Paper
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Rethinking Combat Power
Air Superiority in the Age of Pervasive Threats

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Abstract

In an era of pervasive threats, air superiority faces unprecedented challenges. Rapid advancements in automation and weapons systems are transforming the battlespace, rendering traditional approaches to air superiority obsolete. Air forces must rethink combat power to maintain effectiveness in highly contested environments and be capable of gaining access vectors to achieve air superiority in compressed timelines. Air forces must find new ways of enabling movement and maneuver to fight effectively inside adversarial weapon employment zones. Utilizing a distributed operational model leveraging low-footprint "kill webs," air forces can create a more agile and resilient force structure to enhance force survivability and operational effectiveness. This paper emphasizes the critical role of non-kinetic capabilities, particularly electronic warfare, and the crucial role of AI in enabling multi-domain integration and allowing more superior decision-making and maneuver to "outcycle" adversaries. This strategic repivoting may, however, impose implications that are broader than currently anticipated.

Introduction

Armed with long-range sensing technologies, more lethal cross-domain fires and electronic attack (EA) capabilities, all of which will continue to see rapid advances and become more accessible, adversaries can “sense deep” and “strike deep” better than ever before. Increasing levels of automation are shrinking the kill chain (the ability to find, fix, track, target, engage, and assess targets), allowing combat effects to be delivered more rapidly but also enhancing the timing, precision, and accuracy of weapons systems. Concurrently, the expanding use of unmanned systems is making possible new ways to execute high-risk strike missions and project combat mass into contested theatres. Combined with the introduction of new weapons systems such as hypersonic missiles, directed energy weapons (DEWs), and autonomous swarms, each of which brings game-changing implications, weapon employment zones are being enlarged, and target engagement times are simultaneously compressed. Characterized by such a high density of complex, benign, and pervasive threats, the future operational environment will threaten the survivability and operational effectiveness of air forces with overwhelming adversity. Access vectors to gain or protect control of the air will be dramatically constrained and freedom of maneuver will be fundamentally challenged.

Air forces may well be entering an unprecedented era of “post-power projection” – unless they can find effective responses and “accelerate change” (Thomas, 2010; Brown, 2020). In responding to future air superiority challenges, new approaches emphasizing agility and adaptability are imperative (U.S. Department of Defense, 2022; U.S. Air Force, 2022). Innovative solutions are needed to enable air forces to maneuver and fight effectively inside adversarial weapon employment zones, including by stretching increasingly automated adversarial kill chains. Evolving from “bombs on target” approaches by building the capacity to rapidly generate cross-domain solutions integrating kinetic effects with a wider range of non-kinetic effects will be essential (Kelly, 2023; McDermott, 2017). Future warfare will reinforce the critical importance of dominating the electromagnetic environment (EME), but the fusion of electronic warfare (EW) and cyber warfare, and increasing levels of automation to ‘outcycle’ adversaries with faster and better decision-making, will be just as essential. Crucially, such a rebalancing of combat power must be combined with distributed operations and mission generation capability, creating a new stand-off posture that can allow air forces to fight from positions of advantage by facilitating faster mobility to exploit temporary access vectors (U.S. Air Force, 2022). Such a strategic repivoting, however, highlights new frontiers in future competition and may impose implications that are broader and more significant than air power leaders anticipate.

The Threat Landscape

Medium-altitude long-endurance (MALE) aerial systems, loitering munitions, and small, low-cost drones are allowing fire and combat effects to be projected more flexibly using a rapidly growing mix of stand-off and attack platforms. Unmanned systems have generated a transformative effect on kill chains in recent years, allowing combat power to be projected in new ways and driving a quantum reduction in the degree of physical contact between opposing forces. With hundreds of varieties already fielded or under development, with distinct speed, combat radius, and radar cross-section characteristics, unmanned systems have increased operational flexibility for military users across the service branches. With the ability to deliver different munitions and payloads, unmanned systems enable new weapons-on-target pairings from a wider range of locations (including from closer proximity to targets) and, crucially, in higher numbers. Rapid advances in AI driving the development of autonomous systems will only increase the utility and impact of unmanned systems in warfare, driving the development of collaborative combat aircraft (CCA) to create a more attrition-tolerant/resilient force mix (Penney, 2024; Gunzinger et al., 2024). Making the projection of air power more accessible and at lower price points, the scale, variety, and lethality of future unmanned threats will continue to increase (Gunzinger et al., 2020; Hagardt, 2024; Postma, 2021).

