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Key Points

Kill chains are a process to find, fix, track, target, and engage targets, then determine strike results. Completing precision strike kill chains at scale is the foundation to prevailing in armed conflict. Kill chains are systems of systems that consist of sensors, strike platforms, the weapons they deliver, and the networks they use to share information.

The development of increasingly effective kill chains and countermeasures to defeat them can be described as a long-term competition. China's PLA has developed kinetic and non-kinetic countermeasures to degrade or defeat every step in the U.S. military's kill chains at scale.

The U.S. Air Force must continuously evolve its kill chains to optimize their scale, scope, speed, and survivability to win the kill chain competition against the PLA in a major Pacific conflict.

To maintain its kill chain superiority in the near-to-mid-term, the Air Force must increase its capacity of F-35 and B-21 aircraft that are capable of independently closing kill chains in communications degraded or denied environments.

The Air Force should incorporate kill chains that consist of disaggregated families of systems that are more resilient and difficult to defeat into its force design in the long-term. To outpace PLA countermeasures, Air Force air battle managers must have the tools and authority to define and construct kill chains using these disaggregated systems in real-time.

Scale, Scope, Speed & Survivability: Winning the Kill Chain Competition

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Abstract

"Kill chain" describes the process militaries use to attack targets in the battlespace. The kill chain can be broken down into specific steps—find, fix, track, target, engage, and assess—that enable planners to build and task forces for combat operations. The U.S. military has long relied upon its superior ability to rapidly close kill chains against adversaries. This advantage is now at risk. China has developed countermeasures to obstruct or collapse U.S. kill chains, which could lead to combat failures that have devastating, long-term consequences for the security of the United States and its allies and partners.

To overcome these challenges, the Air Force must increase the scale, scope, speed, and survivability of its kill chains. In practice, the service must determine specific kill chain capability objectives for each of these attributes:

- Scale: The number of simultaneous kill chains a military can close.
- Scope: The distance, area, and duration over which a military can prosecute targets.
- Speed: The ability of a military to outpace adversary countermeasures to deny, disrupt, or break its kill chains.
- Survivability: How well a military maintains the integrity and effectiveness of its kill chains, even under attack.

In the near-to-mid-term, 5th and 6th generation combat aircraft will be crucial to assure kill chain dominance because they are consolidated "sensor-shooter" nodes that can *independently* close kill chains and facilitate the completion of other missions in localized areas of contested battlespaces. These aircraft will continue to provide air battle managers the necessary tools to rapidly compose resilient kill chains well into the future as the U.S. Air Force migrates toward a family-of-systems approach. Over the long term, the Air Force's advanced battle management system (ABMS) system of systems must support kill chains that are highly resilient, interoperable, and have large numbers of distributed nodes that are more difficult for a peer aggressor to defeat.

Introduction

"Kill Chain" is a colloquial term that describes the process militaries use to attack targets in the battlespace, or, as a combat pilot might say, "deliver bombs on target on time." Success in warfare comes down to a military's ability to create decisive combat effects in the battlespace. These effects may be kinetic, such as destroying an enemy missile launcher using a laser-guided bomb, or non-kinetic, like electronically jamming an adversary's radars. To create these effects, military forces must find targets, fix their position or track them if targets are moving, target and engage them with precision, and finally determine if their attacks have succeeded. Completing this process is called "closing" kill chains. It does not matter how many weapons, aircraft, tanks, ships, and satellites a military might have or how exquisite its sensors and processors might be if it cannot close kill chains at the scale, scope, speed, and with the degree of survivability needed to win.

The U.S. military's decisive advantage in combat has long relied upon its superior ability to close kill chains against adversaries. This advantage is now at risk. China has observed how kill chain dominance has enabled U.S. forces to swiftly prosecute targets with near impunity, and it has subsequently developed strategies and capabilities to obstruct or collapse the ability of the United States to close kill chains. One such warfighting strategy, called "system destruction," is designed to obstruct kill chains by jamming U.S. datalinks and communications, degrading or destroying U.S. sensors and shooters across all domains, and forcing U.S. and coalition forces to operate outside the ranges they need to independently locate and employ weapons against targets in the first place. The capabilities China has designed as part of this strategy are, indeed, eroding the U.S. military's ability to close its kill chains at the scale and speed required for decisive operations during a peer conflict. If the United States is unable to maintain kill chain dominance in the face of these challenges, it greatly increases the risk of losing a conflict with China.

The Air Force must evolve its kill chains if it is to maintain a decisive advantage in a peer conflict. In the future, air battle managers at the forward edge of engagements with enemy forces will be the key to identifying, composing, and managing disaggregated kill chains at the speed and scale required for peer conflict.

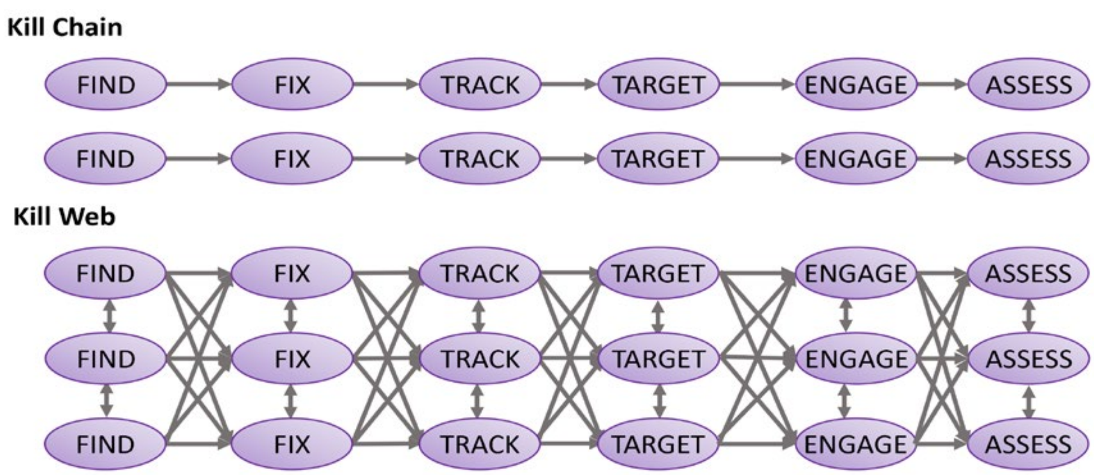

Figure 1: Comparison of Linear Kill Chain and Kill Web. Linear kill chains are difficult to scale and easy to target. Kill webs offer redundant and multiple paths through compatible and functional nodes, thus increasing the quantity and resiliency of potential kill chains.

Credit: Mitchell Institute

In the near-to-mid-term, 5th and 6th generation combat aircraft will be crucial to assure kill chain dominance because they have the advanced sensors, processing power, and other capabilities needed to initiate and complete every step of the kill chain process. In other words, they are consolidated "sensor-shooter" nodes that can *independently* close kill chains and facilitate the completion of other missions in localized areas of contested battlespaces.

Since the mid-2000s, the Air Force has operated an inventory of combat aircraft that is the smallest and oldest it's operated since it became a separate service in 1947.[1] To make the most of this diminished force, the Air Force must rapidly field new capabilities and develop new operational concepts that create more flexible, resilient, and lethal kill chain options. Identifying, building, and executing these kill chains in real-time is a primary objective of the Air Force's Advanced Battle Management System (ABMS) program. ABMS will increase the number of possible kill chain pathways across different operating domains by connecting and rapidly sharing information across a large network of sensors and platforms. This is intended to increase the U.S. military's kill chain resiliency against Chinese countermeasures. For instance, instead of separate and linear kill chains, ABMS could help create "kill webs" that operate much like self-healing mesh networks. The loss of one node or datalink in a linear kill chain could prevent mission success, while the multiple nodes, datalinks, and other capabilities available in kill webs create other options to complete the find, fix, track, target, and engage process. Moreover, disaggregating kill chains in this way will create additional opportunities for warfighters to use sensors, platforms, and weapons from multiple services and across domains to create effects in the battlespace. This further reduces the predictability of the overall operational system, frustrating Chinese countermeasures and thus increasing the effectiveness of U.S. kill chain operations.

The Air Force will need capabilities like stealthy 5th and 6th generation aircraft that can independently close kill chains in highly contested environments to achieve its broader vision of more disaggregated, diversified kill chain operations.

As aggressively as the Air Force is working to develop the technologies, operational concepts, architecture, and other enablers for ABMS, they are still not mature. Moreover, even when disaggregated ABMS-enabled kill chains are mature, they will be operationally complex, require specialized processing, and be difficult to manage at the speed and scale required in a peer conflict. Their networks will also remain vulnerable to attack. A future force consisting predominately of 5th and 6th generation combat aircraft will reduce risk and increase mission flexibility for U.S. forces operating in localized contested areas when long-range networks, command and control, or other external supporting kill chain capabilities are degraded or denied. This means the Air Force will still need capabilities like stealthy 5th and 6th generation aircraft that can *independently close kill chains in highly contested environments* to achieve its broader vision of more disaggregated, diversified kill chain operations.

