while point-defense lasers will serve to target inbound weapons (and aircraft if they stray within range).[17] The United States has successfully demonstrated a megawatt-class, chemical oxygen iodine laser.[18] Current assessments reveal a 100 kilowatt chemical laser has enough power to destroy an aircraft and cruise missiles at long ranges (fig 3).[19] Laser beam quality continues to improve and will be the primary driver for future directed energy system successes.[20] Therefore, planners should expect advanced states to obtain lasers with speed of light targeting capabilities to destroy US platforms and weapons.[21]

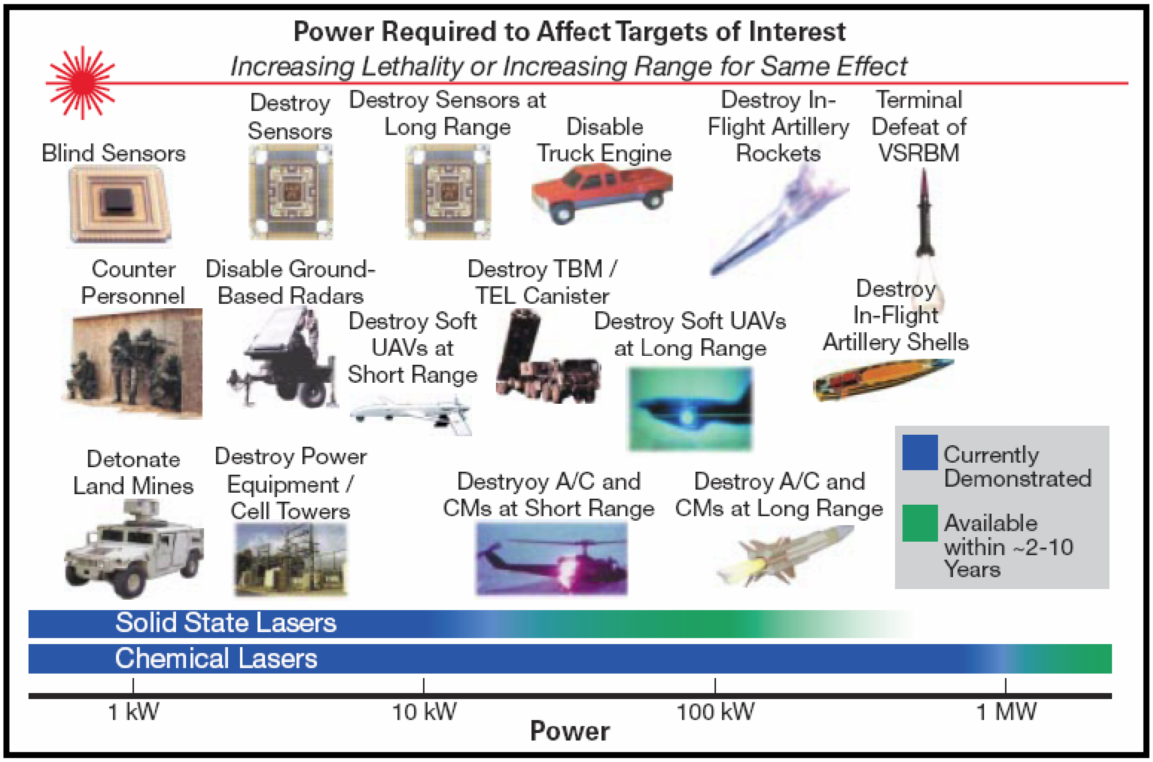

Figure 3. Laser power requirements to affect targets (*Adapted from* Richard J. Dunn, "Operational Implications of Laser Weapons," Northrop Grumman Analysis Center, http://www.northropgrumman.com/analysiscenter/paper/assets/Operational_Implications_of_La.pdf, 7 [accessed 20 November 2010]).

Widespread laser introduction could drive increased weapons requirements to ensure target destruction. Today, air dominance platforms may only require one or two weapons to achieve a desired destruction level. However, a hyper-defended battlespace (with point defense laser systems) may require dozens of weapons to ensure one or two arrive at the target. As a result, US planners may have to modify employment strategies to meet this requirement for mission success.

Summarizing the tactical challenge, directed energy weapons may defeat US air dominance platforms and weapons while employing in hyper-defended battlespace. This would change US acceptable risk level calculations. Therefore, the United States may need to dedicate significant resources toward developing laser countermeasures for air dominance platforms and weapons. Put simply, "to leverage this emerging laser capability, we need operational concepts to guide our investment of laser technology."[22] However, before rushing into planning operational concepts verses one specific threat, US planners must first understand the overall enemy air defense network and the proper approach to defeat it.

Understanding Air Defense Networks

Whether an air defense network is a traditional, monostatic network or an advanced bistatic network, its relative capability depends on both sides' assessment of the network's strengths and vulnerabilities. The result is technological and operational competition where the defender seeks technologies to shore up and mitigate the vulnerabilities of his network (capabilities to enhance), while the aggressor seeks to exploit these same vulnerabilities in order to defeat it (capabilities to defeat). Various command and control assets, platforms, sensors, and weapons comprise these networks. Network capabilities can be thought of in terms of the dynamic targeting steps in Air Force doctrine.[23] These capabilities are to find, fix, track, target, engage, and assess opposing forces. An antiaccess/area denial state tries to enhance their network while opposing air dominance forces seek to defeat this same network.