Autonomous swarms will unleash new possibilities for suppression of enemy air defense (SEAD) and destruction of enemy air defense (DEAD) and "deep" precision strike missions (Shaikh, 2023). Meanwhile, new weapons systems such as air-launched ballistic missiles (ALBMs), hypersonic glide vehicles (HGVs), and DEWs impose formidable challenges of their own. For example, with maneuverability characteristics of cruise missiles and extreme speeds (faster than conventional ballistic missiles), HGVs compress engagement times against long-range targets from hours to minutes (Shaikh, 2021; Karako and Dahlgren, 2022). Small in size and with flight paths low enough to obscure ground-based radar detection, HGVs pose a severe test to threat early warning (TEW) systems, even those reinforced with advanced sensing in the space layer (Shaikh, 2021). Complex to counter, emerging hypersonic weapon systems can effectively evade existing multi-tiered missile defenses and represent a lethal threat against distant and heavily defended targets (Karako and Dahlgren, 2022). ALBMs and HGVs threaten to destroy or degrade strategic infrastructure and high-value assets, such as air bases, command nodes, airstrips, and so on, within minutes – the most efficient way to attrite an opposing force (Gunzinger et al., 2020; Kaushal et al. 2021). Similarly, DEWs promise a revolutionary impact, with the potential for precision engagement against aircraft and missiles at extreme speeds (Obering, 2020).

Increasingly fused with cyber warfare to achieve information superiority, EW has evolved from a primarily defensive mechanism to an essential combat support function into – now – an imperative component of network-centric warfare. Utilizing non-kinetic means to change the quality of information or alter the conditions

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in the electromagnetic environment (EME), EW is a formidable weapon for disrupting adversarial command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) and use of weapons systems (Bronk, 2024; McDermott, 2022a; McDermott, 2017; Kaushal et al., 2021). Creating interference in location and target distribution systems, fire control systems, computers, and networks, EW can prevent adversaries from deploying assets, guide weaponry, and sustain operational effectiveness. Adding depth and credibility to Anti-Access/Area Denial (A2/AD) that denies opponents freedom of action in the air, the fielding of more EW effects to manipulate the EME has become a defining feature of high-intensity air warfare (McDermott, 2017; Deptula 2021). The development of faster EW systems with increased ranges, mobility, and automation will only increase the significance and impact of EW in future warfare where data and information flows will be more critical to success than kinetic weapons themselves (Kelly, 2023).

Put together, the diverse array of legacy and emerging air and missile threats, from Cold War-era tactical ballistic missiles to advanced precision-guided long-range fires that move quickly, unmanned systems, loitering munitions, and multi-tiered air defenses equipped with potent surface-to-air missiles and advanced EW characterize a spectrum of highly complex threats to air forces. However, individual weapons systems alone do not revolutionize warfare; rather, it is the increasing synchronization and integration between new and different generations of weapons and levels of technology that make the battlespace so lethal (Guzinger et al. 2020). The growing access to space and persistent sensors will only support the deeper integration of cross-domain fires with increased ranges and precision. As kill chains are harnessed with increasing levels of automation, the pace of operations is dramatically increased (Allen, 2017). AI will further increase levels of automation, allowing adversaries to rapidly process and exploit much higher volumes of information from a greater variety of sources. These gains from AI will optimize adversarial operational cycles by increasing the capacity and speed at which intelligence can be exploited, improving force protection, and enabling more dynamic C2 of assets to shrink the kill chain.

Rethinking Combat Power

In the face of highly proliferated sensors and fast-moving long-range fires, existing approaches to air superiority call to be re-examined (Gunzinger et al., 2024). Defined as “that degree of control of the air wherein the opposing force is incapable of effective interference within the operational area using air and missile threats,” air superiority is transient – in time, location, and coverage – and can viewed in terms of “windows of dominance” (Deptula and Bowie, 2024). Air superiority will remain essential for gaining or protecting control of the air by neutralizing air threats and air defenses to provide friendly forces the freedom of maneuver to execute follow-on operations, ensuring either the condition of *freedom from attack* (using defensive counterair – DCA) or *freedom to attack* (using offensive counterair – OCA) (Deptula and Bowie, 2024). The conditions of achieving air superiority will logically vary based on specific adversarial capabilities and operational scenarios, but responding to shifts in the threat environment necessitates that air forces move on from "bombs on target" approaches to generate new access vectors to operate in contested domains. To be sure, multi-domain operations will be essential for enabling frameworks integrating the use of space and cyber capabilities, and the EME, to support air forces in achieving air superiority at times and places of their choosing (Deptula, 2021; Ryan, 2022; Kaushal et. al, 2023).