Why Kill Chains Matter

The kill chain competition is one of the foundational struggles that underpin military conflicts. Many strategic competitions to secure and assert an advantage in capabilities, capacity, geography, and industrial and financial resources can shift the balance of a conflict to one side or the other. Indeed, advantages in these areas can make a significant difference in conflict outcomes, which is why they are major defense priorities for many states in both peace and war. Yet any advantages in these areas will not matter if a military is unable to close its kill chains. It does not matter how many bomber aircraft a military possesses if they are unable to locate or engage any targets. Kill chain failures can result from shortfalls in one's own capabilities or an enemy's deliberate countermeasures to disrupt the process from completion. Regardless of the reason, kill chains that are broken at scale can result in failures at all levels of military operations and, ultimately, lead to the loss of a conflict.

Kill Chains are Physical and Informational Processes

While the kill chain is often treated as an abstract concept that can be fluid in construction, in practice, it is made of physical things like sensors, datalinks, platforms, and weapons that have tangible characteristics and limitations. Each of the capabilities and functions in a kill chain has specific informational, physical, and network requirements that can be dependent on the features of the intended target as well as other operational factors. A kill chain that is optimized to strike a hardened aircraft shelter that is fixed and does not move, for example, may not be effective against an airborne maneuvering enemy fighter jet.

These kill chain considerations are key when planners build and task forces for combat missions. The specific attributes of each target set and mission type pose unique problems that often require specialized considerations when composing kill chains. Planners must think backward from the target to optimize the kill chains used to attack it. Target characteristics can dictate the types of platforms, sensors, and capabilities that planners must use to build the right kill chains—nodes that perform similar functions but have different characteristics may not be interchangeable. For example, the type and precision of the sensors used to locate and track a target, the type of weapon and effect, and even the bandwidth and latency of the kill chain's datalinks must be tailored to the target and mission. The mission force package composition matters because every step of a kill chain must be accomplished to achieve the desired effect.[2] If planners cannot compose the right kill chains because the required platforms, sensors, or other capabilities are not available, then the mission may be at risk, and the target may live to see another day.

Understanding How Kill Chains Work

The Air Force has used find, fix, track, target, engage, and assess (F2T2EA) to describe the kill chain since the late 1990s, and it remains a useful model to explain the discrete steps of kill chains and how

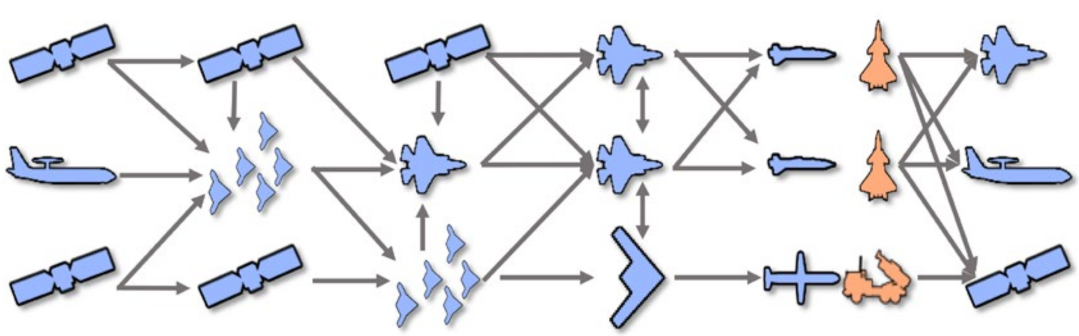

Figure 2: Kill chain nodes and networks are not "agnostic." Each node must be able to complete its function for the specific target set. For example, an air-to-air radar is not the right node for a ground target set. Moreover, the information processed at each step must have the right attributes. Finally, the nodes must be interoperable and the datalinks of the right kind to pass the quality of information needed.

Credit: Mitchell Institute

those steps relate to the physical sensors, platforms, or other capabilities needed to achieve effects in the battlespace.[3]

Find. The first step of any kill chain is the find stage, which includes operations to broadly surveil the battlespace to detect and characterize potential targets.

Sensors used to find a target should be matched to the target's characteristics, windows of vulnerability, and environment. For instance, an electronic signals array that is tuned to detect cell phone frequencies may not be the best means to find a fixed ground target like a hardened aircraft shelter. Windows of opportunity to detect targets is another factor—sensors must be in the right place at the right time to find a target. A satellite that periodically overflies an area of interest is less likely to find highly mobile enemy ground vehicles compared to a long-duration remotely piloted aircraft equipped with ground moving target indicator radar that can loiter. Finally, sensors must be able to effectively find targets in challenging environmental conditions. An infrared search and track (IRST) sensor system might be very capable of detecting the hot signature of a fighter aircraft's engines against the backdrop of a cold sky, but it may not be able to see a target's heat signature through thick clouds or smoke.

Once a potential target has been found, this data must be passed to a sensor or set of sensors that can "fix" the target.

Fix. Fixing is a two-step process used to *locate* a potential target's position relative to the rest of the battlespace and then positively *identify* it as a desired target with sufficient fidelity to enable a weapons engagement. Target location is a matter of using one or more sensors to develop information on a target's position with enough accuracy to attack it. Sensors must then positively identify exactly what the target is and determine if it is an enemy combatant. This combat identification is a critical second step to validate targeting. For instance, it is important to determine if an airborne Su-27 fighter is operated by a friendly or hostile force before declaring it as a target, as both allies and adversaries fly them today.[4]

Track. Tracking the target maintains and updates the tight correlation between its location and identity, which is what warfighters often refer to as maintaining "positive custody" of a target.[5] If positive custody of a target is lost, the kill chain is broken, and the kill chain process must revert to an earlier step.

For example, if radar even momentarily drops contact with a maneuvering target, that radar contact must be reidentified before the kill chain can progress.

Target. The targeting step requires making a deliberate decision to assign a target to the best available weapon delivery platform in preparation for attack. Commanders or battle managers making these decisions must consider multiple variables, including available platforms and weapons, whether those weapons are in range of desired targets, effects they want to create on the targets, target engagement times and vulnerability windows, threat environment, survivability of the platforms used to attack targets, probability of success, and potential follow-on actions.[6]

A 2,000-lb unguided bomb, for example, would not be the best selection to attack a high-value enemy combatant located in a moderately busy civilian street, as avoiding collateral damage would be a concern. Alternately, some weapons might simply be mismatched for the target. A short-range Hellfire missile designed for air-to-ground strikes would not be effective against highly dynamic, fast-moving airborne targets.

Engage. Engaging a target consists of the decision and subsequent actions to kinetically or non-kinetically attack it. This is more than simply providing target data to a weapon and releasing it. The paired weapon, whether kinetic or non-kinetic, must be in an appropriate engagement zone to complete the attack.

Different weapons will have different physical engagement zones and guidance requirements. If the weapon is released out of range, or if its means of guidance is interrupted, countered, or incorrect, the kill chain is broken. For example, the range and axis of an electronic warfare aircraft to a target will have a direct impact on the power needed to effectively attack it, and a fighter aircraft must be within range with the right closure speed, altitude, and aspect for its missile to make it to the target.

China and other adversaries have spent the last 30 years observing and analyzing U.S. military operations to develop capabilities that deliberately target the operational architecture, nodes, and networks that have made U.S. kill chains so very effective in the past.

In addition to the physical maneuvering and other kinetic actions required to close a kill chain, weapons used must have the appropriate data and target location updates to guide to the target and achieve the desired effect. A GBU-38 Joint Direct Attack Munition (JDAM), for example, needs highly accurate mensurated target coordinates (achieved in the fix phase) as well as a continuous GPS signal so that its guidance system can steer the weapon to its designated target. An AIM-120 radar-guided missile needs target updates through a datalink for the first portion of its flight so that when the missile's radar activates to locate its designated target, the target will actually be in the missile radar's field of view.

Assess. In most basic terms, the kill chain does not end when a weapon hits the target. Sensors must evaluate the outcome of the engagement to determine whether a reattack is necessary or if other follow-on actions are necessary. Battle damage assessments (BDA) are essential to prioritizing and maneuvering forces in the battlespace in real-time, managing weapon magazine reserves, shifting battlespace priorities, and planning subsequent mission threads. The kill chain is incomplete if it does not feed back into the current mission thread execution or the commander's planning cycle.

A Model Ripe for Change

Over the last 30 years, the Air Force has made its operational architectures and kill chains more efficient and effective by leveraging advanced technologies, processing, and datalinks. These developments have been critical to maintaining lethality even as the U.S. Air Force combat force inventory has drawn down to the smallest in its history. Moreover, China and other adversaries have spent this time observing and analyzing U.S. military operations to develop capabilities that deliberately target the operational architecture, nodes, and networks that have made U.S. kill chains so very effective in the past. This is a critical challenge for the Air Force—and failing to meet the challenge now could result in devastating consequences for the security of the United States and its allies and partners.