Air Defense Network Breakdown

GENERAL TECHNOLOGY to DEFEAT	NETWORK CAPABILITIES	SPECIFIC TECHNOLOGY to ENHANCE
Stealth/Space/Cyber	**FIND**	Passive/Bi-Static Radars
Stealth/Space/Cyber/ Electronic Warfare	**FIX**	Passive/Bistatic Radars
Stealth/Electronic Warfare/ Hypersonic	**TRACK**	Passive/Bistatic Radars
Stealth/Electronic Warfare/ Hypersonic	**TARGET**	SA-20: Surface-to-Air DF-21D: Surface-to-Surface
Stealth/Deception(Decoys)/ Electronic Warfare/ Hypersonic	**ENGAGE**	SA-20/DF-21D/Directed Energy (Lasers)
N/A to this Discussion	**ASSESS**	N/A to this Discussion

Combinations of stealth, space, cyber, and intelligence, surveillance, and reconnaissance (ISR) technologies are needed to avoid detection. In addition, operational techniques such as decoy, deception, swarming, and saturation enhance the ability of air dominance platforms to avoid being tracked and targeted. As a result, the network must be deconstructed and analyzed sufficiently to determine which red capabilities must be countered and how to accomplish it.

Summing up, advanced air defense networks and robust technological enhancements will challenge future air dominance objectives. US planners must dissect enemy networks to understand their capabilities and their associated enabling technologies. They must determine whether to leverage existing cross-domain capabilities or develop new requirements to invest in future technologies. The challenge is where to begin. Strategists need a simple methodology to aid in problem solving and determine appropriate requirements to guide follow-on decisions.

Problem Solving Approach: A Requirements Model

US planners need a model that reviews air dominance requirements to the appropriate level of detail. Currently, the US Air Force utilizes a capability-based construct, but it is too general in nature.[24] Planners could greatly benefit from an integrated operational systems and acquisition/logistical requirements model. A detailed, multitiered construct would ensure planners thoroughly analyzed capabilities (with associated limitations) to avoid premature investment choices.

Figure 5 outlines specific requirements in a three-tiered approach to develop capabilities to meet future air dominance effects. Defeating the critical nodes of an enemy network hinges on ensuring all tiers are considered in one's requirement decisions. The first tier is operations requirements, the second is the individual systems requirements, and the third is acquisition and logistics requirements. An important consideration to note is each tier's specific requirements apply to all previous tier requirements. Failure to thoroughly plan in one tier could result in an incorrect or incomplete requirement.

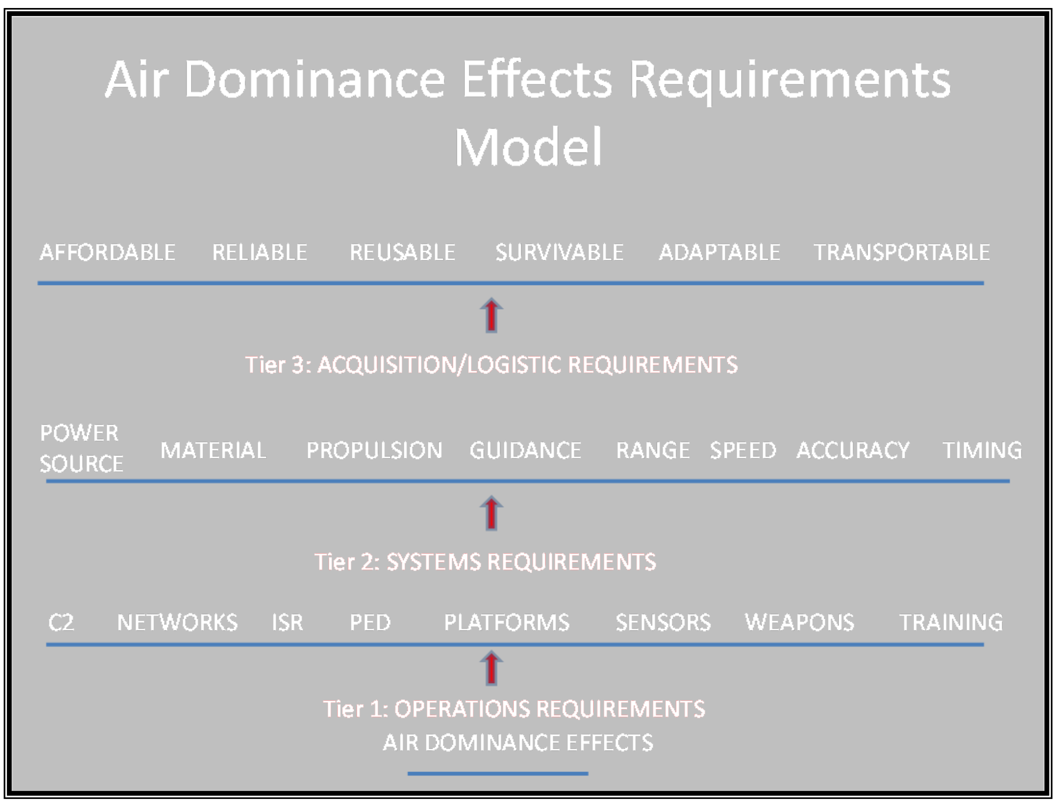

Figure 5. Air dominance effects requirement model (*Created by* the author).

Tier 1, operations requirements, consists of the basic tools used to achieve air dominance effects. Command and control (C2), networks, and ISR will continue to be the brains behind operations. The processing, exploitation, and dissemination of battlespace data may not always be pushed to operators in traditional methods. Platforms may be required to penetrate a hyper-defended battlespace or employ from standoff ranges. Sensors could reside on-board and off-board platforms to assist in penetration and precision targeting. Kinetic and nonkinetic weapons can achieve air dominance effects. Finally, the proper training through development of tactics, techniques, and procedures ensures operators are technically proficient to accomplish air dominance missions.

