RAND CORPORATION

Perspective
EXPERT INSIGHTS ON A TIMELY POLICY ISSUE

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OPERATIONAL IMPERATIVE

Investing Wisely to Bolster U.S. Air Bases Against Chinese and Russian Attacks

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Increasingly aggressive actions by China and Russia toward their neighbors have shifted the attitudes of defense policymakers about both aggressors over the past two decades. Not only is there a growing consensus that China and Russia represent significant threats to U.S. interests, but there are also growing calls for actions to counter the threats.

An extensive body of RAND Corporation research on Chinese and Russian missile threats to U.S. overseas air bases offers early answers for how to counter the threats cost-effectively. Most of the research is classified, but many of the overall findings are not. We synthesize the research and core findings in this Perspective.

Air Force Secretary Stresses Need to Protect U.S. Overseas Air Bases

In January 2022, U.S. Secretary of the Air Force Frank Kendall warned that the U.S. Air and Space Forces must move quickly to offset actions—mostly by China, but also by Russia—that have eroded the United States' military advantage: "We cannot go forward with a presumption of superiority that our military dominance demonstrated in the first Gulf War. . . . A lot of things can change in 30 years and they have" (Pope, 2022).

As described in Pope, 2022, Secretary Kendall listed seven operational imperatives for reconfiguring the U.S. Air and Space Forces for the dramatically changed security environment. Kendall warned that "[t]hese problems are already upon us; they're not future things we have to worry about at some time five or 10 or 15 years down the road. They're here now. We have to address them with a strong sense of urgency" (Pope, 2022).

One of those imperatives is what U.S. Air Force officials call *resilient* basing. To make air bases more resilient, Kendall aims to build on a concept known as Agile Combat Employment (ACE). ACE would move the U.S. Air Force from operating out of a small number of very large, fixed airfields to a more flexible posture of operating from constellations, or *clusters*, of locations that would enable greater movement and agility, theoretically making them more difficult for adversaries to target effectively. A successful ACE concept would both aid in combat power generation during its employment and protect aircraft for later use.

China has rapidly added weapon systems and tactics designed to damage or destroy large, fixed facilities. "ACE is designed to make that problem harder for an adversary," said Kendall, who then hinted that ACE could be just one of many investment options. "That is a piece of the solution but we have to figure out exactly the investments we need to make in the mix of defenses, hardening, deception and proliferation. We've made some progress in that area but we need to be much more specific about the needed investments and allocate resources to them in a cost-effective manner" (Pope, 2022).

Toward that end, RAND has analyzed the cost-effectiveness of numerous alternatives for ACE and for air base resilience more broadly in dozens of reports over the past several years. Early on, RAND defined *resilience* as "the capacity of a force to withstand attack, adapt, and generate sufficient combat power to achieve campaign objectives in the face of continued, adaptive enemy action" (Hagen et al., 2016, p. 3). Achieving such resilience requires close familiarity with the threat, a systematic approach for addressing it, and sustained efforts to build on investments in air base protection.

ACHIEVING SUCH RESILIENCE REQUIRES CLOSE FAMILIARITY WITH THE THREAT, A SYSTEMATIC APPROACH FOR ADDRESSING IT, AND SUSTAINED EFFORTS TO BUILD ON INVESTMENTS IN AIR BASE PROTECTION.

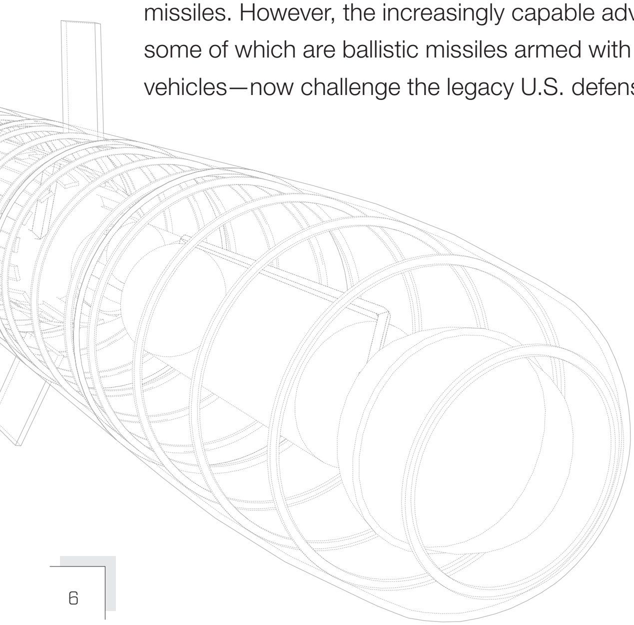
Chinese and Russian Weapons Challenge U.S. Defenses