China's Warfighting Strategy of "System Destruction"

China has long been an ardent student of how the U.S. military conducts combat operations as a system of systems. The U.S. military's ability to successfully close kill chains at war-winning scales, speeds, and scopes in Desert Storm and other conflicts over the past three decades was part of the impetus for the People's Liberation Army (PLA) to shift from a warfighting concept that seeks to achieve victory by attritting opposing forces to "system destruction warfare." This warfighting concept deliberately seeks to disrupt, degrade, and destroy operational architectures and kill chains through offensive operations against U.S. sensor networks, datalinks, C2 architectures, and other nodes. By denying U.S. forces the ability to rapidly share information and complete kill chains at a decisive tempo and scale, China's warfighting strategy seeks to dismantle the pillar of America's decisive asymmetric advantage in combat—the system of systems that U.S. forces now rely on to conduct modern warfare.

A U.S. official associated with DOD's 2022 *China Military Power Report* recently told reporters that China's way of war "is no longer solely focused on the destruction of enemy forces; rather, it is won by the team that can disrupt, cripple, or outright destroy the other's underlying networks and infrastructure."[7] A survey of translated Chinese texts and secondary sources highlight the adversary's operational system as the focus of PLA warfighting strategy. China's Academy of Military Sciences' *The Science of Military Strategy* (2005 edition) identifies information as a key target in modern warfare: "Intelligence, reconnaissance, communication, command and control systems link the battlefield into an organic whole, so the enemy's information systems and decision-making processes are becoming the most important targets in information warfare."[8] *The Science of Military Strategy* (2013 edition) builds upon this thought, explaining that "information soft killing and firepower destroying each complement each other."[9] The China Aerospace Studies Institute's translation of the *2010 Services and Arms Application in Joint Operations* defines information soft kills as electronic attacks that deceive and confuse enemy systems, "distort[ing], remov[ing], deceiv[ing], and block[ing] his information, paralyzing the enemy's network system."[10] Electronic attack (soft kills) can work in concert with kinetic attack to collapse operational systems. While many analysts focus on the information and command and control implications of this strategy, M. Taylor Fravel calls out a specific emphasis in *The Science of Military Strategy* (2013 edition) on negating an adversary's long-range kill chains: "The main way of threat has already changed from a traditional land invasion to space, air-sea and network-air integrated non-contact strikes and our in-depth national territory is under the cover of the enemy's medium and long range fire power."[11]

The following four lines of effort are based on RAND analyst Jeffery Engstrom's analysis of Chinese military writings and doctrine involving China's system destruction warfighting approach.[12] Elaboration on each is from the perspective of this Mitchell Institute research study.

1. **Targeting key system nodes.** These attacks seek to disable or destroy key physical nodes in U.S. systems that execute essential functions. This likely means targeting high-value intelligence, reconnaissance, and surveillance (ISR) assets like the E-3 airborne warning and control system (AWACS) or low-earth orbit (LEO) constellations as well as weapon delivery platforms such as bomber and fighter aircraft and everything in between. These attacks aim to deprive kill chains of key functional nodes.
2. **Degrading or disrupting the flow of information.** These attacks isolate nodes by preventing them from sending or receiving information. Jamming major U.S. datalinks like Link-16, denying the radio frequency (RF) spectrum for any use, or destroying communications relay satellites are examples of how the PLA might disrupt information flows. These attacks could break links between many steps in a kill chain and isolate nodes in the kill chain, neutralizing them without destroying them.

3. **Distorting system relationships and architectures.** The PLA could render U.S. forces ineffective by targeting their ISR, command and control (C2), or communications networks writ large. The wholesale loss of these systems could collapse multiple kill chains. Targeting these kinds of networks would force ad hoc workarounds that would, at best, be inefficient and slow. Worst case, these distortions could paralyze major U.S. combat operations. Of course, this goal is more difficult to achieve and would require the PLA to rapidly execute attacks against very large target sets.
4. **Distorting or extending the adversary's operational tempo.** The objective of this line of effort is to slow down or induce friction, confusion, and chaos into U.S. operations. One way to accomplish this is by timing attacks against U.S. C2 and battle management capabilities in ways that maximize delays and difficulties to U.S. operations.[13] Another method could be to find ways to obscure the U.S. battlespace awareness, causing aircraft or other nodes to be in the wrong places at the wrong times doing the wrong things. Distorting and interrupting the processes of U.S. systems could deprive kill chains of key functions at critical junctures and cause U.S. forces to get stuck in process cycles and fail to act at all, to complete unnecessary kill chains, or to conduct other wasteful operations.

These lines of effort aim to degrade the U.S. military's command and control networks, disrupt its battle management and decision-making processes, break the cohesion of U.S. operations, and create other effects to negate the U.S. military's advantages. The PLA is not only preparing to target the physical things crucial to U.S. operational systems, like long-range airborne sensors, satellites, and command and control facilities but also seeks to jam or obstruct U.S. information networks, including RF datalinks and satellite communications, with the intent to destroy or deny enough of these critical elements to render U.S. military system of systems ineffective. Information operations to deceive and surprise U.S. military and civilian leadership are also objectives of China's system destruction warfighting approach.

The threat from China's anti-access/area-denial (A2/AD) capabilities, like advanced ballistic missiles, cruise missiles, surface-to-air missiles, and other capabilities, is far more formidable when viewed from the perspective of system destruction warfare. These A2/AD threats are commonly understood as capabilities designed to block U.S. access to battlespaces and attrit U.S. forces. In the context of system destruction warfare, China would use these capabilities to deny and dismantle one of America's key strategic advantages: its ability to conduct highly networked, precision warfare. They could achieve this by targeting the operational system of systems that comprise most U.S. kill chains, including the networked systems that provide information from different sources as well as the platforms needed to execute the various F2T2EA functions.

Why System Destruction Warfare is a Threat to U.S. Kill Chains

As both a process and an operational system of systems, legacy linear military kill chains are vulnerable to China's system destruction warfighting approach and targeting priorities. System destruction warfare deliberately places every step of kill chains at risk—from their sensors to their shooters and the networks and information they rely upon. In many ways, dependency on the very technologies that have made the U.S. military's kill chain operations so efficient and effective in the past now makes them more vulnerable to system destruction warfare—especially if assets required to complete multiple kinds of kill chains are only available in limited numbers.

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For example, an airborne AWACS or a future system like a joint surveillance target attack radar system (JSTARS) might support multiple steps in multiple kill chains. If not in the battlespace in sufficient numbers, the loss of such valuable, high-volume nodes could cripple the U.S. military's ability to complete kill chains at the pace and scale needed to achieve a theater commander's objectives. In other words, the loss of even a few of these types of high-volume nodes could have a disproportionate impact on collapsing U.S. combat operations.

Datalinks represent another critical U.S. strength—and a Chinese target set. Datalinks have become a true force multiplier for U.S. kill chains by compressing timelines to transfer key target information with speed, accuracy, and precision through machine-to-machine connectivity.[14] If denied the ability to share information near instantaneously through datalinks, satellite communications, or even radio, current U.S. kill chain operations could be nearly paralyzed.

The loss of critical ISR assets, battle management, weapon systems, and datalinks also means the loss of well-established relationships, tactics techniques and procedures (TTPs), and kill chain operations that U.S. forces have trained to perform. This could create situations where U.S. forces would have to improvise and create ad hoc kill chains that are less efficient, less operationally effective, and have a much lower probability of success.

Finally, system destruction warfare could prevent U.S. forces from closing kill chains not only by breaking them but also by simply preventing them from progressing to their final steps. Countermeasures such as deception, the use of camouflage and decoys, and other measures that degrade, invalidate, or create uncertainty about the validity of information on a target's location or identification could force kill chains to continuously reset to an earlier stage.

The U.S. military integrates its weapon systems into networked operational systems—including its kill chains—to create combat effects that are more than the sum of their parts. This system-of-systems approach to modern warfare has also created opportunities for China to disrupt U.S. kill chain operations. Defense policymakers understand the vulnerability of U.S. forces to China's system destruction warfighting strategy and their inability to quickly compensate for its disruptive effects. This risk to the force is amplified especially now that the U.S. military—including the Air Force—lacks a force that is sized for peer conflict. If the Air Force is to transform to withstand attacks from a peer adversary and prevail, it must increase the resiliency of its kill chains—this is a foundational requirement for the service's future force design.