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Expanding military space capability to support missile warning and tracking, fire control, and enabling pockets of tactical connectivity at specific times and locations will be imperative to ensuring both freedom from attack and freedom to attack in the future. Next, air forces will need C2 and battle management which enables commanders to integrate diverse capabilities in rapid timelines to capitalize on short windows of opportunity for gaining air superiority (Gunzinger et al., 2020; Brown Jr, 2020). Leveraging unmanned systems that can operate remotely for ISR, EW effects, and precision strikes will be an important element but, more importantly, AI-assisted process automation and decision support systems are needed to enable multi-domain integration and allow the operational tempo and maneuver necessary to unleash cross-domain effects in relevant timelines. Finally, air forces must adopt a standoff posture that facilitates movement to exploit access vectors at speed and fight from positions of advantage (Blaser, 2024; Cochran et al., 2022). Air forces will need to reorganize across a new "kill web," leveraging the benefits of low-footprint mission generation capability that is distributed across smaller, highly flexible, and austere locations (DARPA; 2020; Blaser, 2024; Cochran et al., 2022).

Prioritizing Non-Kinetic Capabilities

Traditionally, long-range fires have provided the means to counter air defenses, such as radar, surface-to-air missiles, EW and C2 nodes, and other strategic targets to degrade adversary capabilities to generate or sustain combat power. However, "deep maneuver" will become less possible in the future battlespace; instead, offensive missions will require tight protective bubbles where air forces make use of maneuver and movement to outpace opponents and fight from positions of advantage (Vershinin, 2024; Deptula and Bowie, 2024). Stand-off and stand-in jamming will be essential not only for self-protection but increasing the survivability of other assets in strike packages operating closer to threats and suppressing specific threats to create access vectors for other aircraft or weapons to exploit (Bronk, 2024; Lehoski, 2024). As such, EW needs to be viewed as electromagnetic maneuvering inside a highly contested EME – dominating which will be vital for increasing the survivability and effectiveness of aircraft and weapon systems (McDermott, 2017; Lehoski, 2024). This stresses the scale of future EW requirements, to include electronic warfare support (i.e., electronic intelligence – ELINT – collection, electronic countermeasures – ECM), EA, and electronic protection (i.e., electronic counter-countermeasures – ECCM), as illustrated in Figure 1.1.