Tier 2, system requirements, consists of the specific parts for each operations requirement. Power source, material, propulsion, guidance, range, speed, accuracy, and timing may be similar or different when applied to each operations requirement. The power source must have a sufficient duration to accomplish the mission. The material should deny, delay, or minimize enemy detection. Propulsion needs to be powerful and efficient enough to meet specific mission requirements. Guidance ideally needs to be self-reliant and jam proof to ensure precise navigation. Range and speed will vary from platform to platform, but must be sufficient to reach and penetrate the battlespace. Accuracy is the primary driver to achieve desired weapons effects and ensure sortie and threat exposure are minimized during decisive combat operations. Finally, timing is essential in achieving synergistic effects while countering hyper-defended battlespace.[25]

Tier 3, acquisition and logistic requirements, are the determining factors when finalizing decisions for tier 1 and tier 2 requirements. Affordability, balanced with reliability, will be the primary constraint in future defense acquisition budgets. This drives the design for networks, platforms, sensors, and weapons. Reusability will depend on platform and sensor numbers and specific use. Survivability not only includes the platform reaching its launch point but also the weapon reaching its target. Adaptability must consider potential multirole usages against specific enemy network capabilities. Finally, transportability must be considered to ensure logistical requirements are attainable and sustainable before even commencing operations. In summary, using this requirements model after analyzing enemy air defense networks will aid in developing operational concepts.

Concept of Operations (CONOPS)

Concept of Operations Development

There are several definitions of a CONOPS, but for purposes of this paper, CONOPS integrates required employment capabilities with tactics and required external support to achieve the commander's objectives.[26] Accordingly, 2035 air dominance CONOPS should center on destroying, disabling, disrupting, or denying some or all aspects of the enemies' network "kill chain." Network assessment and requirements models help determine the capabilities required to achieve the desired effect. Tactics maximize capability success and minimize exposure to the network threats. Embedded and/or detached support requirements assist in attacking the enemy network long enough to achieve mission objectives.

On the left side of figure 6, air dominance capabilities and tactics are listed in the first column. The second column identifies the applicable enemy network capability. The last two columns link support level and requirements to highlight CONOPS component interrelationships. Of note, utilizing stealth capability with stealth tactics would require the lowest support because these platforms operate autonomously with on-board weapons, sensors, and countermeasures. However, this is predicated on cloaking technologies reaching maturation by 2035. Conversely, using saturation capabilities through multiplatform packaging would require a high level of support in C2 and target data dissemination.

CONOPS

(Ca Tactics + Support)

AIR DOMINANCE CAPABILITY	ENEMY NETWORK CAPABILITY	PORT VEL	PORT REQUIREMENTS
Stealth	Find/Fix	W	None
Speed (Hypersonic)	Engage	w	orm/Weapon Capability
Altitude	Engage	..	orm/Weapon Capability
Command/Control	[illegible]		Secure Network
Space/Cyber	[illegible]		Secure Network
AIR DOMINANCE TACTIC	**ENEMY NETWORK CAPABILITY**	**PORT VEL**	**PORT REQUIREMENTS**
Decoy/Deception	rget/Engage		C2/Large Numbers
Swarm/Saturation	[illegible]		C2/Large Numbers
			2/Electronic Warfare
			2/Electronic Warfare

CONOPS 1: Standoff

Standoff entails multi-domain coordination to acquire targeting data to feed standoff platforms for weapons employment. This minimizes threat exposure, but is heavily dependent on space/cyberspace to find, fix, and track enemy targets. As depicted in figure 7, the carrier strike group remains outside DF-21D range (1,500nm) while multiple launch platforms stay outside nominal enemy fighter range (500nm).[27] F-22s assist with escort, provided an air bridge is maintained. Therefore, standoff's cornerstone concept is using off-board sensors to cue multiple weapons against fixed target arrays.