U.S. Kill Chains are Still Optimized for the Past, Not Future Conflicts

The Air Force's current kill chains have delivered war-winning capability over the last 30 years of theater contingency operations and low-intensity conflict, especially in permissive environments like the ones experienced during Operations Enduring Freedom, Iraqi Freedom, Inherent Resolve, and others. While adversaries lacked sophisticated means to systematically disrupt U.S. kill chains, the dynamic and fleeting nature of high-value targets during these operations caused the Air Force to develop capabilities to initiate and close kill chains in a matter of minutes and with incredible precision. So why would these kill chains fall short in a peer conflict—why could we not just expect more of the same in the future?

Achieving and sustaining kill chain dominance will be a major challenge that the United States must be prepared to face in a peer conflict. The United States would have to close kill chains against dynamic and fleeting targets at a scale, scope, and speed that it has not faced since the Cold War, if ever. China will deliberately seek to dismantle and destroy the very way that the U.S. Air Force goes to war. Chinese countermeasures can range from direct attacks on U.S. kill chain assets to indirect measures such as moving high-value targets to disrupt kill chain "find, fix, and track" operations. According to one former defense official, roughly 80 percent of targets are anticipated to be mobile or quickly relocatable in the early phase of a Chinese *fait accompli* invasion of Taiwan scenario.[15] Detecting these targets to initiate the kill chain will be a challenge, because ISR assets must continuously be in the right place at the right time to search areas and detect targets that are moving or have emerged from a shelter or a hide site. Once found, strike forces will then have minutes—if that—to complete the rest of their kill chain steps before targets can relocate or take other steps to avoid attacks.

U.S. kill chains that are optimized for low-intensity operations and permissive environments are less likely to prevail or even survive in a highly contested peer conflict.

Complicating the problem of dynamic and fleeting targets is the unprecedented scale of the battlespace and sheer volume of targets in a potential conflict with China in the Indo-Pacific theater. Thousands of kill chains must be closed against thousands of targets at a pace that creates simultaneous effects across a geography that spans thousands of square miles. This scale of conflict will greatly stress the Air Force's limited numbers of both sensors and shooters.[16] With limited resources to cover such a vast geography and huge volume of targets, every ISR asset, every Air Force weapon system, and every U.S. platform in the battlespace will need to collaborate to complete multiple kill chains nearly simultaneously.

All of this must be accomplished in a battlespace where an adversary is aggressively trying to slow the speed or otherwise degrade U.S. operations by destroying critical nodes and effectors; obstructing networks, datalinks, and other communications; and inducing confusion and delays in operations between different U.S. forces. U.S. kill chains that are optimized for low-intensity operations and permissive environments are less likely to prevail or even survive in a highly contested peer conflict. When viewed in the context of China's warfighting strategy of system destruction, it becomes clear that the Air Force's current kill chains are:

- **Vulnerable to nodal attacks.** Current U.S. kill chains are not attrition tolerant. For instance, the Air Force is overly reliant on small fleets of multifunctional aircraft to support numerous kill chains, making those kill chains extremely vulnerable to the loss of a few key nodes. Moreover, the Air Force's small fleets cannot provide enough sensors, aircraft, platforms, or weapons to cover the scale and scope of kill chains that a peer conflict would require.
- **Dependent upon brittle and often incompatible networks.** Current U.S. kill chains are rigid and have narrow and predictable options to share information across a limited mix of sensors, aircraft, or weapons. Targeting a widely used U.S. datalink such as Link-16 could have a disproportionate impact on the integrity of multiple kill chains.

- **Not adaptive.** Relationships between U.S. kill chain functional nodes—the physical platforms that complete kill chain steps—are fairly fixed, and kill chains are unable to adapt if these elements are lost or datalinks are disrupted.
- **Not designed for the pace of modern peer conflict.** The centralized decision-making that has characterized U.S. operations over the last 20 years will be unable to cope with the pace of peer conflict. Current air operations planning and tasking processes may lag the demand to compose and direct assets in real-time to create kill chains.

Characteristics of Kill Chains That Provide a Decisive Advantage

Recent Kill Chain Innovations Point to the Future

Although the Air Force developed its modern kill chains over the last 20 years of low-intensity, counterinsurgency operations, they can address the challenge of dynamic targets and may point the way toward the future.[17] Fleeting targets, such as mobile ground vehicles carrying improvised explosive devices (IED), had only short windows of vulnerability to attacks. The Air Force began using datalinks to connect sensors like JSTARS to shooters like F-16s to rapidly construct and close kill chains in time against these targets. These time-sensitive targeting (TST) tactics effectively pioneered disaggregated kill chains using datalinks and machine-to-machine data exchange to achieve an advantage.

Breaking apart each step of the F2T2EA kill chain process helped Air Force planners to understand how separate sensors, platforms, or capabilities could network together in different ways to create collaborative kill chain engagements.[18] Advanced technologies like computer processing, datalinks, and machine-to-machine data exchanges further increased the speed of kill chain operations, improved target custody, reduced errors, and improved precision of effects.[19] Through these tactics and technologies, the Air Force was able to compress the time to engage a TST target from initial detection to strike into single-digit minutes.[20]

At the same time that the Air Force was developing disaggregated TST kill chains, it was also developing a consolidated kill node, known as the MQ-9 Reaper remotely piloted aircraft (RPA).[21] By concentrating the entire kill chain into a single platform, the MQ-9 could dramatically compress timing to complete strikes and outpace its targets' efforts to evade detection and engagement. MQ-9s were not limited to human flight durations, and the aerodynamics and fuel efficiency of the Reaper enabled long-duration loiter times to wait for targets to emerge. The dedicated intelligence teams and operational concepts developed to support MQ-9 operations allowed the Reaper to rapidly progress through human analysis, rules of engagement, and final engagement decision authorization processes.[22] The Air Force must now seek innovations in its kill chain operations that will provide it with similar advantages in a highly contested, peer conflicts at the scale and scope required in the Pacific.

Critical Attributes that Create a Kill Chain Advantage

For the U.S. Air Force to maintain its kill chain advantage, it must evolve its kill chains to counter adversary strategies to break them. China's warfighting strategy of system destruction seeks to disrupt and dismantle the key nodes, networks, relationships, and tempo of U.S. kill chains. Countering this strategy will require the Air Force to examine how it builds its kill chains through both operational and technical lenses for all threat environments. Failing to do so risks ceding the Air Force's kill chain advantages to future adversaries.

Opposing kill chains represent a competition between two belligerents, and what comprises a kill chain advantage is specific to that conflict. Furthermore, the attributes that provide kill chain advantages generally fall into two categories: those that are necessary to address the unique challenges of a range of different scenarios and those that preserve kill chains against adversary efforts to defeat them.

Kill chains must be relevant to the physical battlespace, target set, and adversary capabilities. If a military does not have the right capabilities and capacity to address these operational problems, it cannot close its kill chains. These considerations are closely linked to a military's force design, campaign strategies, target planning, and operational concepts.

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But what works in one region against a particular adversary may not be relevant in another region and against another adversary. For example, a flight of F-16s in the Middle East could loiter in a kill box waiting for a weapons release approval from the joint force air component commander (JFACC) in the nearby air operations center (AOC) with relatively low risk. This mode of operation is probably not relevant to a highly dynamic fight over Taiwan in a comms-contested environment hundreds of miles from the nearest AOC, in which loitering would likely prove lethal. This is why the kill chains the Air Force developed for operations in the Middle East over the last 20 years are insufficient for a peer conflict in the Pacific. Simply stated, many of the Air Force's current kill chains cannot meet the demands of the geography of the Indo-Pacific and the threats posed by a modernized PLA. The Air Force is not sized appropriately, nor does it have the right sensors, platforms, weapons, or datalinks to successfully close kill chains against thousands of mobile targets in a highly contested battlespace that is located over half a globe away from the United States. Developing these kinds of capabilities is a major focus of Secretary Kendall's operational imperatives.[23]

Second, kill chains must also be able to withstand adversary attacks to break, paralyze, or otherwise render them ineffective. As mentioned, the PLA specifically intends to target U.S. kill chains to deter and defeat U.S. and coalition operations. Attacks on the kill chain can be divided into two lines of effort: defensive and offensive. Defensive efforts to break kill chains could be characterized as "spoilers." In practice, these spoilers can consist of A2/AD threats that push non-stealthy U.S. platforms outside useful ranges for sensing or weapons delivery, camouflage and decoys that could cause U.S. forces to waste weapons, or employing "shoot and scoot" tactics to deny precision target location data to U.S. kill chain operators. Offensively, attacks to break U.S. kill chains might include disabling LEO space constellations, destroying key multifunction nodes like AWACs, or jamming Link-16 or other datalinks to isolate U.S. platforms and prevent them from sharing information to progress the kill chain.