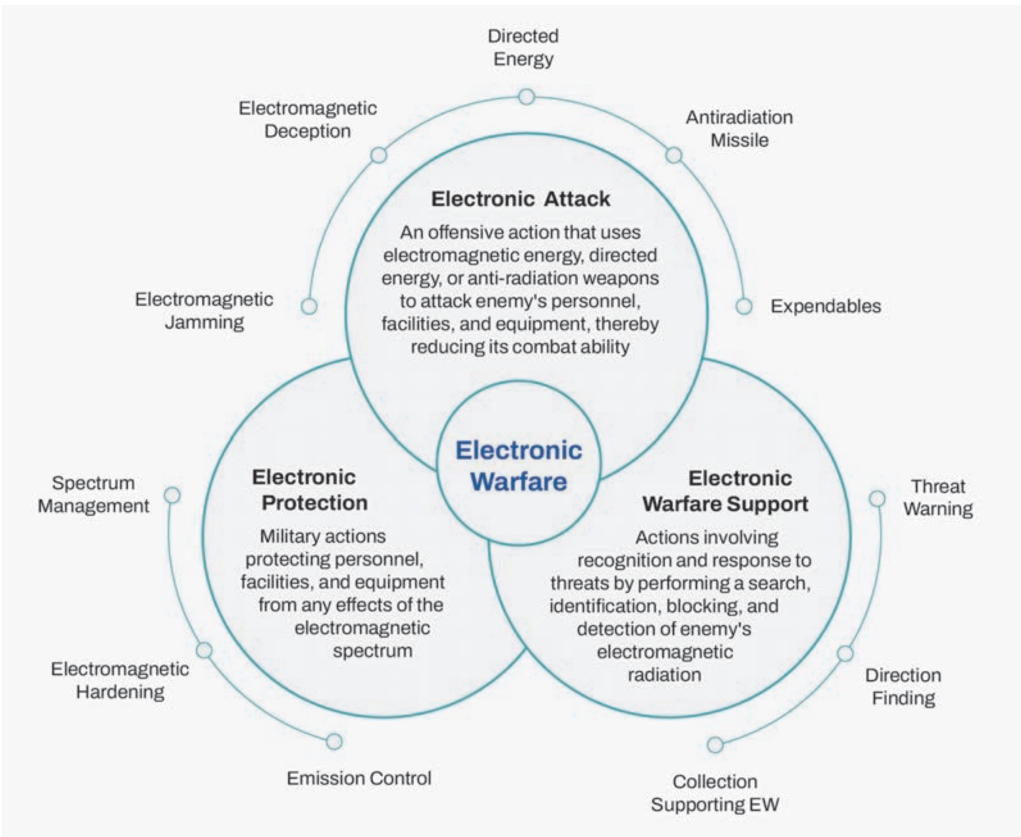

Figure 1.1: Conceptually Deconstructing Electronic Warfare (Adapted from Choi et al., 2020)

The F-35, designed for low-observable strike missions, is a potent airborne EW asset, providing stand-in jamming and limited stand-off jamming against both airborne and surface threats (Gunzinger et al. 2020; Bronk 2024). A few F-35s can significantly enhance the survivability of their own formation and assets operating alongside them – but only in short bursts, given the risk of operators compromising their position (Bronk, 2024). Most other fourth- and 4.5-generation combat aircraft, such as the Dassault Rafale and Saab Gripen, bring advanced ECM for self-protection but are not equipped for dedicated stand-off/stand-in jamming as standard (Bronk, 2024). Essentially, EW capability voids need to be filled by a combination of special mission platforms harnessing new technologies on aircraft, particularly unmanned systems, and space-based systems. However, EW effectiveness is essentially reliant on ELINT to understand threat systems in depth. As adversaries become smarter at adapting behavior and emission signatures to become more difficult to detect, mission data updates for aircraft, weapon seekers, and EW systems are needed far more rapidly, stressing the need for expanding ELINT collection across more sources and movements of airborne assets (McDermott, 2017; Vedula, 2023; Bronk, 2024). Operational and mission data collected and analyzed over weeks, months, and years helps build understanding of adversarial systems, capabilities, and movements to inform mission planning for air superiority operations (Vedula, 2023).

Rethinking Stand-Off Posture

Access to persistent sensors provides increases in observation confidence and, integrated with lethal long-range fires, will enhance adversarial capabilities to strike strategic targets at short notice, such as air bases, parked combat and support aircraft, runways, and so forth. Air forces will need to harden against detection not only through EP but also with improved camouflage, concealment, and deception (CCD) (Blaser, 2024). With its potential to deceive, distract, disorient, and confuse, CCD can stretch adversarial kill chains, increase the survivability of aircraft and strategic assets, and support more rapid maneuver of tactical aircraft to fight inside adversarial weapon employment zones. All other factors being equal, air forces that are more deceptive will succeed, but this will demand a fundamental change in airfield design and operations (Moore, 2024; Blaser, 2024; Hagardt, 2024; Cochran et al., 2022). Utilizing new aircraft paint schemes and low visibility insignia will prevent adversaries from identifying aircraft and tracking movements from space; randomizing parking and making effective use of hangars, shelters, and shades will mask the types and number of aircraft at operating locations, and; deploying decoys with thermal and radar signatures comparable to fighter aircraft may trick synthetic aperture radar, which can 'see through' visual camouflage, and automated systems to slow the adversarial kill chain or draw fire away from real aircraft (Blaser, 2024).

To be sure, large, stationary air bases are becoming less relevant as future threats press the need for air power to be capable of smaller and more dispersed deployment in short timelines (Hagardt, 2024; Cochran et al., 2022). Distributing operational and mission generation capability across multiple locations will alter how air power can be projected and sustained in less predictable theatres of operation (U.S. Air Force, 2022). Agile combat approaches emphasize operational resilience through flexibility; creating a "kill web" that redistributes combat and support assets across numerous operating bases in austere locations will enhance force survivability by removing a single point of failure (U.S. Air Force, 2022; Oppelaar, 2023). Such a dispersion of air power capability across numerous small hubs and spokes, so it is possible to move assets and personnel between locations multiple times per week, will limit exposure to and complicate the adversarial kill chain (Blaser, 2024; Hagardt, 2024). Distributing air power across a network of flexible and multiplatform-enabled bases that support entire mission sets rather than just specific aircraft types will allow air forces to sustain a stand-off posture that facilitates rapid movement within adversarial weapon employment zones (Blaser, 2024; Hagardt, 2024).