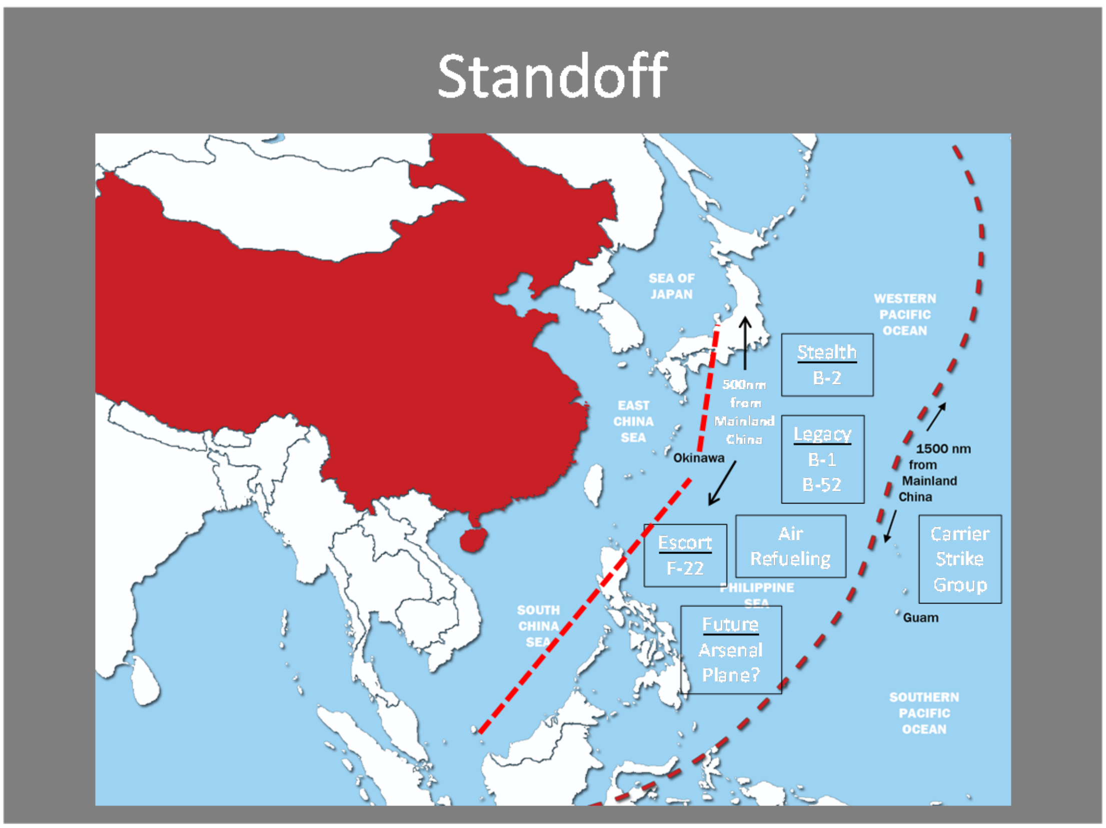

Figure 7: Standoff CONOPS: **China example** (*Adapted from* Mark A. Gunzinger, Andrew Krepinevich, and Jim Thomas, "Air Sea Battle: A point of Departure," CSBA, [2010]: 22). The original image was modified to help describe the standoff CONOPS.

At the operations requirement tier, the US command network needs to be forward based, preferably onboard the carrier strike group. Space access, bandwidth capability, and cyber security to receive satellite intelligence and disseminate to weapons platforms are major requirements. Weapons platforms, like the B-2, B-52, and B-1, could be augmented by arsenal planes to meet the high apportionment targeting requirements.[28] Ideally, hypersonic weapons would increase enemy targeting difficulties while ensuring high weapon survival rates.

From the systems requirement tier, the weapon's power source, material, guidance, range, speed, and accuracy are all important planning considerations. These need to enable fly-out ranges of several hundred miles. The material needs to possess stealth qualities, have electronic warfare attributes, or receive cyber attack support to decrease, delay, or deny detection during fly-out. Guidance and accuracy must ensure the weapon can navigate and hit within distances to achieve desired effects. Overall, weapon systems requirements are the highest priority in this CONOPS.

In the acquisition requirement tier, weapon reliability and survivability are the drivers. Anti-jam, inertially-aided weapons with self-terminal guidance (like cold atom technology) could solve this challenge.[29] In addition, weapons should be shielded from electromagnetic pulses and direct energy weapons. Therefore, affordability needs to be balanced with the overall weapon capability. In summary, standoff succeeds with unimpeded space/cyberspace access and networked command/intelligence support along with weapons able to survive to their intended targets.

CONOPS 2: Penetrating strike

Penetrating strike entails using air dominance platforms to enter antiaccess/area denial battlespace and employ self-targeted weapons. Threat exposure is high so strike platforms need advanced technologies to aid in defending against enemy defense networks. As depicted in figure 8, F-22s escort refueling platforms that remain outside nominal enemy fighter range (500 miles). B-2s or next generation bombers penetrate the battlespace for strike missions. Therefore, penetrating strike's cornerstone concept is self-targeting against fixed, mobile, and hardened arrays.

From the command network operations requirement tier, space and cyber attacks support strike platforms, but these platforms must survive/counter autonomous threats. Strike platforms require significant technological upgrades to counter bistatic radars and advanced surface-to-air missiles. Sensors and weapons need to counter laser defenses long enough to successfully guide weapons to their targets. Limited platform numbers equals lower available sorties which increases the time required to complete decisive combat operations. Overall, these low density, high demand strike platforms can be single points of failure without proper design capabilities.

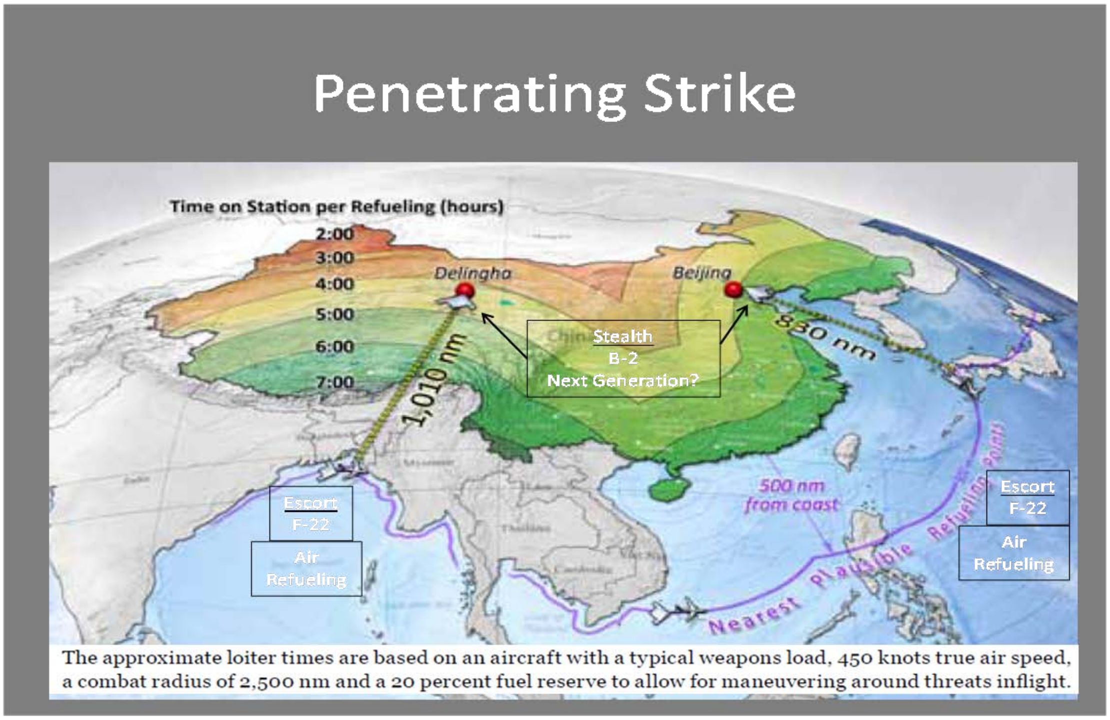

Figure 8. Penetrating strike CONOPS: China example (*Adapted from* Mark Gunzinger, "Sustaining America's Strategic Advantage in Long-Range Strike" [Washington, DC: CSBA, 14 September 2010], 32). Original image was modified to clarify the penetrating strike CONOPS.