China's threat to U.S. Air Force bases in the Indo-Pacific is rooted in a Chinese strategy that emphasizes surprise and preemption and in a Chinese missile force that contains the most formidable arsenal of conventional ballistic missiles in the world, plus ground- and air-launched long-range cruise missiles. China's missile force includes ground-launched DF-21 medium-range ballistic missiles, ground-launched DF-26 intermediate-range ballistic missiles, and bomber-launched CJ-20 long-range cruise missiles. Early in a conflict, China could strike U.S. and partner-nation air bases, air and missile defense systems, and command centers with large ballistic and cruise missile raids. The missiles and their submunitions could be optimized for attacking runways or destroying aircraft on parking ramps. Numerous studies have demonstrated the vulnerability of U.S. and partner airfields to such attacks and the rapidly growing threat to those airfields.

U.S. Air Force bases in Europe face a threat from Russian missiles. In any conflict with the United States and its North Atlantic Treaty Organization (NATO) allies (for example, the Baltic states), Russian doctrine would call for using manned aircraft, ballistic and cruise missiles, and possibly even nuclear weapons to attack NATO air bases. Although the Russian missile force is smaller and less advanced than its Chinese counterpart, the Russian force still represents a threat to NATO air operations. Russian attacks on Ukrainian air bases show Russia's willingness to target airfields. Also, while Russia has expended a considerable portion of its missile inventory in the Ukraine conflict, Russia's potential long-range attack capability—including KH-101 cruise missiles, RS-26 ballistic missiles, and Kinzhal air-launched ballistic missiles—could threaten NATO bases throughout the region in the event of a larger conflict.

NATO air bases do, however, have advantages that somewhat mitigate the threat in Europe. In contrast to the western Pacific, there are many high-quality airfields available throughout western Europe, all of which are accessible by road and rail. In addition, NATO fighter bases generally have hardened shelters for fighter aircraft, and many of those bases have other hardened facilities. The primary problem for NATO is that larger U.S. and allied aircraft—such as tankers; bombers; and intelligence, surveillance, and reconnaissance platforms—would need to operate from more-remote bases to avoid the worst of the Russian threats.

In the Indo-Pacific and European theaters and beyond, the traditional measures for shielding air bases from cruise and ballistic missile attacks are U.S. Army air and missile defense systems, specifically the Phased Array Tracking Radar to Intercept on Target (PATRIOT) system and the Terminal High Altitude Area Defense (THAAD) system. The two systems have complementary roles: The PATRIOT system is designed to shoot down aircraft, cruise missiles, and short- to medium-range ballistic missiles; the THAAD system is designed to shoot down longer-range tactical ballistic missiles. However, the increasingly capable adversary missiles—some of which are ballistic missiles armed with hypersonic glide vehicles—now challenge the legacy U.S. defenses.



RAND Analyses Weigh U.S. Options for Mitigating Attacks

When attacking an air base, an adversary must choose among different attack vectors. Each vector is a unique combination of ballistic and cruise missile allocations aimed at different targets on a base, such as runways, aircraft parking areas, and fuel storage. If a targeted air base has a single runway, a small aircraft parking area, or a single fuel tank, the choice of vector can be quite simple. If a targeted air base has multiple runways, parking areas, and fuel sources, the choice can become complex. Add the differing effects of ballistic and cruise missiles on different targets at different bases, plus the countervailing effects of missile defense systems aimed at shooting down the incoming missiles, and the adversary's choice of attack vector can become overwhelmingly complicated. The cost and effectiveness of both the attacking and the defending options may vary greatly across the spectrum of attack vectors.

Since the early 1950s, RAND has developed and applied the tools of systems analysis to the problem of air base attack and defense. Recent advances in modeling and simulation have allowed analysts to consider many more attack-and-defense combinations than previously possible and to do so in much greater detail.

