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Perspective
EXPERT INSIGHTS ON A TIMELY POLICY ISSUE

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What Is JADC2, and How Does It Relate to Training?

An Air Force Perspective on Joint All-Domain Command and Control

Although the concept of warfare spanning multiple domains is not new,[1] as warfare changes, new supporting concepts must be well defined and clear. Coordination of military operations across land and sea has spanned millennia, and although recent extensions into other domains, such as air, space, and cyber, have expanded the scope, the general premise is foundational. That said, warfare spanning multiple domains has become significantly more complex, both in theory and in practice, over the past decade. This is not only because of the increased number of relevant domains but also the result of emerging technologies that offer novel opportunities for linking, controlling, increasing the speed of, and integrating operations across these domains.

Each of the services and the U.S. Department of Defense (DoD) as a whole are moving forward in attempts to delineate a new conceptualization of command and control (C2) for multiple-domain warfare—now known as Joint All-Domain Command and Control (JADC2). Although newer terms, such as Combined JADC2, are occasionally discussed, and although some use JADC2 interchangeably with the

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Abbreviations

ABMS	Advanced Battle Management System
AI	artificial intelligence
AOC	air operations center
ATO	air tasking order
C2	command and control
CCMD	combatant commands
CCW	Command and Control Wing
CFT	cross-functional team
COP	common operating picture
CT	continuation training
DAF	U.S. Department of the Air Force
DevSecOps	development, security, and operations
DoD	U.S. Department of Defense
IQT	initial qualification training
ISR	intelligence, surveillance, and reconnaissance
JADC2	Joint All-Domain Command and Control
LVC	live, virtual, and constructive (training system)
ML	machine learning
MQT	mission qualification training
OSD	Office of Secretary of Defense
OTI	Operational Training Infrastructure
OTTI	Operational Test and Training Infrastructure
RCO	Rapid Capabilities Office
SCARS	Simulator Common Architecture Requirements and Standards
ShOC-N	Shadow Operations Center—Nellis
USAF	U.S. Air Force
USSF	U.S. Space Force

U.S. Air Force's (USAF's) Advanced Battle Management System (ABMS), JADC2 is the term in general use and, thus, the one used in this document.

However, the concept of JADC2 is still under development, and there is no single, universally agreed-upon, clear, and detailed definition. Although various working groups are addressing specifics, discussions of JADC2 objectives tend to adhere to relatively general lines: some combination of connecting all shooters and sensors much more rapidly and resiliently than is currently possible. This is a stirring vision but presents much room for interpretation. Although there are strengths to this flexibility in that it enables various communities to apply JADC2 to their work in whichever way is applicable, one substantial weakness is that it does not provide an accessible common definition.

Consequently, different communities and personnel with different perspectives might use the term *JADC2* to refer to completely different things. Discrepancies in perspective that need to be resolved are not illuminated, because they are not distinguished with different terms. This lack of common understanding also increases the risk of fostering siloed development and inefficient coordination.

It is necessary to educate airmen early on new concepts in warfare that might require changes to organizational structure and culture, and as JADC2 matures, so should plans for instruction. Training should be based on very specific requirements about what JADC2 is and what it means in practice. The lack of a single, well-understood definition of JADC2, however, highlights the need to lay out the construct as it is currently understood—even if that is necessarily subject to revision—to facilitate conversations that are more detailed and informed. Thus, after presenting an overview of the context for JADC2's development, we pro-

vide definitions and explanations of key terms and concepts relevant to JADC2 for the USAF training community.

We aim to bring operators into the technical discussion by providing a common definition that everyone can use and ultimately revise as needed, pending inevitable future developments. Although achieving the JADC2 vision will require technical virtuosity, its implementation will require general understanding and familiarity across different echelons. Thus, testing and training with the input of operators will be key to this effort, and the goal of this Perspective is to help facilitate that end.

To place our discussion in the appropriate context, we touch on other concepts that might be commonly used and at times confused with JADC2. As part of the training context, we consider both the Operational Training Infrastructure (OTI) and the more-recent development, Operational Test and Training Infrastructure (OTTI). Both refer to technical infrastructure that hosts, enables, and supports a variety of operational testing and training goals that are realistic, integrated, and cross-domain and that explicitly support training elements for air, space, and cyber. Both include live, virtual, and constructive (LVC) training—a family of training modalities that will be key in creating an experience that enables airmen to learn the knowledge and skills they will need in conflict—in a safe, secure, and cost-effective environment.

This Perspective draws from a project that investigates how LVC capabilities can help the USAF support the JADC2 initiative. Within the USAF, current work on JADC2 focuses on the capabilities that air operations centers (AOCs) provide and primarily considers the air, cyber, and space domains. Thus, to facilitate forward-thinking investment strategies for LVC-related training, this project explores how the USAF executes the JADC2 concept for the AOC training audience, with a focus on training at Tier 3 (service component) and Tier 4 (unit and individual) levels. This Perspective is based on a review of JADC2-related literature, policy documentation, and discussions with subject-matter experts across the USAF.

With an eye toward developing appropriate training capabilities, this Perspective summarizes

- the presumed need for JADC2 to adapt to anticipated changes in warfare
- the concept of JADC2 itself
- the context for its development with respect to training infrastructure and capabilities
- the relevant organizations and processes for implementing JADC2 in the USAF
- implications with respect to different stages of training.

Although JADC2 is inherently a joint concept, we view it through the lens of how the USAF will contribute to JADC2.

Why Have JADC2? Trends in the Conduct of Warfare Drive Future Needs

Anticipated changes in the conduct of warfare and the emergence of new and enhanced military capabilities motivate the need for new C2 capabilities, which directly relate to JADC2.[2] In this section, we review how potential changes in the future of warfare will increase the complexity of conflict. Although the prospect of these changes is breaking down the traditional domain-centric division of

roles and missions—for example, air-centric or air-only operations—advances in relevant technologies hold promise for the collection, fusion, and transportation of data that would be necessary to support the domain-spanning approach to C2 envisioned by JADC2.

Near-peer adversaries such as China and Russia can bring to bear many capabilities that the U.S. military has not confronted in military engagements, among them anti-access and area-denial (A2AD) capabilities. Adversary A2AD capabilities can deny U.S. forward forces the ability to maintain connectivity to centralized C2 nodes. Thus, C2 in any near-peer conflict scenario could be contested in a manner that demands new concepts and capabilities, including the ability to distribute C2 nodes. Distributing C2 nodes helps ensure that the ability to exercise C2 in a given mission does not depend on the survival of one central node, for instance, on an AOC (Hostage and Broadwell, 2014). Distributing C2 nodes increases the resiliency of the larger C2 network in contested environments (Air Force Lessons Learned, 2019).

A2AD capabilities also place a premium on the ability to decentralize C2. Decentralized C2 is distinct from distributed C2 in that the latter indicates the physical distribution of C2 capabilities, whereas the former indicates the decentralization of C2 authorities.[3] Under a decentralized C2 concept, C2 authorities would be passed to lower command echelons—that is, *local* C2—under a certain set of prespecified conditions, sometimes referred to as *conditions-based authorities*.[4] The ability to hand off C2 authorities to another level ensures that tactical forces can continue to execute their mission during a period in which connectivity to centralized nodes is lost. Maintaining operations in such conditions might require use of mission-type orders, in which headquarter guidance is given to lower echelons such that tactical forces can execute their mission without being told exactly how to execute it (Mulgund, 2021).