A New Engine for Operations

The shift away from legacy air-basing models, expansion of unmanned systems in future force structures, and multi-domain integration will increase the complexity of operational logistics, planning, and execution exponentially (Gunzinger et al., 2020; Hagardt, 2024). Responding quickly to windows of opportunity and against time-critical threats will require C2 and battle management that accelerates the observe-orient-decide-act (OODA) loop ahead of adversarial decision-making and reaction timelines (Rickli and Mantellassi, 2022). The information superiority necessary for such a warfare paradigm highlights the need for a new AI/ML capability to act as an OODA engine, where algorithms exploiting vast, sanitized datasets will provide higher-quality information in near real-time, identifying patterns, predicting outcomes, and assessing risks based on operational and mission data, and historical analysis (Layton, 2021; Lingel, 2021). Already, commercial technologies have been used to automate time-intensive analysis previously completed by dozens of intelligence analysts over hundreds of hours. Despite lacking the judgment, experience, and intuition provided by human analysts, techniques leveraging process automation can allow for results that surpass human abilities to generate actionable information without bias in rapid timelines (Blaser, 2024; Cochran et al., 2022).

Artificial neural networks, which measure degrees of criteria rather than simple binary pathways – for example, instead of equipment being broken (0) or functional (1), it could be measured more precisely as 0.5 (partly functional) or 0.9 (highly functional) – could process desired effects by considering vast metrics and generate multiple courses of action. With variable parameters such as size (number of units), location (airbases, forward locations), maneuverability (aircraft, counterair battery), munitions (conventional munitions, electronic), capabilities (speed, combat radius, radar cross-section), and vulnerabilities (small diameter bombs, precision-guided munitions), these algorithms could solve the challenge of optimally pairing weapons with targets, calculating risk probabilities, and predicting engagement results. For example, by exploiting robust databases containing extensive information on adversarial capabilities, AI could recommend variable attack options based on adjustable risk levels (Hagardt, 2024). AI would be able to rapidly pair specific aircraft with weapons based on payload requirements, platform availability, and proximity to the target while calculating weather impact around the target area, potential adversarial responses (before takeoff or while flying to the mission area), and the availability of other assets that could be tasked or re-tasked for support or follow-on missions (Hagardt, 2024). Such a decision support engine would proactively push information to commanders instead of waiting for assessments to be requested, revolutionizing the targeting and air tasking order (ATO) cycles and speed of C2 in future warfare.

Conclusion: Implications for Future Force Planning

Effectively leveraging the potential of unmanned systems, enhancing capabilities to integrate non-kinetic effects, and leveraging advanced AI/ML for operations, air forces may be able to repivot toward a more agile, resilient, and effective force structure capable of achieving and maintaining air superiority in dense threat environments. Rethinking combat power to preserve survivability and operational effectiveness while creating new strategic advantages this way will demand future force planning to refocus in several key areas:

Force Restructuring and Multi-Skilling

As the threat environment becomes increasingly complex, air forces must develop pathways to reassign more core mission functions to unmanned systems with increasing levels of automation and autonomous capability. This shift should rebalance dependency away from larger, more expensive manned platforms, enhance operational flexibility and survivability for high-risk missions, and bring more dynamic stand-off/stand-in support to piloted aircraft and strike packages. Secondly, to support an agile combat approach, multi-skilling the workforce to distribute mission generation capability across multiple locations will be imperative (Cochran et al., 2022; Oppelaar, 2023). By fusing workforce development with force restructuring, air forces will be able to create a more adaptable and resilient posture to operate effectively in contested environments. Force restructuring priorities must encompass:

- Increased integration of EW-hardened unmanned systems exploiting CCD techniques, with more advanced human-machine teaming to support collaborative combat concepts
- Cross-training personnel for multiple roles to support low-footprint distributed operations and revising recruitment and training programs to align with future operational needs

- Developing deeper cooperation with allies and partners to distribute mission generation capability outside national territories to support discrete shared multinational "kill webs"