RAND's recent projects on air base resilience have developed a suite of integrated models that take advantage of the recent advances. The models assess the vulnerability of land-based U.S. and allied aircraft to missile attacks, identify cost-effective mixes of investments in air base resilience, gauge the impacts of prepositioning strategies on force arrival times and sustainment costs, and suggest how to improve an airfield's infrastructure and force protection (for example, with security forces and reorganized base defenses). Table 1 encapsulates how the full toolkit of models works together.

TABLE 1 | Integrated Models for Improving Air Base Resilience

Inputs	Models	Outputs
Force postures • U.S. and allied bases and force beddowns • U.S. and allied CONOPS • Air base infrastructure database • Adversary attack vectors (capabilities and launch points) against parked aircraft, runways, fuel storage, munitions storage, etc.	• TAB-VAM • GF-VAM	Force postures • U.S. and allied sortie generation under attack • Damaged aircraft (fighters, bombers, tankers, etc.) • Available runways • Destroyed and consumed fuel • Damaged missile defense systems • Personnel casualties (killed, wounded, evacuated, died of wounds, returned to duty)
Geospatial target data • Location geometry data for air bases, ports, army staging areas	• APO	Geospatial target data • Adversary missile allocations
Resiliency options, costs • TAB-VAM scenario • TAB-VAM force posture • Adversary attack vectors • Active defense options • Passive defense options • Infrastructure options • Recovery capabilities • Location-specific constraints	• TAB-ROM • APT	Resiliency options, costs • Portfolio of active defenses, deployable passive defenses, and infrastructure options • Pareto frontier of optimal investment portfolios across the cost curve • Sortie generations under attack • Location-specific investments for each portfolio
Logistics requirements, costs • Transportation • Storage • Personnel	• Lean-START • PRePO	Logistics requirements, costs • WRM requirements • Combat support prepositioning options • Medical requirements

NOTES: In this context, the Pareto frontier is the set of investment portfolios that provides the most sortie generation for a given set of investment levels. APO = Aimpoint Optimization; APT = Asset Placement Tool; CONOPS = concept of operations; GF-VAM = Ground Forces Vulnerability Assessment Model; Lean-START = Lean Strategic Tool for the Analysis of Required Transportation; PRePO = Prepositioning Requirements Planning Optimization; TAB-ROM = Theater Air Base Resiliency Optimization Model; TAB-VAM = Theater Air Base Vulnerability Assessment Model; WRM = war reserve materiel.

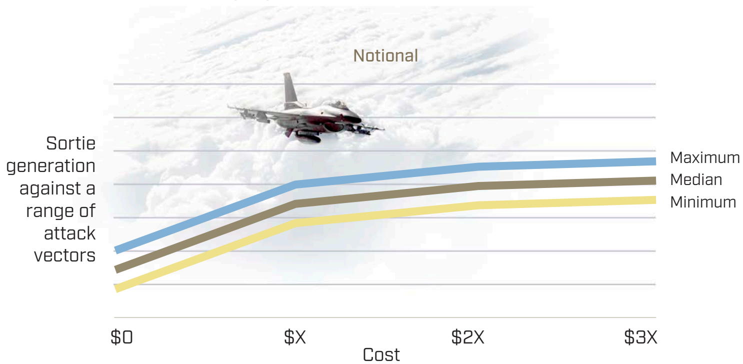
Four categories of inputs feed into seven RAND-developed models (TAB-VAM, GF-VAM, APO, TAB-ROM, APT, Lean-START, and PRePO), which generate four corresponding categories of outputs. For instance, the Theater Air Base Vulnerability Assessment Model (TAB-VAM) assesses the impact of attacks on air bases. TAB-VAM simulates a variety of attack vectors, calculates the probable damage to critical assets (such as runways, aircraft, and personnel), and determines the expected effects of the attacks on U.S. aircraft sortie generation. Although Table 1 shows a linear process, many model outputs feed back into the model inputs in a continuous feedback loop.

TAB-VAM is designed to account for uncertainty. Because the adversary decides the attack vector, the model simulates a wide variety of vectors to estimate a variety of feasible results. This approach hedges against assessing the attack strategy incorrectly and becomes critical when predicting the impacts of threat mitigations because an adaptive adversary can shift to a new attack vector using new investments made by the defender. In a multi-move competition, the shifting incentives for different attack vectors can necessitate different mitigations as well.