Of course, near-peer capabilities have implications for more than just C2. More generally, greater power, reach, and scale of near-peer capabilities—for example, long-range strike and highly capable intelligence, surveillance, and reconnaissance (ISR) assets—mean that future conflicts will likely overrun traditional areas that have defined the operational boundaries of geographic combatant commands (CCMDs) (see Winkler et al., 2019). Greater adversary capability has the same implications for distributed and decentralized C2. If near-peer adversaries can generate sufficient standoff, the forward forces' ability to exercise C2 at a local level becomes more important. Distributed and decentralized C2 capabilities can allow forward forces to execute their mission under such circumstances. For example, sophisticated adversary ISR capabilities place a premium on keeping communications between rear and forward forces to a minimum while enabling local C2.[5] Increased adversary capability also implies a need for C2 concepts and capabilities that allow dynamic tasking that is responsive to rapidly changing tactical and operational scenarios. Such scenarios might arise due to a high-velocity weapon crossing areas of responsibility, where commanders in different areas might need sensors from other domains or other commands to effectively execute missile defense (Hitchens, 2020a).

The increasing sophistication of ISR capabilities means that the future battlefield will be awash with greater volumes of data that must somehow be organized to facilitate quick, accurate, and efficient decisionmaking. This means

that decisionmakers will confront a greater signal-to-noise ratio. The proliferation of ISR sensors across domains—from maritime sensors and sensors aboard fighter aircraft to low-earth orbit satellites—and the potential relevance of data from commercial applications will demand the capability to fuse and process massive amounts of data to accelerate decisionmaking (Winkler et al., 2019). Even with the ability to ingest and store large volumes of data, C2 organizations need appropriate tools to filter out noise and provide relevant information to decisionmakers.[6] This requires the development of artificial intelligence (AI) and machine-learning (ML) applications and their insertion at the right points throughout the C2 process.[7]

Adversaries will employ AI/ML applications in their own C2 processes for the same purpose of accelerating their decision cycles. In addition to new capabilities such as hypersonic weapons, these capabilities are likely to drive an increase in the pace of conflict and an ability to reduce the time between decisions (Winkler et al., 2019). China, for example, is considering the use of AI at the tactical and strategic levels of warfare (Kania, 2017).

AI/ML tools also enable U.S. and adversary use of unmanned platforms to operate independently or in human-machine teams. The use of unmanned platforms alongside AI/ML applications that enable rapid, coordinated behavior (e.g., swarms of small drones) demands extremely fast C2 capabilities to counter such threats.[8]

These shifts in the conduct of warfare will require that C2 tools and processes adapt. The necessary adaptations will likely represent changes in degree and not in kind: The military is used to coordinating effects across domains but will need to do so faster (potentially at greater-than-human speed).[9] The military must be prepared to manage C2 when communications are contested and reliance on distributed C2 nodes is necessary. DoD currently fuses data from a variety of sensors, but it will need to do so with more data, increased automation, and increased speed.[10] These shifts in warfare motivate the need for new C2 concepts such as JADC2.

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What Is JADC2? Vision and Goals

The evolving trends in warfare require a new operational concept so that the United States remains competitive against future adversaries. This section provides an overview of JADC2 as a response to this need. It includes a summary of requirements for JADC2, the primary supporting organizations, and a description of the ABMS as a technical cornerstone. JADC2 has emerged as the new concept and is defined in USAF doctrine as follows:

JADC2 Goal

Provide an advantage over near-peer adversaries with faster and more-informed decisionmaking:

- deliver capabilities to support faster decisionmaking in a high-end conflict
- link tactical and strategic networks to enable the fast ingestion, fusion, and transport of data across domains
- enable dynamic tasking and retasking
- enable resilient C2.

> [T]he art and science of decision-making to rapidly translate decisions into action, leveraging capabilities across all-domains and with mission partners to achieve operational and information advantage in both competition and conflict [Air Force Doctrine Note 1-20, 2020].

At a very basic level, JADC2 is an attempt to change the way that DoD fights and to support that change with appropriate organizational structure and technology. Discussions of JADC2 often focus on the goal of linking every sensor to every shooter, such that the most-appropriate platform is chosen to generate a desired effect, regardless of domain. The JADC2 concept aims to deliver a more-general set of capabilities to support faster and more-accurate decisionmaking; in support of this, the JADC2 aims to link tactical and strategic networks together to enable the fast ingestion, fusion, and transport of data across domains.[11] The goal is to provide a decisionmaking advantage over near-peer adversaries by leveraging sensor data from all domains, automation tools, resilient networks, and distributed C2 structures (Hoehn, 2022b).

JADC2 is meant to enable a variety of functions to support decisionmaking in high-end conflict. The ability to construct a common operating picture (COP) is central to operational planning across domains. Given the speed of conflict and the nature of threats that cross geographic areas and domains, JADC2 is meant to enable dynamic tasking and retasking, such that an appropriate course of action is produced as threats and opportunities rapidly change.

JADC2 is intended as a concept in high-end conflict, it should enable resilient C2 in the face of adversaries' abilities to contest and degrade information and communication environments. Not only can near-peer adversaries disrupt and destroy communication nodes, they can also operate in a way that requires U.S. forces to function at greater distances from the battlefield, making distributed C2 nodes more valuable.

Supporting Requirements

Achieving the JADC2 goals requires a combination of automation tools, infrastructure, common data architectures, organizational and process changes, and training capabilities. As noted previously, automation tools, such as AI/ML algorithms, will be important for directing unmanned assets and enabling manned-unmanned teams. More generally, AI/ML tools will be necessary to process large amounts of data and make recommendations to human decisionmakers for courses of action (Freedberg, 2020). These tools will also be important for closing holes

in disrupted networks to ensure continued C2 in contested environments and for speeding up C2 processes to match the increased pace of conflict.

New data-sharing capabilities will be central to JADC2. Consequently, networks with high bandwidth and low latency will be required to handle the large amounts of data that will contribute to the COP. Joint and service organizations will also need to adopt common data architectures and standards, or otherwise have documented and accessible interfaces, to enable seamless data-sharing across domains and platforms. Given the need to coordinate across DoD, industry, civilian agencies, research institutions, and international partners (Hitchens, 2021b), implementing common data standards and enacting incentives for their tested use could present a significant challenge (Marler et al., 2021). Furthermore, authoritative and trusted data sources and standards will be important for enabling data-sharing (Secretary of the Air Force Public Affairs, 2019).

JADC2 will likely require local data storage and processing capabilities to enable forward C2. These are key capabilities for enabling conditions-based authorities to be passed in the contested environments.[12] The degree to which these capabilities will be necessary to support JADC2 depends in part on which new organizational concepts—such as a multidomain or an all-domain operations center—the USAF and the DoD ultimately settle on (Air Force Lessons Learned, 2019). These new concepts might support greater degrees of C2 decentralization and distribution, as discussed earlier.

Related to the above organizational concepts, JADC2 will also likely require new capabilities to enable commanders to leverage information from other domains to synchronize effects or deconflict fires. This will entail merging data streams from across domains into a COP that a commander can use to, for example, select the right effect for taking out an air defense system.[13]

Finally, JADC2 will require new training capabilities to match the scale and complexity of the operations that the concept is meant to address. JADC2 training will require the ability to simulate large numbers of entities, degraded and contested environments, and credible effects from all domains and from tactical to strategic levels of war. Cross-service training in complex tactical and operational environments can be time consuming and resource intensive; the ability to use interoperable simulation-based training capabilities across services will therefore be crucial to expanding such training opportunities.