The systems requirement tier hinges on technological advances that must outpace air defense network capabilities. Platform materials need to maximize cloaking capabilities in the radio frequency, infrared and electro-optical spectrums. Metamaterials could provide this capability.[30] Weapon propulsion, range, and speed are not as critical as in the standoff CONOPS since platforms deliver them close to the target. However, guidance and accuracy weapons must counter jamming and possess the same characteristics as weapons in the standoff CONOPS.

The acquisition requirement tier presents challenges for strike platform capabilities. Affordability is the major constraint since strike platforms, sensors, and weapons must be reliable, survivable, and adaptable against air defense networks. Also, emerging technologies, like metamaterials, need to reach acceptable maturation levels by 2035. If platforms cannot reach weapons release and weapons can't survive to the target, the acceptable risk level is exceeded prior to mission execution. In summary, penetrating strike succeeds with highly advanced strike platforms which exceed air defense network capabilities (barring any serious time constraints).

CONOPS 3: Swarm and Saturation

Swarm and saturation combines manned stealth platforms, high/low tech unmanned air systems, and legacy strike platforms to overwhelm air defense networks. Some platforms penetrate and employ onboard weapons/decoys while others launch standoff weapons/decoys to achieve desired effects. Threat exposure is medium, based on each platform's usage and penetrating depth. F-22s escort refueling and legacy platforms remain outside nominal enemy fighter range (500 miles) and launch standoff weapons (fig. 9). Unmanned air systems penetrate/saturate air defenses while deploying swarming assets (decoys/weapons). Finally, B-2s or next generation bombers penetrate the battlespace to execute strike missions. Therefore, swarm and saturation's cornerstone concept is to overwhelm defense networks with the full spectrum of assets against fixed, mobile, and hardened target arrays.

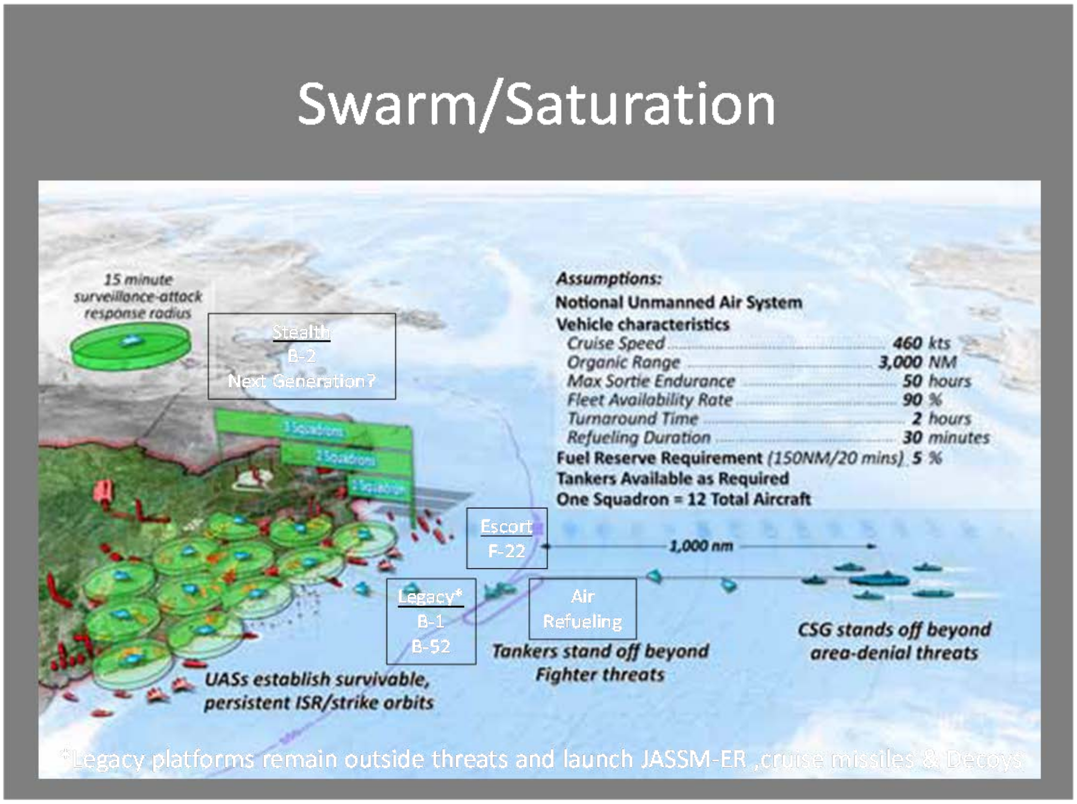

Figure 9. Swarm and saturation CONOPS: China example (*Adapted from* Gunzinger, "Sustaining America's Strategic Advantage," 68). The original image was modified to clarify the penetrating strike CONOPS.

The operations requirement tier has both high and low tech considerations. The command network requirement for legacy platforms and unmanned air systems is similar to the standoff CONOPS. B-1s and B-52s would require targeting data while other penetrating assets may self target. Swarming platforms like micro air vehicles or saturation platforms like the X-47 could perform self-targeting functions.[31] Therefore, these sensors and weapons could be reusable or disposable depending on use. Overall, operations require large inventories of existing legacy systems and advanced technologies all synchronized through a secure command network.