TAB-VAM also estimates the effects of the threat mitigation options. The Theater Air Base Resiliency Optimization Model (TAB-ROM), a companion model to TAB-VAM, then seeks to identify the *most-cost-effective* mitigation options. There are literally billions of combinations of active and passive defense investment options because any number of each option could be purchased for each air base in each theater. To avoid having to calculate the effects of billions of possibilities (which might take years for TAB-ROM to compute), the model uses a *genetic algorithm*—a search method inspired by Charles Darwin's theory of natural selection—to find the *fittest* (or most-promising) investments. TAB-ROM does this by running TAB-VAM tens of thousands of times across *generations* (stages in the evolution toward an optimal solution), first exploring the universe of possibilities for investments that show promise against dozens of plausible attack vectors and then narrowing down the investments to those that appear to be the most *viable* (or cost-effective). The most-viable options yield the highest sortie rates—or numbers of sorties per day—at the lowest costs.

TAB-ROM calculates the maximum sorties that can be generated at various spending levels, starting with no additional investments in air base resilience. The results can be used to generate results such as those in Figure 1, which shows the minimum, median, and maximum numbers of theaterwide sorties that could be generated at each spending level, assuming a variety of possible attack vectors. If the budget is $100 million, $500 million, or any specified level, TAB-ROM estimates the sortie rates that can be generated, complete with breakdowns of what mitigations to buy and where to put them. The unfilled table within Figure 1 shows that TAB-ROM specifies which assets to buy at which investment level to achieve which sortie rate. The results can point to an investment level known as the *knee in the curve*, at which point higher investment levels would yield diminishing returns. (Absent any explicit operational requirement, the "knee" can become the recommended spending level.)

FIGURE 1 | TAB-ROM Buying Suggestions for Operational Air Base Resilience at Each Cost Level



Mitigation	Cost $X	Cost $2X	Cost $3X
Enhanced runway repair			
Additional fuel capacity			
Aircraft shelters			
Additional active defenses			

This toolkit of models has been invaluable in providing a structured and capable approach for addressing the complex problem of air base resiliency against future threats. Our work with these tools has yielded a wide variety of lessons learned, both general and specific. Top-line findings from the complete corpus of work include, but are not limited to, the following:

- The U.S. Air Force's logistics enterprise must be able to mitigate and recover from attacks.
- Mitigation and recovery will require a portfolio of options, including active defense (shooting down incoming missiles) and many forms of passive defense.
- The most-cost-effective ways to improve air base resilience are robust, passive defenses. Passive defenses include hardened shelters for aircraft; dispersal of aircraft; redundant fuel supplies; prepositioned munitions; rapid runway repair capabilities; and tailored forms of camouflage, concealment, and deception.
- Active defenses (that is, ballistic and cruise missile defense systems) are useful, especially in combination with passive defenses, but can be vulnerable to attack and less cost-effective.
- On-base dispersal—especially of parked aircraft, fuel systems, and munitions storage—significantly improves the ability to conduct air operations while under missile attack.
- Larger air bases are generally more resilient than smaller air bases because the former allow for the on-base dispersal of assets (across larger physical plants).

- Distributed operations (dispersal of aircraft across bases, along the lines of ACE) could be key to increasing survivability. However, the U.S. Air Force's limited combat support capacity constrains how many distributed locations could operate simultaneously.
- Counterintuitively, distant operating locations may not be more survivable than those closer to the threat if the farther bases can be brought down by a small number of missiles.
- Prepositioned stocks, host-nation support, and resilient supply chains are essential for rapidly transitioning from peacetime activity to combat operations and for conducting logistics under attack.

Future Analyses Can Help Maximize Returns on Additional Investments

The collected insights from RAND research on threats to U.S. overseas air bases suggest that ACE should be one—but not the sole—U.S. Air Force investment in enhanced air base resilience. Beyond the array of options for active and passive defenses discussed above, for example, RAND has gained additional insights regarding the sustainment and communication systems required for operating in any contested environment, but especially in a dispersed environment. In short, the greater the dispersal, the greater the challenges for sustainment and communications.