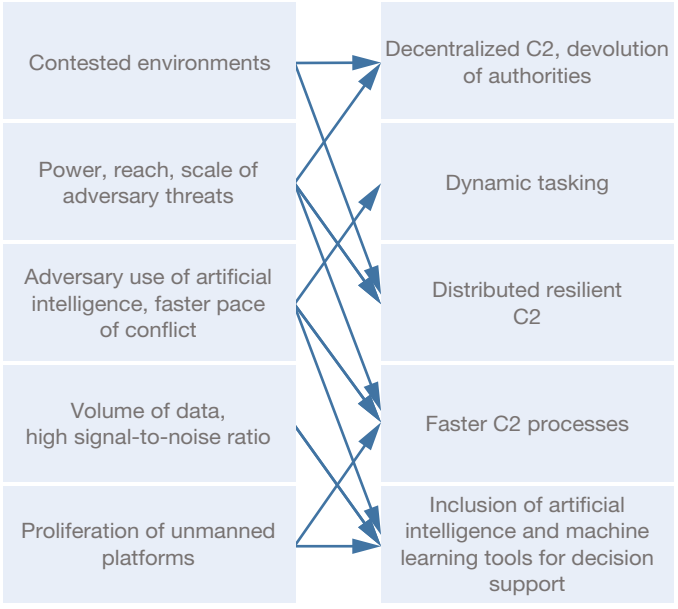
Figure 1 depicts how anticipated changes to the conduct of warfare relate to the JADC2 vision and goals. The connections in the figure indicate that a specific aspect of the future of warfare drives a given need under the JADC2 column. The aspects of the future conduct of warfare and the connections to JADC2 implications are spelled out in the "Why Have JADC2? Trends in the Conduct of Warfare Drive Future Needs" section above and drawn from the literature and interviews discussed in that section.

Roles and Responsibilities

As an overarching concept for C2 across the services and with multinational partners and allies, JADC2 involves many actors that coordinate to ensure the alignment of various C2 efforts. The USAF is playing a central role in its development. Although DoD as a whole is involved in efforts to implement JADC2, various services and offices

FIGURE 1

How Anticipated Changes in War Drive the Development of JADC2



have particular areas of responsibility. The USAF is tasked with leading the effort on C2 for the Joint All-Domain Operations concept. The primary roles and responsibilities pertaining to the USAF and to JADC2 oversight are summarized in Table 1.

A JADC2 cross-functional team (CFT) was chartered in January 2020 to lead these efforts. The JADC2 CFT includes general/flag officer and civilian equivalent representatives from the services, the Office of the Secretary of Defense (OSD), the Joint Staff, CCMDs, other government agencies, and some allied states. The CFT is tasked with supporting the Joint Requirements Oversight Council in making determinations on requirements, identifying capability gaps, and generally supporting the integration of service efforts, but it does not have decisionmaking authority (Hitchens, 2021a). The Joint Staff J6 is taking the lead on coordinating JADC2 efforts across the services (Hoehn, 2022a).

The USAF is developing the ABMS as its primary contribution to JADC2.[14] Within the USAF, the ABMS CFT in Air Force Futures is providing strategic direction to the USAF's JADC2 efforts, including the development of a campaign plan for ABMS. Concept and technical development are spread across multiple organizations within the USAF. The U.S. Department of the Air Force (DAF) Rapid Capabilities Office (RCO) manages the acquisition portion of the ABMS program. The Chief Architect's Office under the Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics is responsible for the ABMS demonstrations, which bring together the services and industry to experiment with capabilities for ABMS.[15] Future ABMS exercises are intended to place a heavier emphasis on CCMD participation in experimenting with JADC2 capabilities, including the use of virtual environments.[16]

Other organizations play important roles in developing, testing, and implementing aspects of JADC2. The 505th Combat Training Group supports training, experimentation, and tactics development for multidomain C2 for joint and coalition audiences. Under the 505th group, the 805th Combat Training Squadron (also called the Shadow Operations Center—Nellis, [ShOC-N]) is the venue for experimentation, testing, and development of technical solutions and tactics for JADC2. In October 2019, the 16th Air Force was tasked with providing CCMDs and the intelligence community with "combined

TABLE 1

Primary Roles and Responsibilities Pertaining to the USAF and to JADC2 Oversight

Organization	Responsibility
JADC2 CFT	Serve as primary lead for JADC2 efforts
Joint Staff J6	Serve as JADC2 CFT lead
U.S. Army	Serve as lead for Project Convergence
U.S. Navy	Serve as lead for Project Overmatch
DAF ABMS CFT	Provide strategic direction for ABMS; operational lead
DAF RCO	Manage ABMS program of record; technical lead
DAF Chief Architect's Office[a]	Handled initial ABMS demonstrations
DAF Air Combat Command	Handle the operational test and evaluation of the entire C2 portfolio, including the AOC
DAF Air Force Futures	Serve as lead for DAF's ABMS campaign design
DAF 505th Combat Training Group	Provide experimentation, tactics, and training for multidomain C2
DAF 805th Combat Training Squadron	Provide experimentation, testing, and development of technical solutions and tactics
DAF 16th Air Force	Manage and defend a network to enable the fusing and sharing of ISR and weather data from across domains
Air Combat Command	Operational test and evaluation of C2 portfolio, including AOCs
Office of the Secretary of Defense (Research and Engineering)	Manage software architectures for JADC2
DoD Chief Information Officer	Oversee data and standards
Office of the Secretary of Defense (Acquisition and Sustainment)	Provide acquisition oversight for JADC2
Kessel Run	Develop C2 capabilities for USAF

SOURCES: Hoehn, 2022a; Hitchens, 2021a; McLeary, 2020; Feickert, 2021; interview with Department of the Air Force official, March 24, 2021; interview with Department of the Air Force official, July 12, 2021; and Naegele, 2020.

[a] As of April 2022, the Chief Architect's Office is no longer connected to ABMS, and there are no demonstrations.

[ISR], cyber, electronic warfare, and information operations" (Naegele, 2020). The 16th Air Force is intended to support JADC2 by managing and defending a network to enable the fusing and sharing of data from across domains and providing weather data, impacts, and effects into the joint network. Finally, although Kessel Run focuses on developing new software for AOCs, the methods being established and products being developed by Kessel Run overlap with operational goals for JADC2 for the air and space domains.[17]

Because this Perspective focuses on the USAF, we do not explore the organizational details of other services' approach to JADC2 in detail. Nonetheless, to date, the other services' concrete efforts toward JADC2 include the U.S. Army's Project Convergence, which involves a series of demonstrations to incorporate AI/ML tools into multidomain operations and more generally to pursue joint and coalition interoperability, and the U.S. Navy's Project Overmatch, which is an effort to develop a tactical network that links sensors across domains. The Navy intends for this network to "plug into JADC2" in the future (McLeary, 2020). Joint Modernization Command's JADC2 Division (under Army Futures Command) is leading the Project Convergence effort.[18] The Army involved the USAF and the Navy in its Project Convergence 2021 exercise and will involve multinational partners in 2022 (Feickert, 2021). Because of the inherently joint nature of JADC2, however, it is clear that alignment among the services will be critical.

Advanced Battle Management System

To serve as the technical cornerstone of JADC2, the DAF has initiated the ABMS program of record. This software development program has evolved significantly, along with JADC2, since its conception and will most likely continue to evolve because of the political climate, emerging requirements, changing technology, and multiple stakeholders.[19] The effort started out as a way to replace the service's aging E-8C Joint Surveillance Target Attack Radar System, the mission of which is to provide theater ground and air commanders with ground surveillance to support attack operations and targeting that contribute to the delay, disruption, and destruction of enemy forces (DAF, 2015). However, ABMS is intended not only to accomplish this mission but also to enable joint force connectivity and C2, so that the joint service can communicate and target across joint assets. The USAF and U.S. Space Force (USSF) have indicated that they expect requirements to evolve through multiple methods such as wargaming, exercises, experiments, and analysis. In fact, the USAF and USSF have

ABMS Objectives

- Digitally unify, modernize, and connect the joint and coalition forces by enabling connectivity of diverse C2 systems and platforms.
  - Enable all echelons to have rapid access to joint capabilities.
- Provide a strategic advantage on a global scale by connecting sensors, decision nodes, and effects to optimize decisionmaking.
- Enable a data-centric approach to warfare.

indicated that, as technology changes, ABMS should continue to evolve (DAF, 2020). Nonetheless, it is important to understand the overall intent of ABMS and how it will support JADC2, and this intent will provide the foundation for evolving requirements.