The systems requirement tier is complex due to varied technology levels in the operations tier. A resilient command network with cyber defense is crucial to asset synchronization. B-2s and penetrating unmanned air systems have similar material requirements as the penetrating strike CONOPS. While stealth strike systems may require upgrades, legacy platforms would use existing capabilities. So, the number and type of assets will drive the overall level and cost of technology upgrade.

The acquisition requirement tier includes considerations from the standoff and penetrating strike CONOPS. Reusable swarming and saturation assets will require costly upgrades for survival verses disposable platforms. Thus, affordability will drive force structure. Reliability and survivability only pertains to reusable assets which makes this feasible. In summary, swarm and saturation succeeds when advanced technologies and legacy systems overwhelm an air defense network long enough for lethal strikes to erode its capability.

In review of the CONOPS, all three are potential solutions to the antiaccess/area denial challenge. All have unique attributes regarding capabilities, tactics, and support and all share similar technological development challenges to enable their success. Figure 10 compares critical CONOPS components (optimized target type, threat exposure, strike/support assets, and dominant future technologies) for each

CONOPS Comparision

CRITICAL CONOPS COMPONENTS	Standoff CONOPS	Penetrating Strike CONOPS	Swarm and Saturation CONOPS
Optimized Target Type	Fixed	Fixed/ Mobile/ Hardened	Fixed/Mobile/ Hardened
Threat Exposure	Low	High	Med-High
Current Strike Assets	B-2,B-1, B-52	B-2	B-2
Escort/Support Assets	F-22/Tankers	None/Tankers	F-22/Tankers
Dominant Future Technologies	Space/Cyber Arsenal Plane Hypersonics Cold Atom	Metamaterials Next Gen Stealth Electronic Warfare	Space/Cyber UCAS (X-47) Micro Air Vehicles

communication lines to standoff platforms. Improvements in defensive counterspace and cyber network defense is the first priority. Then cyber attack and offensive counterspace can provide direct support for long range weapons against enemy air defense networks. Disrupting bistatic radar command/control and laser cueing greatly assists standoff weapons. Even if cyber attack and offensive counterspace drive defense systems into autonomous modes, the weapons still need to make it to the target.

The United States can continue long range missile development like the joint air-to-surface standoff missile (JASSM) extended range. It should have initial operational capability in 2012; the United States contracted 2,500 weapons at a cost of 7.7 billion.[32] This weapon is under spiral development from the original JASSM so production costs should be minimized. This system along with air launched cruise missiles and tomahawk land attack missiles could be modified with stealth technologies, or an entirely new system could be developed.

The future cruise missile should be a hypersonic weapon. If hypersonic weapons are fully operational in 2035, enemy air defense systems will have extreme targeting difficulties. The United States would "overcome the constraints of distance, time and defense that already limit conventional aerospace power projection."[33] Of note, in May 2010 the United States successfully completed the first flight test of the X-51A "Waverider."[34] This air breathing scram jet was launched at 50,000 feet mean sea level and reached a speed of about Mach 4.8. This validated its potential future application as a weapons platform. Therefore, hypersonic weapons would provide suppression of enemy air defenses and destruction of enemy air defenses. Overall, standoff provides a medium to high cost investment depending on modifications to existing technologies or development of new advanced systems.

CONOPS 2 (penetrating strike) requires extensive upgrades to the B-2 stealth platform or the development of a next generation stealth strike platform. Similar space and cyber attack upgrades from the standoff CONOPs would assist in network attack. Investments must focus on material and electronic warfare upgrades to protect the B-2 deep inside an air defense network. B-2 electronic attack upgrades could be internal or other airborne electronic attack platforms ("Phantom Ray" or RQ-170) could support the B-2.[35] Overall, electronic warfare is a far less challenge than material upgrades.

Metamaterials are being developed to potentially provide advanced stealth capabilities. Rodger M. Walser first described metamaterials as "macroscopic composites having a manmade, three-dimensional, periodic cellular architecture."[36] The layman's definition is building artificial materials in order to control electromagnetic signals. Metamaterials in the 3–30 gigahertz (GHz) range appear to have reached "analytical and experimental critical function and/or characteristic proof of concept."[37] Of note, only certain frequencies at precise angles can produce "invisible" effects when tracked by a radar scope. Therefore, in 2035 these barriers most likely will be overcome, but the United States needs to ensure it reaches operational capacity first.

Metamaterial technological barriers exist in two critical spectrums. Currently, metamaterials in the infrared spectrum (300 GHz to 300 terahertz [THz]) and the electrical optical spectrum (>300 THz < 3 petahertz) are not seeing advances. “Difficulty exists in generating magnetic interactions in the optimum regime to provide cloaking effects.”[38] As a result, it is uncertain whether these metamaterials will reach maturation. Overall penetrating strike is a high cost investment since technology development is in initial stages for both B-2 upgrades and a potential next generation stealth platform.

CONOPS 3 (swarm and saturation) requires investment in low/high tech unmanned air systems to serve as weapons platforms, sensors, and decoys inside enemy air defenses. In addition, similar standoff weapons investments are required for use on legacy platforms outside the air defenses. Since saturation is one outright method to exhaust an adversary’s initial weapons volley, investments in B-2 upgrades depends on the micro air vehicles and UCAS X-47 ability to degrade an air defense network.

Micro air vehicles are two feet in length or less, capable of operating below rooftop level in an urban environment.[39] Along with the UCAS X-47, these swarming assets would operate covertly to collect, interrupt, and disable enemy networks. Large numbers of these two disposable and nondisposable systems are required to execute this CONOPS. Additionally, disposable miniature air-launched decoys, improved tactical air-launched decoys and legacy drones will aide in saturation.[40] Existing QF-4 and QF-15 drones could shield nondisposable manned and unmanned air dominance platforms for a very low cost. Overall, swarm and saturation is a low–medium cost investment depending on asset type and numbers utilized.