To overcome these evolving offensive and defensive challenges, the Air Force must increase the scale, scope, speed, and survivability

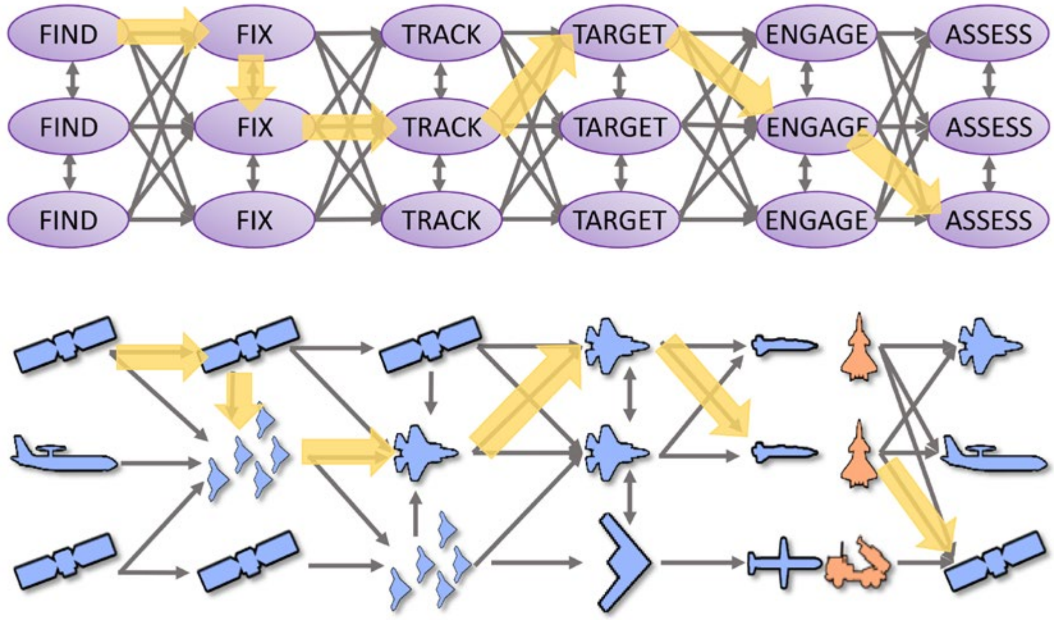

Figure 3: A system-of-system approach to kill chains (i.e., a kill web) can increase the scale of potential kill chains. The more compatible and interconnected the nodes of a kill chain system are, the more possible paths exist for kill chain closure. This pathing optionality can provide resilience when some nodes or networks are degraded or destroyed, frustrate adversary targeting through unpredictability, and increase the scale of possible kill chains within the operational system.

Credit: Mitchell Institute

of its kill chains. These four enduring attributes are an effective way of thinking about and defining requirements for future kill chain systems of systems. In practice, the Air Force must determine specific capability objectives for each of these attributes if it is to maintain its precision strike advantage over its new pacing challenge—a modernized PLA that is prepared to contest every element, every node, and every process of the service's kill chains.

Kill chain scale. Scale is the capacity of an operational system to generate and close the necessary volume of simultaneous kill chains at any point in time. Scale is an outcome of the absolute number of nodes in the battlespace and how they must be integrated to create multiple kill chains. If kill chains are linear—in which the individual node can only support a single kill chain at one time—then the operational system's ability to scale is limited. If, however, the individual nodes and effectors can collaborate and support multiple kill chains simultaneously, the number of kill chains can scale dramatically.

Kill chain scope. Scope is the physical ability of a kill chain system to span both space and time. Kill chains must be effective over the necessary ranges and across the area of the battlespace, as well as for the required mission durations (persistence). The distances that must be overcome in the Pacific theater, for example, will favor the use of long-range strike assets like bombers over shorter-range assets like land-based artillery. As the Pacific Air Forces (PACAF) Commander General Wilsbach stated at a recent event, the Pacific theater "spans 16 time zones."[24] The vast square mileage of the Pacific will also impose physical attributes on kill chain nodes, especially if persistent surveillance is required.

Kill chain speed. Speed refers to the ability of the kill chain to outpace adversary efforts to deny, disrupt, or break its operational systems. U.S. kill chains must go from initial detection to effect closure before the adversary can spoil or actively break them. Factors that can affect speed include sensing accuracy, datalink latency, processing power, physical proximity, and node airspeed.

Kill chain survivability. Survivability is the ability of a kill chain to maintain its integrity and effectiveness under attack, withstanding an adversary's efforts to disrupt or break it and still close against the target. Survivability can hinge on individual effectors and nodes, such as stealthy aircraft and robust communication links, or rely on other strategies to maintain kill chain resilience even when nodes and links are lost.

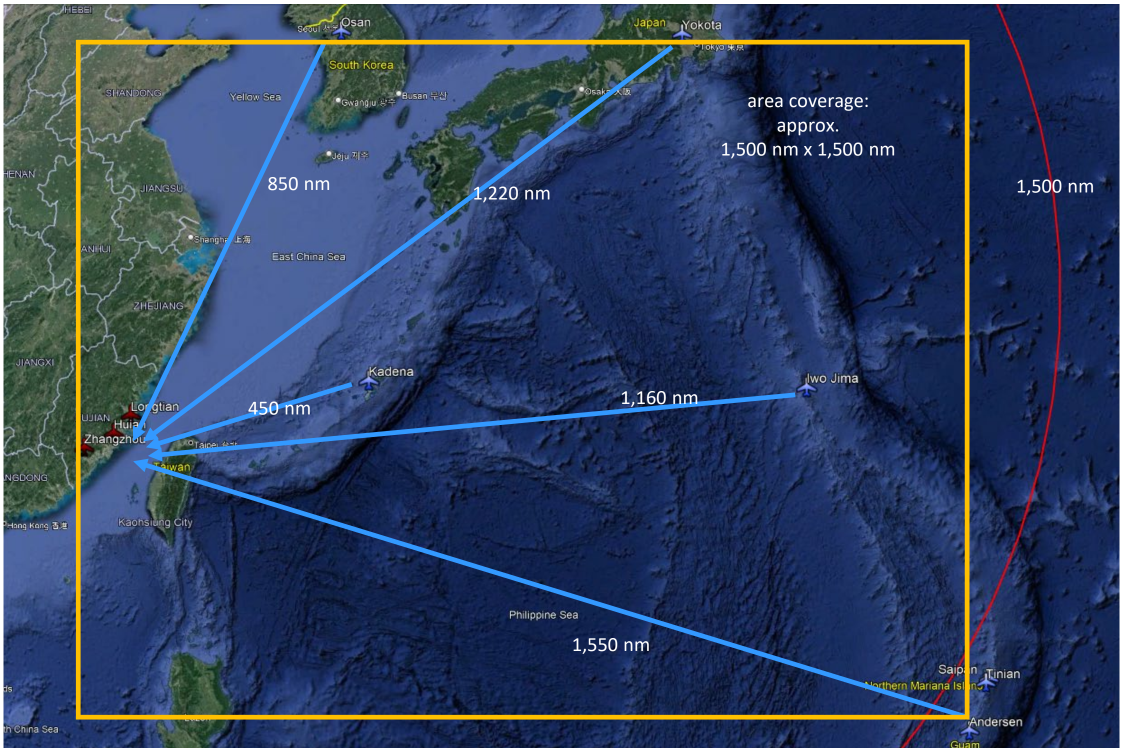

Figure 4: A fact of combat operations is that distance equals time. For example, an aircraft cruising at 350 kts would take over four hours to fly from Guam to the Taiwan Strait. Kill chains must be able to span the ranges and vast areas of the Pacific and have the persistence to be effective in combat.

Credit: Mitchell Institute

Building the Kill Chain Advantage for the Future

The Air Force's Battle Networks and Advanced Battle Management System

Joint All-Domain Command and Control (JADC2) is the Department of Defense's (DOD) initiative to develop a kill chain advantage against the PLA and other adversaries. Contributing to this initiative, the Air Force has a series of efforts that fall under what senior Air Force leaders describe as the Department of the Air Force's battle network. The battle network is the physical architecture of sensors, platforms, and weapons connected to each other as an operational system. Under the umbrella of the DAF battle network is the command, control, communications, and battle management (C3BM) enterprise, and under that is the Advanced Battle Management System.[25] These efforts align under Secretary Kendall's second operational imperative (OI), Operationally Focused ABMS. The Air Force is currently pursuing a total of seven OIs to ensure it will have the capabilities and operating concepts to deter and, if necessary, defeat peer aggression in the future.[26]

General CQ Brown, Chief of Staff of the Air Force, has described ABMS as a joint kill chain that will take "data, put it into a cloud and then be able to access the data through applications and not do it service by service by service. So, we don't have an Air Force kill chain, or have a Navy kill chain, a Marine Corps kill chain, [and an] Army kill chain."[27] With the right datalinks and interoperability, this commonality could create the opportunity for any sensor, platform, weapon, or other capability—regardless of domain or service origin—to contribute to the kill chain process.[28]

In this distributed or disaggregated battle network, each step of the F2T2EA process might be performed by different platforms across different domains. For example, a satellite sensor might initially detect and find a potential target, then pass that information off to an airborne sensor. The airborne sensor could fix and track the target, update and maintain the target's position and identification information, then pass data to a ground-based battle management node. The battle management node would then task a weapon system, such as a bomber, which would then engage the target with appropriate weapons. In this scenario, a different sensor satellite might even guide the bomber's weapons to the designated target. Finally, an airborne sensor might conduct battle damage assessment to help battle managers determine if the target was destroyed or if another engagement was required.