ABMS Intent

USAF and USSF intend for ABMS to digitally modernize and connect the joint and coalition forces and to power JADC2 by enabling all echelons to have rapid access to joint capabilities (DAF, 2020). Ideally, ABMS will provide U.S. and coalition forces with a strategic advantage on a global scale by connecting sensors, decision nodes, and effects. ABMS's ultimate objective is the convergence of joint coalition, civilian, and commercial data, sensors, C2, and combat power to optimize decisionmaking for the United States globally (DAF, 2020).

Currently, there are multiple disparate unconnected systems and platforms that are intended—but fail—to enable timely C2 across the joint force (with increased disparity between U.S. and coalition forces; Allvin, 2021). ABMS will unify the force by enabling connectivity of diverse C2 systems and platforms. Users will be able to leverage capabilities of multiple platforms by integrating effects across domain, meaning services could capitalize on sister service effects and deliver an optimal mix of kinetic and nonkinetic effects across different domains. Currently, coordinating effects across domains is a time-intensive process specifically when it spans across different service domains of responsibility (Allvin, 2021).

In addition to enabling the connectedness of the joint force, ABMS is intended to enable a data-centric approach to warfare. The current platform-centric approach to warfare is no longer sufficient, no matter how exquisite the individual platforms might be (DAF, 2020). Currently, DoD is unable to capitalize on available data and joint capabilities at the speed of relevance because the joint and coalition forces spend too much time and too many resources transferring data through security barriers, translating data across systems, and conducting human-in-the-loop processes to move data from sensor to operator and commander. In some cases, joint and coalition forces simply have not been able to inform potential users where data are available or how to access it. Data quickly become stovepiped, and the service components and the joint force fail to integrate them. These disconnects lead to multiple perceptions of the operational environment and delays in decisionmaking, both of which are key elements of C2. With ABMS, the USAF and USSF aspire to enable joint operations by providing timely and relevant data from joint systems to the warfighter, commanders, and decisionmakers.

In summary, the USAF and USSF intend for ABMS to enable a data-centric approach to warfare and integrate joint force capabilities (DAF, 2020). ABMS itself will be enabled through the development and acquisition of hardware, software, a digital architecture, and appropriate standards. Note that ABMS is not self-sufficient; it relies on DAF programs outside ABMS that enable the digital and open architecture not only for ABMS but also for enterprise systems across the USAF and USSF.[20]

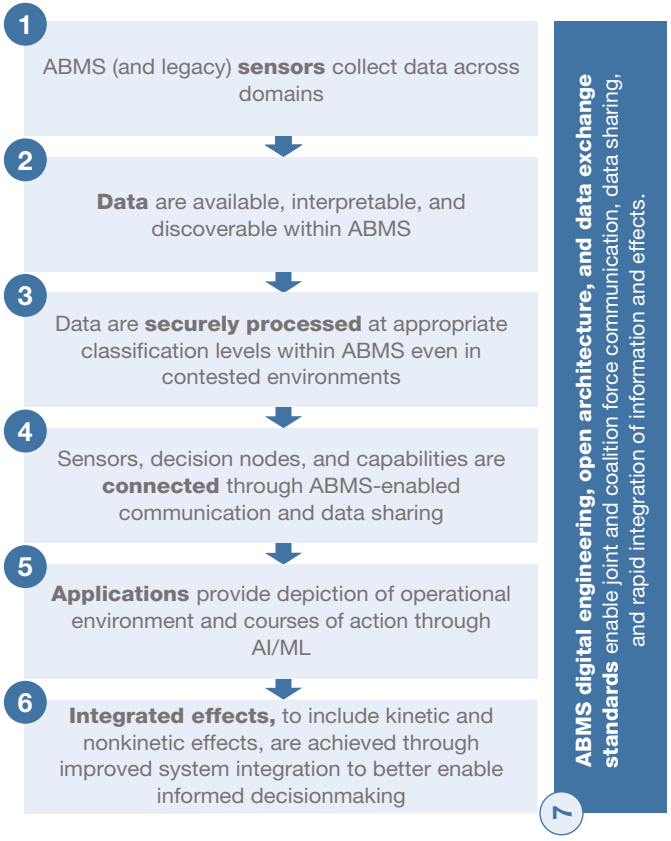
ABMS Elements

Although ABMS has evolved, understanding how the program was originally conceptualized helps break down the multiple different components that could make up the future of ABMS. The development of the program is still in

flux, and although the terms might change, the concepts, most likely, will not.

ABMS is made up of seven elements shown in Figure 2. The new ABMS (and legacy) sensors will produce data, which will need to be routed and managed through data tagging, standardization, and merging. The data will be securely processed; this will be particularly challenging because, for JADC2 to succeed, data security needs to be maintained while allowing all relevant parties to access relevant data. The network will be enabled by a combination of government and commercial connectivity products, which include software that facilitates connectivity between weapon systems, allowing information to flow in the current information environment. Software applications are intended to clarify the battlespace with the use of technologies like AI/ML. Finally, these applications will present options to achieve the desired kinetic or nonkinetic effects. These effects can be enabled through improved system integration that streamlines the dissemination of information across systems and augments the human decision activities that are a part of the C2 processes (Tucker, 2021b). Underlying these six elements are digital engineering, open architecture standards, and data exchange standards.

FIGURE 2
ABMS Elements



SOURCES: Derived from DAF, 2020; and DAF, 2021.

ABMS Users

Although ABMS is expected to be the technical backbone of JADC2, joint force operators and strategic decisionmakers' ability to operate ABMS and capitalize on capabilities will be crucial to JADC2 employment. Therefore, training the warfighter and decisionmakers on ABMS will be critical. ABMS will require human-machine teaming, as it will ideally

- provide the user a near real-time COP or user-defined operating picture of the combat environment

- provide connectivity to enable battle management, command, and control between users in highly contested and congested environments
- generate potential courses of action in real time—a capability that is inconsistently available to decisionmakers above the tactical level of conflict.

ABMS will fuse and filter information from the air, space, cyberspace, maritime, and ground domains, as applicable, providing users and decisionmakers with awareness and promoting shared awareness. However, users will have to interpret these data. How the team and its members interpret the data can be shaped by training, education, and different mental models (SAS-050, 2006). Therefore, training users on how to understand the data presented by ABMS will be critical. Providing connectivity, courses of action, and a COP will support the JADC2 effort by enabling rapid decisionmaking and shared situational awareness.

Where Is ABMS Now?

As of February 2021, despite the need for trained users, there are no established requirements for training future users of this system and no requirements for LVC systems to enable training. Given the complexity of the undertaking, getting in on the ground floor with training considerations is essential, as human interaction with ABMS and JADC2—supported by training—will be key. In a meta-analysis of innovative organizational change efforts, technology alone was not a sufficient lever to drive organizational change; rather, changes in structure (such as changes in hierarchy and authority) and human resource efforts such as training were necessary predictors of organizations' success at innovation (Macy and Izumi, 1993).

As of February 2021, four exercises have included ABMS with limited successes, including connecting an F-35 to an F-22 and enabling information sharing.[21] There are mixed reviews of the capabilities that ABMS has been able to provide, but ABMS is still in development. At the time of writing, the RCO is leading the acquisition and development of ABMS.

In addition, the term *ABMS* is evolving. Within the DAF, ABMS has grown not only to define the technical backbone of JADC2 but also to represent JADC2 itself, and ABMS and JADC2 are now used interchangeably by some. However, if the USAF and USSF are to communicate effectively with joint counterparts and Congress, the Headquarters Air Force and DoD will need to clarify the distinction between JADC2, which is an approach to decisionmaking, and ABMS, which is a system that enables that approach.[22]

What Is the Context for JADC2 Training? Infrastructure and Capabilities

Given the complexity of JADC2 and the inherent changes to how the USAF will fight, training will likely play a significant role in its implementation. To prepare for anticipated changes in the future character of warfare, training capabilities must also be advanced from their current state to support readiness for joint operations over all domains. A key part of this evolution in warfighting depends on the operational capabilities constituted by test and training infrastructure (Datzman, 2019; and Hoehn, 2022b). Thus, just as it is important to consider the development of

JADC2 in the context of trends in warfare, it is necessary to understand the training context, including OTI and OTTI. This section provides an overview of this training context with key definitions, including definitions for LVC and its components.