Figure 11 outlines the various investment options associated with each CONOPS. It breaks down air defense network capabilities and the technologies needed to counter each of those capabilities. Relative costs serve as an initial comparative snapshot and varies depending on rate of future technology development. In addition, type and number of assets will vary depending on the specific hyper-defended battlespace composition.

Investment Options

CONOPS	To Counter: Find	To Counter: Fix	To Counter: Track	To Counter: Target	To Counter: Engage	Notes/ Overall Cost
Standoff	Space/Cyber	Space/Cyber	Advanced Stealth Cruise Missiles	Hypersonics Arsenal Plane	Hypersonics Arsenal Plane	
Relative Cost	Med	Med	High	High	High	Med-High
Penetration Strike	Metamaterial Next Gen Stealth ElectronicWarfare	Metamaterial Next Gen Stealth ElectronicWarfare	Metamaterial Next Gen Stealth ElectronicWarfare	Metamaterial Next Gen Stealth ElectronicWarfare	Metamaterial Next Gen Stealth ElectronicWarfare	
Relative Cost	High	High	High	High	High	High
Swarming / Saturation	Micro Air Vehicles	Micro Air Vehicles	UCAS (X-47) Decoys Legacy Drones	UCAS (X-47) Decoys Legacy Drones	UCAS (X-47) Decoys Legacy Drones	**If B-2 is upgraded advanced stealth: Cost=High**
Relative Cost	Low	Low	Med	Med	Med	Low-Med

disruption of an air defense network is a low cost capability. Overwhelming numbers of low tech, disposable platforms and weapons provide the means to exhaust initial enemy weapons volleys. This provides high tech platforms with a window of opportunity to penetrate and destroy fixed, hardened, and mobile targets. Eventually, enemy air defense systems will erode and US air dominance returns to a level we are accustomed to fighting during decisive combat operations. Defeating an antiaccess/area denial enemy requires this type of synthesized, multidomain strategy.

In closing, US planners need a framework like the one presented to solve future air dominance challenges in antiaccess/area denial states. It begins with understanding potential enemy technical challenges and air defense network capabilities. Then a requirements approach model is used to develop sound CONOPS. Only after these steps are accomplished can proper technologies be identified for investment. It is ultimately technology which will enable platforms, sensors, and weapons to succeed in future decisive combat operations.

Notes

1. Jan Van Tol, Mark Gunzinger, Andrew Krepinevich, and Jim Thomas, *AirSea Battle: Point-of-Departure Operational Concept* (Washington, DC: Center for Strategic and Budgetary Assessments [CSBA], 18 May 2010), xii. The authors present an in-depth discussion surrounding China's and other state's rising antiaccess, area denial

capabilities and the US failure to modify their forces to counter such capabilities.

2. Andrew F. Krepinevich, *Why Air Sea Battle?* (Washington, DC: CSBA, 19 February 2010), viii.

3. Arend G. Westra, "Radar vs. Stealth: Passive Radar and the Future of U.S. Military Power," *Joint Force Quarterly* 55, no. 4 (October 2009): 139. The author discusses multiple advanced countermeasures to current US stealth technology throughout the entire electromagnetic spectrum and implications for future air power.

4. Krepinevich, *Why Air Sea Battle?*, 5. The author argues that early US basic power projection capability dates back to the Spanish-American War in 1898 and force projection to forward bases during the Cold War was never contested by the Soviet Union. Only major combat operations are considered in this assertion.

5. Thomas L. Friedman, *The World is Flat* (New York: Farrar, Straus & Giroux, 2005), 176. The author details 10 world flatteners and their convergence which has created this new web-based platform for collaboration. This inexpensive and quick collaboration is helping states increase their education, research, and war-making capabilities.

6. "Editorial: Remain Watchful of China's Ascent," *Aviation Week and Space Technology*, 18 January 2011, 1.

7. Harry Foster, "Air Power and Anti-Access/Area Denial Networks," (lecture, A2/AD conference, Washington, DC, 28 October 2010), slide 3.

8. Wendell Minnick, "China Builds First Anti-Ship Ballistic Missile Base," *Defense News*, 5 August 2010, 1. The author describes the DF-21D having the potential range of 1,500–2000 kilometers which covers 70 percent of the South China Sea.

9. Foster, "Air Power Anti-Access/Area Denial Networks," slide 8. Assumes missions are flown at 480 knots ground speed to the target with a one hour mission delay and three hour turn time upon landing.

10. Tol, Gunzinger, Krepinevich, and Thomas, *AirSea Battle*, 24. Consequences of losing forward air bases in an antiaccess/area denial conflict are outlined to include reduced sortie rates and increased tanker demands.

11. David A. Fulghum, "Russia Sells SA-20 to Iran," *Aviation Week and Space Technology*, 12 December 2008, 1.

12. "Stealth Aircraft Vulnerabilities," *Global Security.org*, 7 November 2011, http://www.globalsecurity.org/military/world/stealth-aircraft-vulnerabilities.htm.

13. Robert P. Haffa and James H. Patton, Jr., "Analogues of Stealth: Submarines and Aircraft," *Comparative Strategy* 10, no. 3 (July/September 1991), 15. The author discusses that bistatic radars

would require large computing power to collect and analyze the multiple radar beans received across several antennas.

14. Ibid., 14.

15. Ibid., 15.

16. Richard Dunn, "Operational Implications of Laser Weapons," in *Conference on Lasers and Electro-Optics/Quantum Electronics and Laser Science Conference and Photonic Applications Systems Technologies*, OSA Technical Digest, CD-ROM, Optical Society of America, 2007, 3.