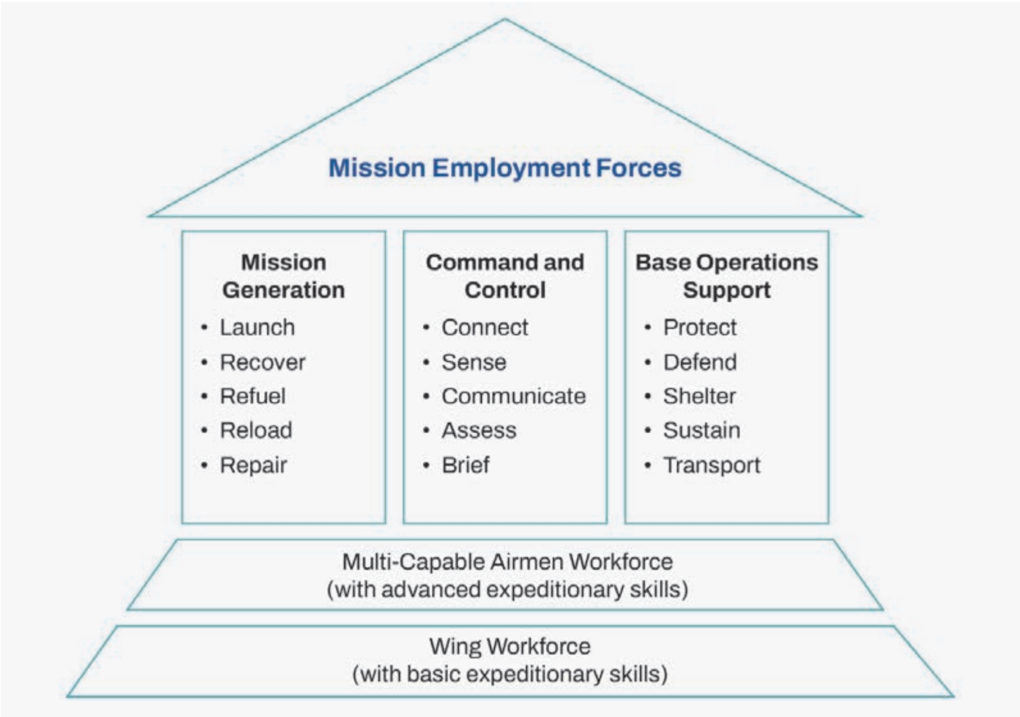

Figure 1.2: Multi-Capable Airmen Mission Pillar Structure (Adapted from U.S. AFEC, 2021). Multi-skilled, cross-functional support teams will be able to reduce manpower requirements without a corresponding drop in sortie generation capability. While such an approach may increase training costs, the resulting cost-savings from lower manpower requirements and performance gains more than compensate for any temporary loss in personnel availability (Cochran et al., 2022).

Expanding Space and Cyber Capabilities

The space domain and cyber capabilities will be critical for enhancing C4ISR to support future air superiority missions. Space-based capabilities will play a pivotal role in providing connectivity and persistent, wide-area surveillance to support TEW, detection, tracking, and engagement against advanced threats (Ryan, 2022). Secondly, the fusion of EW and cyber warfare will allow air forces to manipulate the information environment to degrade adversarial decision-making and use of weapons while protecting friendly assets from sophisticated electronic and cyber attacks. Air forces need to prioritize:

- Developing advanced space-based capabilities to support missile warning, tracking, fire control, and EW for kill chain optimization against high-value threats
- Enhancing high-capacity satellite communication networks to support distributed operations and investing in technologies that enable rapid, secure information-sharing across domains
- Fusing cyber warfare and EW to create synergistic effects that support access vectors to be generated in contested air domains by exploiting information superiority

Leveraging Big Data and AI

Harnessing the power of big data and AI, air forces will be enabled with a more seamless acceleration in the OODA loop, resulting in more optimized resource allocation that will provide a decisive edge in complex operational environments. To operationalize the advantages of big data and AI/ML at scale, air forces must develop a comprehensive strategy with specific programs aimed at:

- Creating robust data infrastructure with enterprise-level classification and encryption to support AI/ML applications across all operational areas
- Accelerating AI innovation through wargaming, simulated exercises, and establishing partnerships with industry and academia
- Implementing AI-driven decision support systems for multi-domain integration and developing algorithms for real-time threat analysis and human-in-the-loop response models

The need for continuous innovation and adaptation is emphasized across future force planning verticals and will allow air forces to stay ahead of evolving threats. However, strategically repivoting air power toward an AI-assisted, low-footprint distributed mission generation capability for future air superiority missions highlights new frontiers in future competition with implications that may be broader and more significant than air force leaders anticipate.

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