Broadly, OTI and OTTI refer to technical infrastructure that hosts, enables, and supports a holistic range of operational testing and training goals that are realistic, integrated, cross domain, and explicitly supportive of training elements for air, space, and cyber.[23] As the concept of JADC2 develops, the OTI and OTTI take supportive roles, as does the LVC family of training modalities within OTI and OTTI. Here, we provide a brief overview of relevant concepts.

Operational Training Infrastructure

Operational Training and *Operational Training Infrastructure* are defined as follows:[24]

- **Operational Training:** Mission-oriented training in support of warfighter readiness, distinguished from initial training due to its focus on employment of a weapon system in an operational setting as opposed to basic use of equipment or development of basic skills
- **Operational Training Infrastructure:** A framework that includes training systems, live ranges, simulators, environment generators, threat emitters, aggressors, networks, training centers, and multidomain C2 training systems.

OTI includes training-related technical infrastructure assets and supporting systems, such as facilities, networks, data systems, simulators, integration software, and performance measurement systems that are applied in support of force training (U.S. Air Force, 2017). Although OTI includes simulation and simulators—the synthetic aspects of training associated with LVC training—it is not limited to LVC. Being infrastructure centered, OTI and OTTI are distinct from LVC training.

Operational Test and Training Infrastructure

The concept of OTTI extends OTI and integrates the technical infrastructure for test and training assets to enable realistic and relevant environments that also support weapon systems testing and warfighter readiness training (Jaime and Trnka, 2020; and Moschellam, 2020).[25] Based on USAF usage of terms related to test and training environments, we define OTTI as follows:[26]

- **Operational Test and Training Infrastructure:** Technical infrastructure that groups test and training assets to enable realistic and relevant environments supporting operational testing of weapon systems and warfighter readiness training.

OTTI is a shift away from the perspective that weapon systems, test infrastructure, and training infrastructure should be developed independently from one another. Rather than promoting better training and testing, the current acquisition, testing, and training approaches—in which training and testing are considered relatively late in the acquisition life cycle—can present risks to missions and force readiness (Jaime and Trnka, 2020; and U.S. Air Force, 2017). Thus, the OTTI concept intends to break the paradigm of "weapon system first, test and training infrastructure second" (Moschellam, 2020; and U.S. Air Force, 2017).

Operational test and training systems might rely on the same basic infrastructure to achieve weapon system testing goals and enable operational training. Thus, OTTI can bring together key intelligence, test, and training communities to promote holistic and relevant environments for test and training. In addition, test and training infrastructure assets can essentially combine and factor in the design stage of future weapon systems concurrently. OTTI (as opposed to OTI) fosters this approach.

Simultaneously, there is potential to improve the cost and availability of test and training infrastructure for future weapon systems. With its expanded emphasis on test and experimentation, OTTI can facilitate real-world implementation of technology and help highlight potential issues earlier in the acquisition process. Viewing test and training infrastructure capabilities alongside—and on equal footing with—the development of future weapon systems can enable the force to be ready for the future threats motivating the JADC2 concept.[27]

OTTI for Existing and Future Capabilities

Distributed throughout the USAF are many training systems that relate to OTTI, but these systems are not always integrated within a common architecture. Thus, there could be gaps in the USAF's ability to align existing capabilities with an OTTI concept, to construct a realistic training environment, to integrate efficiently, and to provide warfighter training across geographically separated training sites (Toukan et al., 2022). This is a problem internal to the USAF as well as the more-integrated JADC2 concept. Although there are some efforts to fill these gaps, summarized in this section, developing training infrastructure to support JADC2 could provide an opportunity to improve coordination.

The Simulator Common Architecture Requirements and Standards (SCARS) program is being implemented to address these integration issues. SCARS is a sustainment initiative to establish a standardized technical baseline for disparately interoperable systems and to broaden their accessibility from an OTTI perspective (Jaime and Trnka, 2020). SCARS will enable common environment models and applications.

As part of the Air Combat Command future training concept, multiple lines of effort are underway to improve the ability to leverage training-related infrastructure and system improvements. Goals include the following:

- improve simulation concurrency, fidelity, and connectivity
- mature live training range environments
- optimize convergence of simulated and live environments
- evolve proficiency-based training (Moschellam, 2020; and U.S. Air Force, 2017).

OTTI in its current form, however, might be insufficient for future training and testing needs (Toukan et al., 2022), and the 2021 Air Force Warfighting Integrating Capability goals advocate a unified approach to OTTI and for synthetic (virtual and constructive simulation capabilities, as defined in the subsequent section) OTTI to close test and training gaps. In fact, synthetic OTTI is among the top ten key capabilities included in the 2023 Program Objective Memorandum (Air Force Warfighting Integration Capability, 2021).

Live, Virtual, and Constructive Training

The different components of LVC, as well as the overall concept, provide key aspects of OTI and OTTI and can help support training for JADC2. Based on an aggregation of various documents, we use the following definitions for the elements of LVC (DoD, 2014; Air Force Instruction 16-1005, 2016; and Air Force Instruction 16-1007, 2019):

- **Live simulation:** A simulation involving real people operating real weapon systems but without a live enemy. Although the term "live simulation" might seem like an oxymoron, it is common in the literature and constitutes a simulation because it does not represent an actual military event.
- **Virtual simulation:** A simulation involving real people operating simulated systems. Virtual simulations inject human-in-the-loop in a central role by exercising motor control skills (e.g., flying an airplane), decision skills (e.g., committing fire control resources to action), or communication skills (e.g., indicating the location of a target).
- **Constructive simulation:** A constructive simulation includes computer-generated entities whereby simulated people operate simulated systems. A constructive simulation is a computer program. Real people might stimulate (provide inputs to) such simulations, but they are not involved in determining the outcomes.

Although these three independent aspects are well defined, the more-general idea of LVC as an overall construct can sometimes spur confusion. Depending on the context, it is not always clear whether the use of the term implies (1) the full integration of LVC simulation concurrently or (2) any use of synthetic training elements, in which the term *synthetic* implies the use of virtual and/or constructive elements. Blended training refers to the combination of live training with virtual or constructive elements.[28] Furthermore, discussions of LVC can sometimes erroneously imply extension beyond just simulation capabilities and include a broader enterprise similar to OTI.

Nonetheless, given JADC2's substantial changes to the way the USAF and, more generally, DoD might integrate and operate, LVC capabilities can help support the scale and complexity of the operations that JADC2 is meant to address. Although discussing details of applications is beyond the scope of this work, each aspect of LVC—as well as the overall integrated construct—can support JADC2 in different ways.

How Will the USAF Implement JADC2? Air Operations Centers

Given the need to provide appropriate training for JADC2, one must also consider the training audience—end users to whom JADC2 will be deployed. In practice, the conceptual shifts in C2 constructs, which are central to JADC2, will likely center on the heart of operational C2 in the USAF: the AOC (Hitchens, 2020b). This section provides an overview of the AOC, how it is structured, and how it operates.

Fundamentally, an AOC is a command center. The AOC weapon system, often termed the *Falconer system*, is a system of systems that incorporates multiple software applications.[29] It generally enables C2 of joint theater air and missile defense, multidomain target engagement

operations, and ISR operations management (Defense Acquisition Management Information Retrieval, 2016). It is normally employed by the Joint Force Air Component Commander to exercise control of air forces in support of combined and joint force objectives.