Building a system that can prosecute targets this fluidly will require force planners' perspectives on the physical and operational problems of the battlespace, technologists' insights to build the right battle networks, and the experience of battle managers to bring everything together.

Building a system that can prosecute targets this fluidly will require force planners' perspectives on the physical and operational problems of the battlespace, technologists' insights to build the right battle networks, and the experience of battle managers to bring everything together. A JADC2 architecture that successfully connects sensors, platforms, and weapons across the services could create a kill chain system of systems with the scale, scope, speed, and survivability advantages a conflict with China would demand.

Scale

To maintain a kill chain advantage over China and other adversaries, the Air Force must increase the number and interoperability of their critical nodes—including sensors, platforms, and weapons—to ensure its forces can scale its kill chain operations to required levels in a highly contested environment.

Increasing node quantity. Simply increasing the number and functions of nodes the Air Force can project and sustain in the battlespace creates the opportunity for its forces to increase the volume of kill chains it can prosecute at any single point in time. Secretary Kendall has already expressed his intent for the Air Force to procure at least 1,000 uninhabited aircraft called collaborative combat aircraft (CCA) and 200 Next Generation Air Dominance NGAD fighters to prepare for operations to defeat Chinese aggression.[29] In addition to these sensor-shooter nodes, the Department of the Air Force (DAF) should also aggressively develop and launch proliferated low-earth orbit constellations consisting of dozens or even hundreds of small, sensor and communications satellites to further increase its kill chain scalability.[30] Connecting DAF kill chain systems more extensively with sensors and platforms from other services would further increase the number of potential nodes to support kill chains across the services. The actual munitions used against targets are a different case. While sensor and platform nodes may be able to support multiple kill chains, air-to-air and air-to-ground missiles, bombs, and other weapons are generally dedicated to a single kill chain. The Air Force must increase its weapons production and stockpiling to ensure that there are enough weapons to close the thousands of kill chains that a peer conflict will demand.[31]

Improving interoperability across kill chains. The DAF's battle network does not need to connect "everything to everything" that it operates in the battlespace or share all data with every platform and operator to be effective. A ground moving target common operating picture does not necessarily need to be shared with an operator launching an air-to-air missile, for example. The location of distant threats does not need to be shared

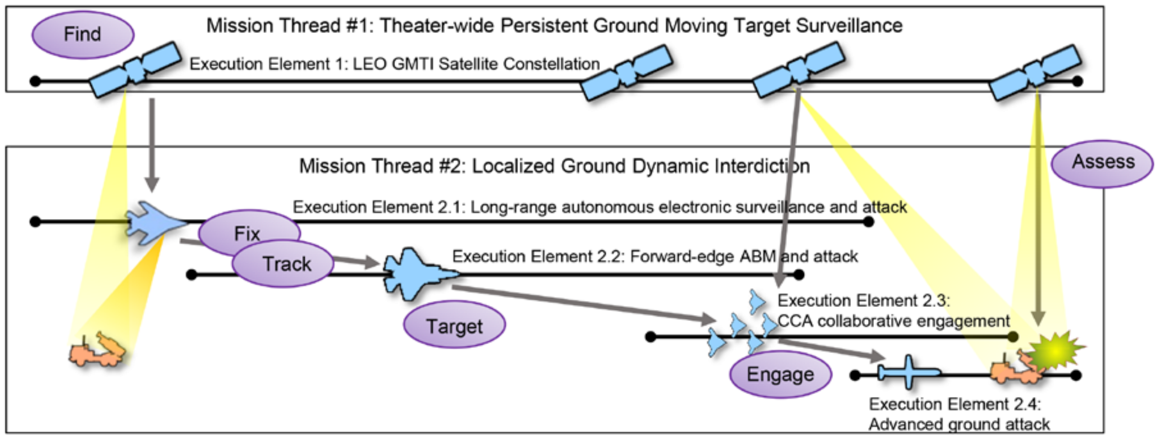

Figure 5: A highly simplified, notional example of how the ABMS OI team's decomposition of mission threads can identify assets that could be capable and available to contribute to other mission thread kill chains. In this case, the taregeting fighter aircraft and the CCAs do not need to dedicate themselves to a single kill chain for its duration.

Credit: Mitchell Institute

with aircraft that will remain well out of range of those threats. Instead, the DAF must understand what nodes are relevant to what missions and what data must be shared across kill chain nodes to achieve the required scale of kill chain operations without excessive redundancy and wasted effort.

This means the Air Force's ABMS OI team must strive to understand the attributes and functions of the sensors, platforms, and weapons to determine their relevance to future specific kill chains. This will require analysis that brings force planners, operational planners, and technologists together to map out how the service could maximize the number of possible kill chains in future battlespaces. This type of analysis should identify which kill chain assets will have useful information for other kill chains and how they should be interconnected. The Air Force should also focus on creating the machine-to-machine datalinks needed to connect the right nodes in and across kill chains to increase the volume of possible kill chains.

Scope

Developing and acquiring long-range weapon systems and other capabilities in quantity will also increase the *scope* of the U.S. Air Force's kill chains. Designing kill chains for a theater of operations requires matching the range, mission endurance, and other attributes of physical platforms, weapons, and datalinks to the dimensions of the theater, then procuring them in quantities that will provide theater commanders with their required kill chain coverage. Numbers matter to achieving and assuring the right scope of kill chain operations, especially in theaters that are as large as the Indo-Pacific. Even if a single platform can support multiple kill chains, too few of that type of platform can limit the scope of kill chain operations and increase the vulnerability of kill chains that depend on that single node. In other words, if multifunction nodes like 5th generation aircraft are not fielded in sufficient quantities, they become extremely high-value targets to adversaries and can disproportionately weaken the larger operational system.

Increasing the quantity and range of physical kill chain platforms. The Air Force must buy long-range capabilities in quantities that matter. Quantity is key to increasing the scope of kill chain operations because one kill chain system, like a combat aircraft, cannot be in more than one place at one time. Range is another important consideration for kill chain operations that must span the vast distances of theaters as large as the Indo-Pacific. Defense analysts expect that the Air Force's new B-21 bomber will be capable of unrefueled ranges of approximately 6,000 nm.[32] Based on the Mitchell Institute's assessments of force design requirements, the Air Force should procure at least 225 of these long-range, penetrating bombers to reach the scope of kill chain operations needed to defeat PLA aggression in the Indo-Pacific.[33] The Air Force's NGAD air superiority fighter element will also have a significant range to give it the capability to reach targets located well beyond the PLA's outer A2/AD umbrella. Like the B-21, Air Force leaders should seriously consider increasing its planned fleet of NGADs to meet theater requirements. B-21s and NGADs will be accompanied by uninhabited and semi-autonomous CCA wingmen. CCAs teaming with B-21s and NGADs to construct and close kill chains can help expand the areas that the B-21 and NGAD can cover. In combination, these platforms will carry multiple weapons per sortie to further increase the **scope and scale** of U.S. kill chains.

Achieving affordable weapons mass. Greater weapon ranges also increase the areas kill chains can cover, effectively extending the reach of their delivery platforms. The Air Force should pursue a mix of long- and mid-range weapons to achieve the kill chain scope necessary to strike tens of thousands of targets during an operation to defeat PLA aggression in the Pacific theater. Long-range weapons with ranges of 750–1,000 nm could be very effective against certain high-value PLA targets, such as fixed radar sites. However, very long-range "stand-off" missiles can be expensive due to the need to design them with features like engines, guidance systems, datalinks, and other capabilities required for long-range flights—all of which are expended when the weapons hit their targets. Mitchell Institute analyses indicate that precision-guided munitions with ranges between 50–250 nm that can be delivered in large quantities by reusable stealthy fighters and bombers would help extend the scope of the Air Force's kill chain operations, compress kill chain times, and achieve "affordable mass" for strikes against very large target sets.[34] Moreover, the areas that penetrating aircraft can cover using these mid-range weapons can be much greater in scope compared to single-target, single-use surface-to-surface missiles that lack the range to strike targets deep in contested areas.