Two central insights, which sum up the challenges of air base resilience in general, pertain especially to the challenges of sustainment. First, to generate sorties, an air base must bring

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together multiple assets, including maintenance personnel, functional aircraft, sufficient fuel, and an operational runway. **An adversary needs to deny only one of these assets to inhibit combat power generation**. Second, although the dispersal of aircraft across bases might be key to complicating adversary attacks and improving theaterwide resilience, *how widely* the Air Force can disperse can be limited by support asset requirements. Some of these obstacles might be mitigated through new concepts, such as runway-independent aircraft, but these systems have their own unique logistical needs that would also need to be assessed, fulfilled, and sustained.

Two additional insights sum up the challenges of communications. First, the communication paths currently available for ACE are extremely limited because of logistical and resource constraints; the required ease of use; and Chinese and Russian capabilities to degrade, deny, and target an opponent's use of the electromagnetic spectrum. Second, the potentially deleterious effects of contested environments on communications—degradation, denial, disruption, destruction, manipulation, and unauthorized access—can result not only from adversary targeting but also from non-adversary challenges, such as policy restrictions on local access to the radio-frequency spectrum and interoperability issues with partners and allies.

Such insights as those discussed here, regardless of how straightforward or intuitive they may seem, require rigorous analysis to ascertain. It can be difficult to determine which bases are preferable for dispersed aircraft, for example, because those decisions depend on such factors as country access, base geometry, and proximity to the adversary. There may be cases in which no amount of investment can make a base viable, but there might be other cases in which a modest investment can result in a substantial benefit. The issues that the Air Force faces are complex, and a proficient modeling and simulation capability can be a critical tool in addressing them.

The insights from RAND's work on air base resilience, sustainment, and communications can help the U.S. Air Force address its pressing needs. Whether built for the long term or temporarily dispersed, any U.S. air base within striking distance of a near-peer adversary must be prepared to operate while under attack. The general impression over the past few decades that U.S. air bases were somehow sanctuaries was a historical anomaly. With the return to a more historical norm of air base vulnerability, investments to improve air base survivability must now be made. These investments are, in the words of Secretary Kendall, an "operational imperative" (Pope, 2022).

Because the increasingly aggressive threats continue to evolve, RAND will continue to identify the most promising, cost-effective options for air base resilience in the Indo-Pacific and European theaters. The insights outlined here apply to both theaters, but the optimal mix of investments will differ for each theater because of its distinct geography and infrastructure and the dissimilar size and capabilities of each adversary's missile inventory. RAND has developed its toolkit to quantify the likely returns from a vast array of alternative resiliency investment portfolios for each theater, to suggest the optimal components of each portfolio and to help the U.S. Air Force reap the maximum returns on U.S. investments in air base resilience.

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List of Abbreviations

ACE: Agile Combat Employment

APO: Aimpoint Optimization

APT: Asset Placement Tool

GF-VAM: Ground Forces Vulnerability Assessment Model

Lean-START: Lean Strategic Tool for the Analysis of Required Transportation

NATO: North Atlantic Treaty Organization

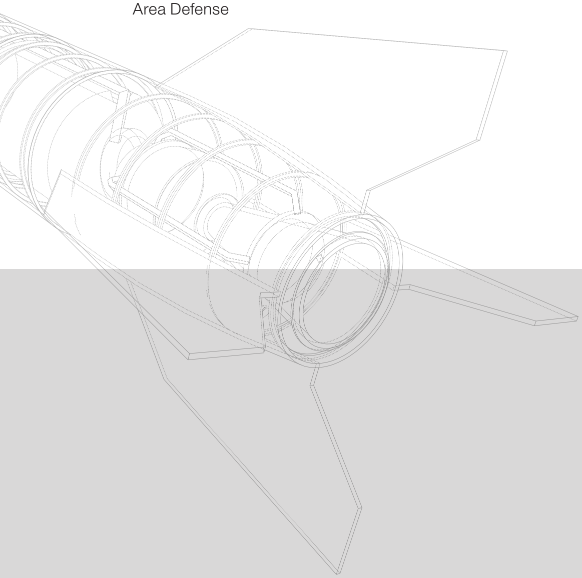
PATRIOT: Phased Array Tracking Radar to Intercept on Target

PRePO: Prepositioning Requirements Planning Optimization

TAB-ROM: Theater Air Base Resiliency Optimization Model

TAB-VAM: Theater Air Base Vulnerability Assessment Model

THAAD: Terminal High Altitude Area Defense



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