There are seven *geographic* AOCs and five *global* AOCs located around the world. Global AOCs support functional CCMDs in the areas of global strike, space, mobility, special forces, and cyber. Geographic AOCs support geographic CCMDs and the planning and execution of theater operations in support of the joint force commander (Lingel et al., 2020, p. 2).

The technology underlying the AOC is a web of C2 software systems that enables all phases of the air tasking cycle, which is a nominally 72-hour cycle that provides orders and documentation to translate an airpower strategy from the operational to the tactical level.[30] The cycle begins with the AOC Strategy Division defining objectives, effects, and guidance for the air tasking order (ATO) period. An ATO is essentially a detailed flying schedule. Given its current centrality, it is helpful to have a basic understanding of an ATO's status quo form to better consider how it might change to facilitate JADC2.[31]

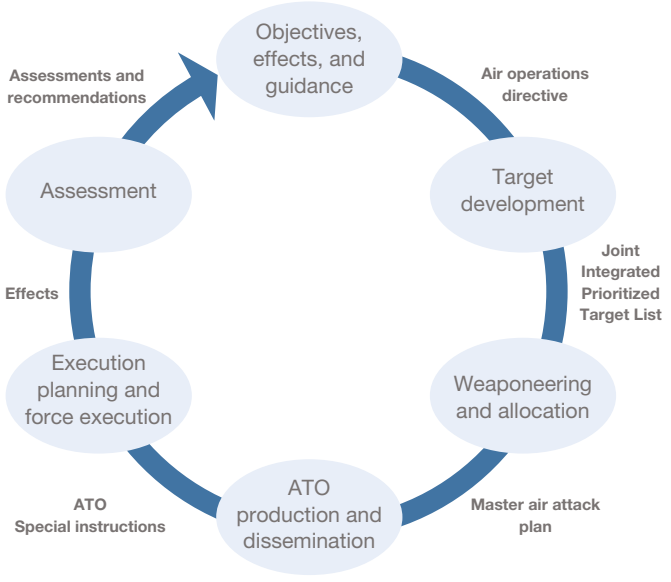
Air Tasking Cycle

The air tasking cycle is a personnel-intensive and deliberate cycle of coordination in which targets are developed, platforms are chosen to maximize probability of success and minimize risk, and legal and commander reviews are incorporated at multiple points (Lingel et al., 2020, p. 4). Figure 3 illustrates some of the complexity of this process.[32] The continuous nature of the air tasking cycle means that as the Combat Operations Division is executing and monitoring a given day's ATO, the Combat Plans Division is planning the next day's ATO, and the Strategy Division is preparing for the subsequent day.

Capabilities to Support AOC Operations

The USAF has pursued technologies to enable the AOC to access information across domains as rapidly as possible. Although capabilities from air, space, maritime, ground, and cyber domains contribute to military operations, it

FIGURE 3
Air Tasking Order Cycle



SOURCE: U.S. Air Force, *Operational Employment: Air Operations Center*, AFTTP 3-3.AOC, March 31, 2016.

JADC2 Audience and Primary Mechanism

Primary Air Force audience for operational-level JADC2 execution:

- AOC

Primary mechanism for JADC2 operations:

- Air tasking cycle

is difficult and time consuming for AOCs to synthesize information across domains to rapidly understand the environment and inform C2 decisionmaking. The process is primarily manual and is accomplished through coordination meetings; despite inherent inefficiencies, it is doctrinally how the USAF integrates other domains (Air Force Doctrine Publication 3-30, 2014, Appendix B). The AOCs' emphasis on deliberate planning and intensive personnel coordination to generate the ATO might at times be too slow for today's technological environment, in which decisions might need to be made in seconds (Lingel et al., 2020, p. viii). Difficulties sharing information across classification levels and on multiple *air-gapped systems* (systems that are physically disconnected from networks) also pose a challenge (Lingel et al., 2020, p. viii). Other limitations to decision speed and cross-domain coordination relate to authorities, command relationships, disparate processes and battle rhythms across domains, varied C2 structures in different regions, and communications difficulties (Lingel et al., 2020, p. viii; and Priebe et al., 2020).[33]

USAF innovation efforts have focused on mitigating these limitations. Rather than seeking an external contractor for this work, the USAF adopted a new in-house approach, initially known as *Pathfinder*, which uses an agile software development technique known as *DevSecOps*. With DevSecOps, software developers speed the delivery of software for integration in the AOC early, deliberately, and continuously. Airmen then test the software and provide feedback to continue the cycle (Insinna, 2017). Pathfinder has since evolved to become the AOC Modernization Block 20 effort, which is being led by the Kessel Run Experimentation Lab under the management of the Air Force Life Cycle Management Center (Kenner, 2019).

One of Kessel Run's main goals is to support JADC2 with new AOC software that allows for rapid decisionmaking across domains. As one Kessel Run official explained it, "Warfighting commanders should be able to call for effects from every domain as easy [sic] as they can hail a cab" (Hitchens, 2020b). Kessel Run is working with the Air Force Chief Architect to develop software tools as part of ABMS, and it is partnering with various other software development units related to ABMS, such as Kobayashi Maru, a group building software to track objects in space (Katz, 2020).

The 609th AOC in Qatar is actively employing some Kessel Run applications, including Slapshot, which automates manual tasks of data entry to create an ATO, and Jigsaw, which assists with tanker planning.[34] As these applications roll into the broader ABMS architecture, proliferate across the AOCs, and begin to address more-complex challenges like integrating data across domains or security levels, a key question will be how to train AOC staff to operate these new technologies. Technologies that dramatically expand the potential for rapid cross-domain integration will likely require changes across the doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy. Although intuitive software might ease

the burden of training AOC aircrews to use the new technology, the USAF might still need to update its approach to C2 training to accommodate these innovations.

Is JADC2 Currently Implemented in Training?

Even with a clear and consistent definition and a thorough understanding of the potential training audience, for any new concept to be successful, it must be implemented in practice with understanding and familiarity across different echelons. This requires training that might have to adapt as JADC2 matures. In this section, we review the various phases of training at AOCs with an eye toward integrating JADC2 training.

Formal C2 training in the USAF is classroom focused or obtained on the job through shift work on the AOC operations floor or participation in exercises. Only a few of these exercises incorporate aspects of LVC, and these are mainly focused on the air domain. As a result, the training plans are not well aligned with developing JADC2 capabilities. Although USAF C2 training organizations are closely tracking technological shifts relevant to JADC2 (including the move to the Block 20 AOC and the introduction of ABMS and Kessel Run applications), their training plans do not yet consider these changes. In addition, LVC training efforts are not necessarily developing in parallel with the new AOC technology. Finally, C2 training in general is not being guided by a coherent vision of JADC2 that clearly explains why and how airmen should command and control forces across domains.[35] Nonetheless, the three basic parts of AOC training—initial qualification training (IQT), mission qualification training (MQT), and continuation training (CT) exercises—could eventually support training needs related to JADC2. This section outlines the current stages of AOC training.

> Technologies that dramatically expand the potential for rapid cross-domain integration will likely require changes across the doctrine, organization, training, materiel, leadership and education, personnel, facilities, and policy.

Training begins with IQT, followed by MQT, after which airmen receive "combat mission–ready" status. Airmen then maintain their combat mission–ready status through CT. Every AOC is required to produce an annual training plan that outlines the proficiency training (IQT, MQT, and CT) needed to achieve and maintain combat mission–ready status (Air Force Instruction 13-1 AOC, 2019).

The 505th Command and Control Wing (CCW) plays a key role in helping AOCs to prepare airmen for C2-related assignments and providing ongoing C2 training and testing of C2 concepts and technology. There are two groups beneath the wing. The 505th Test and Training Group conducts IQT for all AOCs, delivers tailored operational C2 mission training and CT for joint and coalition forces and provides operational C2 lessons learned. The 505th Combat Training Group conducts C2-related operational assessments and experimentation, develops advanced tactics, and trains forces for multi-domain integration.