Proliferating space-based sensing and networks. Finally, satellites and other space capabilities can expand kill chain scope across geography and time. One of the unique attributes of space constellations, whether in geosynchronous orbit (GEO) or LEO, is their ability to span the globe—space is the ultimate high ground that can provide warfighters with a view of the battlespace unlimited by aircraft ranges and sortie durations. Building these space-based constellations can provide crucial air moving or ground moving target indication (AMTI or GMTI, respectively) sensing to support operational kill chains, and they can do so in a way that provides persistent surveillance.[35] A large number of satellites (nodes) in a LEO constellation, for example, can also enable collaboration with satellites in other constellations and orbits to ensure continuous and persistent coverage of an area. In addition to extending kill chain find, fix, and track functions to any region on the earth, space-based assets can provide the datalinks needed to connect all nodes in a kill chain and share information as needed across kill chains.[36] Due to the dramatic growth in demand for real-time connectivity through communication satellites and other space assets across the DOD, the Space Force has requested $1.2 billion dollars across FY 2024–2028 to develop these capabilities.[37] Once on orbit and integrated with airborne platforms, the Air Force's space-based sensors, communication assets, and other capabilities will become the backbone of its long-range kill chains for air-to-air and air-to-surface strikes in highly contested environments.

Speed

The Air Force must also increase the speed of its kill chain nodes, networks, effectors, and processes to maintain its advantage over peer adversaries. Kill chain speed is exactly that: how quickly a kill chain can move through its entire process, from initiation of "finding" specific targets to "assessing" the effectiveness of strikes against them. The time required to close kill chains can depend on the speeds of their physical and informational components and processes. On the physical side, this means how fast a platform or weapon can fly to reach a target or how quickly a sensor can reach a position where it would be able to detect a potential target. On the information side, kill chain speeds refer to how fast computers can process data or how fast a datalink can send information to the right kill chain nodes. In a highly contested peer conflict, the need for a battle manager to identify a required weapon-target pairing and how fast they can construct an ad hoc kill chain with available assets may be even more important than the speed of a kill chain's physical elements.

Increasing kill chain speeds is essential to successfully prosecute fleeting, dynamic targets during challenging operations, like blunting a Chinese invasion force, which may involve target sets that are over 90 percent mobile or moving.[38] The window to initiate and close kill chains against such time-sensitive targets may be in the realm of minutes. At the campaign level of kill chain competitions, improving kill chain speeds—even at the margins—can make the difference between the success or failure of an operation.

Accelerating the speeds of physical kill chain nodes. The Air Force should continue to accelerate its ability to close kill chains by increasing the speed of their physical components where feasible. Next-generation air-launched missiles with greater speeds than current air-to-air or air-to-ground missiles would improve the service's ability to close kill chains faster than peer adversaries. "Stand-in," penetrating combat aircraft like the F-35 and B-21 are another way to accelerate kill chains. Because penetrating aircraft can operate closer to target areas located in contested areas, they may be able to close more kill chains faster than long-range, stand-off weapons launched by non-stealthy stand-off surface launchers and aircraft.

Increasing kill chain network speeds. Space-based communications can greatly increase the speed of kill chain operations, especially when kill chain nodes are located beyond-line-of-sight of each other. The Air Force's future LEO satellite transport layer will become an essential backbone of a system of systems that accelerates kill chains in future highly contested battlespaces. Proliferated LEO constellations can provide a space-based communications network to support both long-range and short-range localized kill chain operations. Although LEO communication constellations cannot match the single-digit millisecond latency of line-of-sight datalinks like Link-16, they do not suffer the seconds-long latency issues of SATCOMs in GEO.[39] Moreover, the advanced network architectures, laser communications, and processing of LEO constellations could provide up to 350 megabits per second (Mbps) of instantaneous bandwidth to support kill chain operations.[40] By comparison, Link-16 terminals are now limited to 14 Mbps of instantaneous bandwidth.[41] Accelerating the development and fielding of a LEO communications constellation and ensuring that key long-range sensors, platforms, and weapons have the right hardware and software integration to exploit this capability should continue to be a priority for the Air Force.

Accelerating kill chain process speeds. How quickly targets can be located and identified, paired to the right platform and weapon, and then have their engagement approved is reliant on technological and human components of kill chains. These technological components include the tools that aid battle managers and commanders, like the display scopes on an AWACS or a common operating picture provided by the Blue Force Tracker system. The speed of a kill chain's human components can hinge on factors like the doctrine and training humans have received, the span of their target engagement decision authority, the rules of engagement they must adhere to, and a theater commander's risk tolerance.

To accelerate kill chains in a highly contested peer conflict with distributed kill chains, the Air Force should develop automated tools that can provide its air battle managers (ABM) with fused, accurate, and timely common operating pictures that can facilitate target pairing and kill chain construction. Today's air battle managers risk being saturated with information. Automating kill chain functions like identifying and prioritizing threats and targets, pairing targets and weapons in ways that account for probability of kill, threat proximity, fuel and weapons remaining, and so forth can greatly reduce air battle manager task saturation. The Air Force's ABMS OI team should accelerate experimentation with air battle managers to develop the tools and decision aids they will need for peer conflicts, as well as the underlying architectures and battle network capabilities needed to accelerate kill chain processes.

Improving the human components of kill chains is a far more difficult task than improving the technologies they depend on. The Air Force's established centralized kill chain engagement authority, developed during the decades of operations in Iraq and Afghanistan, is based on criteria that are time-consuming and risk-averse. The Air Force is now leaning into a new doctrine of centralized command, distributed control, and decentralized execution, but what this means in practice is not yet clear.[42] To achieve speed in the human domain of kill chains, the Air Force must move beyond slogans and develop a better understanding of where human and bureaucratic frictions exist in its kill chain operations and then develop the right doctrine, training, organization, and policies to reduce them.

Survivability

The Air Force must enhance the survivability of its kill chains to counter an adversary's efforts to disrupt, degrade, and defeat them. Increasing nodal and network survivability and risk tolerance are two approaches to achieving the kill chain resiliency needed for peer conflict.

Increasing nodal and network survivability. The survivability of nodes and networks is critical to the success of U.S. kill chain operations. Achieving the degree of survivability needed in highly contested environments means that penetrating kill chain sensors, weapon platforms, and the munitions they launch must be low observable. Radar energy, heat signatures, and other emissions from platforms that operate in contested areas must be mitigated to avoid detection by adversary warning and targeting systems. This is achieved by a combination of shaping stealthy aircraft and weapons in ways that deflect radar energy, coating them with radar-absorbing materials, and employing smart tactics to ensure they avoid high-risk threats. In addition to these stealth attributes, kill chain platforms can use speed, maneuverability, and electronic attack to avoid detection and disrupt an adversary's countermeasures. Networks with datalinks that are designed with low probability of intercept/low probability of detection (LPI/LPD) features will be the baseline for kill chains that have the resiliency required for highly contested environments. Likewise, directionally focused datalinks, power modulation, frequency hopping, or even different mediums like laser communication or different technologies like quantum radio frequencies may enhance overall network survivability.

Increasing nodal and network attrition tolerance. The U.S. military's future kill chains must be survivable in contested environments, even when some of their nodes or networks are degraded or lost. Increasing the quantity of kill chain nodes and creating "self-healing" networks are key to realizing this objective. To the first point, an operational kill chain system of systems must have sufficient redundancy to rapidly replace or work around nodes that are lost due to equipment failures or enemy attacks. This means excess nodes must be available and present in contested battlespaces. Moreover, replacement nodes must be of the right kind, interoperable with multiple diverse systems, in the right physical locations, and connected to other kill chain nodes and effectors. To the second point, self-healing networks must act as a "mesh" by having the ability to jump their data across alternate network paths to ensure kill chain nodes receive the data they need to close the kill chain.

A force structure designed for distributed kill chains confers advantages that will be foundational to winning a kill chain competition against a peer adversary such as China in the Pacific.

A Caution: Networks Could Be the Achilles' Heel of Disaggregated Kill Chains

While disaggregated kill chains could offer significant advantages in scale, scope, speed, and survivability, such systems of systems are extremely dependent on datalinks. In a peer conflict against an adversary like the PLA, Air Force planners and warfighters must expect that their networks and datalinks will be contested. While senior leaders have expressed that loss of communications connectivity will not be a light switch—on or off—any degradation to data exchanges can have disastrous consequences to kill chain dominance. The Air Force must develop resilient communications for contested environments where even the intermittent loss of communications may be sufficient to collapse a significant number of kill chains or at least prevent them from closing.

U.S. and coalition forces cannot rely on hardening datalinks and communications links alone to assure kill chain dominance. While these efforts are important, they can result in rigid, brittle, or slower networks, and DOD must assume that the PLA and other adversaries will eventually develop measures to degrade or counter "hardened" communications. In this kind of spectrum-contested battlespace, 5th and 6th generation aircraft will be key to assure kill chain dominance because they can serve as consolidated kill chain nodes to flexibly initiate and close kill chains independently or as part of a disaggregated system.