17. Ibid.

18. Dr. William D. Schneider, "Defense Science Task Force on Directed Energy Weapons," (Washington, DC: Office of the Under Secretary of Defense for Acquisition, Technology and Logistics, December 2007), 6.

19. Dunn, "Operational Implications of Laser Weapons," 7.

20. Ibid.

21. Ibid., 10. These laser systems are expected to have the following capabilities: multiple target engagement, rapid retargeting, exceptional accuracy, low logistical support requirements, and flexibility in carriage and employment.

22. Ibid., 4.

23. Air Force Doctrine Document (AFDD) 2-1.9, *Targeting*, 8 June 2006, 49. This Air Force document states on the cover that it complements related discussions found in Joint Publication (JP) 3-60,

Joint Doctrine for Targeting, 17 January 2002. Additionally, the dynamic targeting process is also referred to as the "kill chain."

24. Dr. Werner J. A. Dahm, *Technology Horizons: Vision for Air Force Science and Technology during 2010–2030*, vol. 1, Washington, DC, Office of the US Air Force Chief Scientist, 15 May 2010, 43. The Air Force Research Laboratory uses a general construct in its attempts to define a future war-fighter's needs. They use eight focused long term challenges as their current guideline; the fourth challenge is persistent responsive precision engagement defined as, "maneuver through antiaccess/area denied environments to deliver effects rapidly and/or persistently."

25. AFDD 1, *Air Force Basic Doctrine*, 17 November 2003, 31. "Synergistic Effects" is one of the seven tenets of air and space power. Specifically, AFDD 1 describes that its objective is the precise, coordinated application of the various elements of air, space, and surface power to bring disproportionate pressure on enemy leaders to comply with our national will.

26. The definition of what comprises a concept of operations (CONOPS) varies considerably from the strategic level to the tactical level. The US Air Force defines its service CONOPS as "the highest Service-level concept comprising a commander's assumptions and intent to achieve desired effects through the guided integration of capabilities and tasks that solve a problem in an expected mission area." JP 5-0, *Joint Operation Planning*, 11 August 2011, II-24. This publication's Level 4

planning CONOPS described integrated tactical actions with high fidelity. For information on Air Force CONOPS, see Air Force Instruction 10-2801, *Air Force Concept of Operations Development*, 24 October 2005, 2. For information on CONOPS in joint planning see JP 5-0, 1–18.

27. Krepinevich, *Why Air Sea Battle?*, 19. The author states that carrier forces would need to maintain a distance of 1,000–1,600 nm from the China coastline to avoid the advanced surface-to-surface threats. Airborne platforms would also need to maintain a distance of 500 nm to remain outside a Chinese fighter's nominal unrefueled max range, assuming they return to their original mainland air base.

28. Eric Weidanz, email to the author, 6 January 2011, 1. Arsenal plane is a Boeing 777 platform converted to a strike platform capable of launching standoff missiles such as the JASSM-ER. Each plane is estimated to hold 52 missiles and have a combat radius of 4,000 miles.

29. Stefanie Tompkins, "Precision Inertial Navigation Systems," Defense Advanced Research Project Agency, http://www.darpa.mil/dso/thrusts/physci/newphys/pins/, 1. Cold atom interferometers are being developed to replace the global positioning system for navigation. This technology would require no external transmissions and would still provide precise navigation capability.

30. Bora Ung, "Metamaterials: A Metareview," Ecole Polytechnique of Montreal: http://www.polymtl.ca/phys/doc/art_2_2.pdf, 1.

Metamaterials are manmade materials that exhibit unique electromagnetic properties that theoretically could be undetectable in the radio frequency, infrared, and electro-optical spectrums. This will increase stealth platform cloaking capabilities.

31. US Air Force Fact Sheet, "Micro Air Vehicle Integration and Application Research Institute," http://www.wpafb.af.mil/library/factsheets/factsheet.asp?id=17006, 1. Micro air vehicles are designed to provide close covert sensing capabilities to enhance situational awareness and targeting data. Also see Gunzinger, "Sustaining America's Strategic Advantage," 69. The X-47 is an unmanned carrier air vehicle with stealth, surveillance, and self-targeting capability.

32. Deagel.com, "AGM-158 JASSM-ER," http://www.deagel.com/Land-Attack-Cruise-Missiles/AGM-158-JASSM-ER_a001073002.aspx, 1.

33. Richard P. Hallion, "Hypersonic Power Projection," Mitchell Institute for Airpower Studies, http://www.afa.org/mitchell/reports/MP6_0610.pdf, 8.

34. US Air Force, "X-51 Waverider makes Historic Hypersonic Flight," *Air Force News*, 26 May 2010, http://www.af.mil/news/story.asp?id=123206525.

35. Gunzinger, "Sustaining America's Strategic Advantage," 75.

36. Akhlesh Lakhtakia, "Evolution of Metamaterials," Department of Engineering Science and Mechanics, Pennsylvania State University, April 2007, www.esm.psu.edu/~axl4/lakhtakia/documents/Lakhtakia_07_7.pdf, 12.

37. James W. Bilbro, "Technology Readiness Levels," JB Consulting International, http://www.jbconsultinginternational.com/Pages/TechnologyReadinessLevels.aspx3.

38. Laura Rea, "Sensors Directorate Applied Metamaterials" (lecture, Air Force Research Laboratory, Wright-Patterson AFB, Ohio, 20 September 2010), slide 7.

39. US Air Force Fact Sheet, "Micro Air Vehicle Integration," 1.

40. Global Security.org, "Miniature Air Launched Decoy (MALD)," http://www.globalsecurity.org/military/systems/aircraft/systems/mald.htm, 1.

41. Westra, "Radar verses Stealth," 142. The author describes how current stealth technology alone will be less effective over the years relative to passive radar improvements. The United States cannot simply invest in stealth without understanding the rapidly developing counters to stealth.