Initial Qualification Training

AOC IQT training is classroom focused, leverages Microsoft Office products, and emphasizes C2 fundamentals and the air tasking cycle. IQT concludes with a capstone exercise in a mock AOC.[36] The goal of IQT is to provide airmen with a basic understanding of the AOC weapon system that generally applies across regional and functional AOCs. Not all airmen attend IQT at the 505th CCW; instead, some receive "in-unit" IQT when they arrive at their assigned AOC (Air Force Instruction 13-1 AOC, 2019).

AOC Training Phases

1. IQT focuses on a basic understanding of the AOC weapons system.
2. MQT focuses on geographic and functional needs of a specific AOC and on the specific position of an airman within the AOC to which an airman is assigned.
3. CT focuses on maintaining combat mission–ready status.

Mission Qualification Training

Once airmen complete IQT, they move on to MQT, which takes place at the respective AOCs. The 505th CCW does not play a central role in this stage of training, which is tailored to the geographical and functional needs of a specific AOC and to the position within the AOC to which an airman is assigned. MQT is a unit responsibility, so it is individualized to the AOC. It generally involves a mix of methods including training with a trainer and subject-matter experts, classroom academics, self-study, and performance tasks (Air Force Instruction 13-1 AOC, 2019).

Continuation Training

CT, which allows airmen to maintain their combat mission–ready status, also takes place at the AOC. CT expands operational-level C2 knowledge and skills and ensures that AOC crew members are always ready to support the combatant commander, the joint force air component commander, and the area air defense commander. Major commands develop training requirements for AOCs in their chain of command, but AOCs can also add AOC-specific training requirements to their annual training plan. In addition to these requirements, the Air Force Instruction on AOC training indicates that geographic AOC crew members should participate in one exercise per year (or one exercise every two years for the Air Reserve Component; Air Force Instruction 13-1 AOC, 2019).

The USAF's Air Force Instruction lists more than a dozen suggested exercises to meet the CT requirement (Air Force Instruction 13-1 AOC, 2019). Two of those exercises are hosted by 505th CCW squadrons and serve as important opportunities for gaining operational- to tactical-level C2 training and experience. In contrast to IQT and MQT, these exercises, known as BLUE FLAG and VIRTUAL FLAG, provide some exposure to cross-domain C2 concepts. Although these exercises are internal to the USAF, the squadrons that manage them seek joint and cross-domain participation to bring an element of cross-domain C2 realism to events. These exercises also feature aspects of LVC training. However, although these exercises provide an opportunity for participants to leverage cross-domain effects—a cyber capability might contribute to the takedown of an integrated air defense system, for example—they do not robustly or seamlessly integrate C2 across domains, as envisioned under JADC2.[37] Space and cyber activities, in particular, are often stovepiped in various ways owing to classification and authorities issues, so although it might be possible to report space and cyber effects in a large exercise, it can be challenging to integrate domains to execute JADC2 seamlessly. Another challenge is that systems to support JADC2, such as ABMS, are being pushed into the AOCs, but there is no concurrent effort to replicate the capabilities that those technologies are expected to provide in USAF modeling and simulation.[38]

Future Directions

Although there is not yet a coordinated effort to develop JADC2-specific training curricula, some programs and organizations in the USAF are seeking to develop the JADC2 concept further, which could have implications for changes in C2 training. For example, the USAF has considered (and since discontinued)[39] a Multi-Domain Warfare Officer (13O) Air Force Specialty Code, which would focus on facilitating cross-domain C2. The idea is for these officers to act as designated planners in the AOC that can help to effectively integrate C2 across domains at the operational level of war. Their IQT takes place at the 705th Training Squadron, where they are steeped in joint

Although these exercises provide an opportunity for participants to leverage cross-domain effects—a cyber capability might contribute to takedown of an integrated air defense system, for example—they do not robustly or seamlessly integrate C2 across domains.

planning processes and the joint lexicon. However, there is no formally designated position in the AOC for these individuals, so their role in the AOC is left to the discretion of commanders, who might use them in different roles depending on mission requirements.[40]

From a technological perspective, the 505th CCW's 805th Combat Training Squadron is hosting experimental, cross-domain events to test out new C2 technologies in ShOC-N.[41] The 805th CCW has participated in ABMS on-ramp experiments and sees its top priority as supporting joint experimentation for JADC2,[42] followed by USAF-level experimentation with JADC2 concepts.[43] The idea behind ShOC-N is to provide a venue for cross-domain experimentation, consisting of new concepts and new technologies. As those experiments with cross-domain integration yield new lessons learned, those can be integrated into new software development and new tactics, techniques, and procedures to support JADC2.

Despite these promising developments, JADC2 is not a central focus of the USAF's IQT, MQT, or flagship C2 exercises that could be part of AOC CT. USAF training organizations are monitoring technological innovations for the AOC weapon system but are not yet accessing LVC tools to train or experiment with those innovations. Furthermore, particularly in the case of IQT and MQT, the focus tends to be on preparing personnel for the activities that will greet them in the AOC jobs they must do today, as opposed to preparing airmen for a future requiring cross-domain C2 expertise.

Conclusion

The USAF and DoD must anticipate the challenges of near-peer competition as described in the National Defense Strategy (DoD, 2018). JADC2 in some form will be required for success. However, the concept is still in development, and broad and consistent understanding of what JADC2 is and how it evolves remains critical.

With an eye toward developing appropriate training capabilities, a target audience not yet intimately familiar with the technical details, and a focus on JADC2 in the USAF, this Perspective summarized

- the presumed need for JADC2 in adapting to anticipated changes in warfare
- the concept of JADC2
- the context for JADC2 development with respect to training infrastructure and capabilities
- the relevant organizations and processes for implementing JADC2 in the USAF
- implications with respect to different stages of training.

This Perspective serves as a primer that organizations inside and outside the USAF (and DoD) can use as a baseline for understanding this critical effort.

JADC2 will require engagement at all levels, including service members who are not technical experts. Therefore, to help the USAF move forward with an understanding of what JADC2 will entail, it is necessary to provide an aid to help bring operators into the discussion. This is done in the context of training infrastructure because training-driven requirements tend toward specificity, and the principles of OTTI suggest preemptive consideration of training, rather than incorporation of training as an afterthought to the acquisition process. We summarize our discussion with a review of the major points of this Perspective and broader considerations in general.

JADC2 in Brief: A Review

Why JADC2? Anticipated shifts in the character of warfare drive JADC2 and will require the adaptation of C2 tools and processes to provide an advantage over near-peer adversaries with faster and more-informed decisionmaking.

What is JADC2? As stated in USAF doctrine, JADC2 is "the art and science of decisionmaking to rapidly translate decisions into action, leveraging capabilities across all-domains and with mission partners to achieve operational and information advantage in both competition and conflict" (Air Force Doctrine Note 1-20, 2020).

What is the context for JADC2? JADC2 must be developed not only in the context of anticipated changes in warfare but also in the context of anticipated changes in training. This will require adapting OTI and OTTI as well as leveraging of LVC capabilities.

How will the USAF implement JADC2? Although ABMS is envisioned as the technological backbone for the JADC2 concept, in practice, conceptual shifts in C2 constructs will likely be built around the heart of operational C2 in the USAF: the AOC. AOC personnel will be the primary users and thus the primary training audience. A common understanding of this C2 baseline can help airmen think about how best to undertake any necessary organizational changes.

How is JADC2 implemented in training? As a concept under development, JADC2 does not currently have a significant role in training implementation. However, training for the AOCs (including IQT, MQT, and CT) offers a lever to help the USAF implement the changes that will be necessary. Training for airmen in the USAF's 13O career field could serve as a focal point for testing and training JADC2 capabilities and developing airmen who are well-prepared to employ these capabilities.

Discussion

Fundamentally, JADC2 is a joint concept. It will require a level of coordination that has always been a challenge for DoD. Army General Mark Miley captured this need as follows:

> Up until today, all the services, for years, decades, have been developing their own internal systems. . . . And we end up having to do all these bridges and workarounds etc. So they optimize development for their own internal requirements and they sub-optimize for anything that's needed for the joint role. But we don't fight wars as an Army, a Navy. . . . We fight wars as a nation and we fight wars with allies and partners [Tucker, 2021a].

JADC2 will require a balance between centralized coordination and decentralized needs, which will require some deconfliction between services (Hitchens, 2021c; and Underwood and Ackerman, 2021). In turn, this will require consistent and effective communication of relevant terms and concepts; this Perspective helps support this fundamental need.

Coordination (and associated necessary connectivity) will also require not only new technical capabilities but also new organizational alignment (Tierney, 2021). The need to balance centralized coordination with decentralized needs is often neglected with respect to organizational structure, especially when quickly developing new and complex concepts and systems (Marler et al., 2021). In addition, proper coordination will again require constant and effi-

JADC2 development must align with end user needs, which will follow changes in warfare.

cient communication—transparent plans and data across DoD. The JADC2 CFT helps with such coordination on a high level, but additional communication and transparency could foster improved understanding of JADC2 across different echelons within the USAF and across the joint community. Accordingly, each service should ensure that there is an internal group or organization, whether it be the JADC2 CFT representatives or otherwise, that can provide aggregated relevant information within and across services.

As aspects of JADC2 evolve, the current state and plans for future efforts must be communicated effectively across DoD at every echelon on a regular basis. Such communication will ultimately have to include international partners as well as U.S. services, and this will add a substantial layer of complexity that is best addressed as the concept develops, rather than afterward (Underwood and Ackerman, 2021).

A critical first step to ensuring consistent and effective communication is developing and conveying a clear set of terms—a common language—and broadly distributing that baseline. This is especially critical with any emerging technology, which often couples complexity with novelty and might be particularly challenging to deploy among users not yet intimately familiar with the technical details (e.g., airmen at AOCs who have not yet adopted JADC2-related software or operations). Given that a potentially nontechnical audience will ultimately be involved in implementing various aspects of JADC2, bringing them into the discussion early offers the advantage of aligning JADC2 with their needs and concerns.

JADC2 development must align with end user needs, which will follow changes in warfare. OTTI offers a framework to consider both training and testing concurrently with concept development. The training aspect of OTTI, in particular, can help ensure that JADC2's adaptations incorporate warfighter needs early and that warfighters are ready for the future.

Notes

[1] In this context, concerning C2, domain generally includes air, land, maritime, space, and cyberspace. For a more nuanced discussion of military domains, please see Donnelly and Farley, 2018.

[2] For an overview of anticipated change in the conduct of warfare, see Morgan and Cohen, 2020; and Winkler et al., 2019.

[3] Decentralization and distribution are used interchangeably in some literature; see, for example, Morell, 2021. We adopt this distinction because the two concepts do not necessarily overlap along all relevant dimensions. For example, C2 authorities assigned to a given organization and command level, such as an AOC, might be distributed but not decentralized if a given AOC is distributed across space; those same authorities might be both distributed and decentralized if those authorities are handed off to a different command level based on a set of contingencies.

[4] On different constructs to enable decentralized C2, see Priebe et al., 2020.

[5] Interview with Department of the Air Force officials, March 25, 2021.

[6] Interview with Air Operations Center official, May 11, 2021.

[7] For an analysis of where AI/ML applications may fit within Air Force C2 processes, see Lingel et al., 2020.

[8] On unmanned platforms and consequences for C2, see Horowitz, 2019.

[9] Interview with Department of the Air Force official, January 28, 2021.

[10] Interview with Air Operations Center official, May 11, 2021.

[11] Interview with Department of the Air Force officials, January 28, 2021.

[12] Interview with U.S. Navy officials, June 18, 2021.

[13] Interview with Department of the Air Force officials, March 16, 2021; and interview with Department of the Air Force officials, March 25, 2021.

[14] Interview with Department of the Air Force official, March 24, 2021.

[15] Allied and partner state participation is a stated goal for JADC2 experimentation, although participation has been limited to date.

[16] Interview with Department of the Air Force official, July 12, 2021.

[17] Kessel Run's focus is on air and space domains.

[18] The Futures and Concepts Center and the Combat Capabilities Development Command's C5ISR also support JADC2 and Project Convergence efforts.

[19] Based on interviews with DAF personnel, the USAF and USSF are facing doubt from Congress concerning ABMS due to nebulous requirements and numerous JADC2 interpretations across the DoD (Interviews with Department of the Air Force personnel, March 2020).

[20] Cloud One is the platform that enables cloud computing, and Platform One is the DoD DevSecOps Enterprise Services team. DevSecOps (development, security, and operations) is a software engineering technique that is intended to rapidly deliver software securely for integration in an early, deliberate, and continuous manner; U.S. Chief Software Office, "Cloud One," undated-a; and U.S. Chief Software Office, "Software Ecosystem," undated-b.

[21] This information is based on interviews with operators at U.S. Air Warfare Center, February 2021. See also Trevithick and Rogoway, 2021.

[22] This information is based on interviews with Headquarters Air Force personnel, March 2021.

[23] Air Force Instruction 99-103 provides definitions for Operational Testing and Operational Test and Evaluation, which are broader in scope and inclusive of organizational processes, personnel, and policy.

[24] Adapted from Air Force Instruction 16-1007, 2019.

[25] Multiple objectives for the OTI enterprise, as described in U.S. Air Force, 2017, discuss both test and training as part of a single infrastructure or environment.

[26] RAND-proposed definition based on usage of terms related to test and training environments in Jaime and Trnka, 2020, and the U.S. Air Force, 2017. OTTI includes test and evaluation systems, training systems, live ranges, airspace, simulators, environment generators, threat emitters, aggressors, networks, training centers, and multidomain C2 training systems.

[27] Note that the services do test new technology as part of the acquisition cycle, but both testing and training are not necessarily considered concurrently during the development process.

[28] DoD, 2014, describes a war game as a simulation game for which constructive simulation is a synonym.

[29] The AOC is designated the AN/USQ-163 Falconer weapons system. The designation as a weapons system was to drive proper management and standardization of the system, beginning with the designation of a Lead Command and Program Executive Officer for the system. See also Lynch, 2017.

[30] See "Contingency and Crisis Execution: The Tasking Cycle" in Air Force Doctrine Publication, Annex 3-0 2016, p. 116.

[31] Per Air Force Doctrine Publication 3-30, 2014, an ATO is a method used to task and disseminate to components, subordinate units, and C2 agencies projected sorties, capabilities, and/or forces to targets and specific missions.

[32] For more detail, see Air Force Annex 3-30, 2014; and Lingel et al., 2020.

[33] RAND discussion with the 505th Command and Control Wing official, 2020.

[34] Discussion with 609th Air Operations Center officials, 2021.

[35] Discussion with 505th Command and Control Wing officials, December 16, 2020; discussion with 505th Command and Control Wing officials, November 20, 2020; and discussion with 505th Command and Control Wing officials, November 25, 2020.

[36] Discussion with 505th Command and Control Wing official, November 25, 2020.

[37] Discussion with 705th Combat Training Squadron staff, November 20, 2020.

[38] Discussion with 505th Combat Training Squadron staff, December 16, 2020.

[39] The intent of discontinuing the career field was to incorporate the skill set more widely into USAF developmental education (see U.S. Air Force, 2022).

[40] Interview with 505th Command and Control Wing, December 8, 2020.

[41] Discussions with 505th Command and Control Wing officials, February 2, 2020.

[42] An on-ramp is a technical demonstration of a new system, or a component of a system, in a simulated operational environment, such as an exercise.

[43] Discussions with 505th Command and Control Wing officials, February 2, 2020.

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