Summary

A force structure designed for distributed kill chains confers advantages that will be foundational to winning a kill chain competition against a peer adversary such as China in the Pacific. As senior leaders transform the DAF, they must consider how their research and investments will increase the scale, scope, speed, and survivability of their kill chains in highly contested environments. Emphasizing kill chain dominance over cost savings or efficiencies will require the DAF to redefine what constitutes accepted wisdom, which is currently based on the last 30 years of low-intensity conflict in permissive aerospace environments. The pacing threat has changed dramatically, and this change must be reflected in the Air Force's future kill chain capabilities and operating concepts.

The DAF must, therefore, buy enough physical platforms to maximize the number of kill chains it can employ simultaneously in the Indo-Pacific theater during a protracted high-intensity conflict with the PLA. Stated bluntly, this means procuring F-35, B-21, NGAD, and CCA at rates and quantities much greater than currently planned; launching robust proliferated LEO sensing and communication constellations; and developing and fielding the right mix and quantity of stand-off and stand-in weapons. The Air Force must also map out kill chain operations to determine what nodes can contribute to specific kill chain functions, then ensure that the networks that connect them are survivable. Finally, the DAF must provide air battle managers with the tools they will need to identify, construct, and assign kill chains to attack large numbers of targets at speeds that outmatch the enemy's countermeasures.

Emphasizing kill chain dominance over cost savings or efficiencies will require the DAF to redefine what constitutes accepted wisdom, which is currently based on the last 30 years of low-intensity conflict in permissive aerospace environments.

There are many factors that are moving the U.S. Air Force toward developing a more disaggregated force design, but the earliest that its warfighters could expect to see nascent versions of this future force is likely to be in the early 2030s. It does not yet exist. The sensors, platforms, weapons, networks, or battle management systems at the scale, scope, speed, and survivability needed for peer conflict are not fully developed or fielded. Moreover, the reliance of distributed kill chains on legacy datalinks has the potential to play directly into China's system destruction warfighting approach. The Air Force needs a bridge strategy to ensure it can achieve a kill chain advantage as it migrates into this future force. This means consolidated kill nodes in the form of 5th and 6th generation aircraft will be essential to ensuring the resiliency and effectiveness of U.S. operations in a highly contested environment.

The Role of 5th Generation Aircraft in Creating Enduring Kill Chain Advantages Now and Long into the Future

The Enduring Value of Consolidated Kill Chain Nodes

During the Cold War, the Air Force consolidated its kill chains and increased its reliance on what defense leaders would later describe as "exquisite" platforms. What made these aircraft exquisite was highly advanced technologies that allowed them to initiate and close kill chains independently with reduced reliance on external assets. For example, fighters with powerful and advanced active electronically scanned array (AESA) radars were not completely reliant on AWACS to find enemy aircraft, and their identification friend or foe (IFF) interrogators and non-cooperative target recognition (NCTR) capabilities enabled them to positively identify radar contacts. The Air Force upgraded its combat aircraft mission software to counter an enemy's electronic deception efforts, and the active radar-guided missiles that exquisite fighters carried could complete a strike—close the kill chain—before an adversary could launch a counterattack. While other systems like JSTARS and AWACS enhanced the operational effectiveness of joint force kill chain operations, modern fighters and other combat aircraft capable of performing as consolidated kill nodes greatly increased the resiliency of the Air Force's strike operations.

The Air Force continued to increase the scale, scope, speed, and survivability of its kill chains by upgrading its combat aircraft in the 1990s and 2000s. For example, the B-2's long ranges, large payloads, and stealth allowed its crews to create kill chains of unprecedented scope, speed, and survivability. The F-22's ability to supercruise (fly at supersonic airspeeds), powerful sensors, ability to rapidly fuse information from multiple sensors, and stealth give its pilots a "first look, first kill" advantage of closing kill chains against enemy fighters. The advanced mission systems that characterize these 5th generation aircraft give them an unrivaled ability to survive *and* close kill chains against enemy systems independently in contested environments. The problem is that DOD's budget-driven decisions in the 1990s and 2000s prevented the Air Force from acquiring its planned force of F-22s and B-2s in sufficient numbers. The consequences are a current Air Force combat air inventory that still lacks sufficient capacity to independently close kill chains at scale in contested and highly contested environments against a peer adversary.

Air Force leaders should not abandon this approach. 5th and 6th generation aircraft continue to provide critical advantages in contested battlespaces. And because these aircraft are networked within the larger operational system of systems, 5th generation aircraft act as multifunction nodes that increase the scale, scope, speed, and survivability of the Air Force's kill chains. To resolve the capacity issues, the Air Force should maintain and continue to modernize its B-2s and remaining F-22s as it accelerates F-35 and B-21 production. In short, 5th generation aircraft will continue to amplify kill chain advantages as part of the Air Force's larger operational system of systems well into the future.

The Air Force should pursue ways to enhance the kill chain scale of 5th generation aircraft in the near-to-mid-term

To increase the *number* of kill chains that 5th generation aircraft can close over the next 10 to 15 years, the Air Force should accelerate procurement of F-35 and B-21s while sustaining all its F-22s and B-2s; pursue smaller, advanced munitions suitable for 5th generation aircraft; increase its datalink interoperability; and rapidly field CCAs to increase the number of weapons available per combat sortie.

- **Quantity = scale.** Stealthy 5th generation aircraft can close kill chains in contested environments where 4th generation cannot survive and operate with an acceptable degree of risk. When these advanced aircraft operate as consolidated kill nodes, the scale of kill chains they can provide in the battlespace is linear: the number of kill chains is equal to the number of aircraft in the battlespace and how many weapons each can simultaneously employ. Quantity and availability matter. Increasing F-35 and B-21 production rates and total quantities will directly increase the scale of the Air Force's operational kill chain system of systems.
- **Smaller weapons = more kill chains.** The more weapons an aircraft can carry internally, the more kill chains it can close per sortie. Increasing targets per sortie can have a major, potentially

decisive impact on the timing and outcome of a campaign, especially given the diminished size of the Air Force's combat air force. However, legacy munitions are large and have unitary warheads, meaning that fewer can be carried per sortie and each weapon can hit only one target. By developing and integrating smaller weapons that can be carried internally by 5th generation aircraft, the Air Force can increase the total lethality of individual aircraft.

- **Increasing datalink interoperability.** 5th generation aircraft share information, but their datalinks for off-boarding information are generally limited to their formations. The F-22's LPI/LPD intra-flight data link (IFDL) and the F-35's multifunction advanced data link (MADL) are limited to small numbers within the formation and do not share information broadly across the battlespace. While the F-35 can share information on Link-16, the F-22 can only receive information over this legacy network. The Air Force has long desired to enhance connectivity for the B-2, F-22, and F-35. Off-boarding information from these aircraft to other aircraft in or near the contested battlespace is crucial to increasing the number of off-board kill chains they can support.
- **CCAs may provide additional weapons depth for 5th generation aircraft.** Fighter-sized 5th generation aircraft must carry their weapons internally to remain stealthy. This can constrain the number of kill chains any one aircraft can complete per sortie. Secretary Kendall intends to begin fielding CCAs at scale by the end of the decade, and some of these CCAs could act as "weapons trucks" that will increase the number of kill chains available to meet theater commander taskings in the battlespace.

The Air Force should aggressively develop and procure advanced air-to-air and air-to-ground munitions and fully exploit 5th generation aircraft datalinks to increase kill chain scope

Developing advanced air-to-air and air-to-ground munitions is crucial to increasing the distance, area, and duration of kill chains that 5th generation aircraft can close. Smaller medium-range (50–250 nm) next-generation precision-guided munitions, for example, could dramatically increase the organic kill chain scope of 5th generation aircraft. To optimize kill chain scope, 5th generation aircraft also must be able to support both organic and off-board—and even long-range—kill chains. Planned Block 4 upgrades for the Air Force's F-35s will provide the datalink connectivity needed for these distributed kill chains.[43]

- **Achieving affordable mass.** In addition to developing advanced munitions, senior leaders should consider the mix of weapons that will provide the optimal kill chain scope needed to prevail in a protracted peer conflict. Prioritizing the acquisition of cost-effective stand-off and stand-in weapons is key to overcoming the tyranny of distance in the Indo-Pacific, achieving necessary kill chain concentration over large areas, and sustaining kill chain operations for the duration of a peer conflict affordably.[44]
- **Taking advantage of 5th generation aircraft as penetrating kill chain nodes.** The ability of 5th generation aircraft to navigate and maneuver in response to real-time events in contested environments allows them to fill gaps in kill chain coverage and compensate for other types of shortfalls, especially in the early stages of a conflict when connectivity will be contested. Their presence in the contested battlespace also provides a backup for

stand-off weapons in case those more vulnerable and complex long-range kill chains are broken.

Only 5th generation aircraft can close kill chains at operationally relevant speeds over global ranges and in contested environments

The *speed* at which 5th generation aircraft can respond to unfolding crises enables them to close conventional kill chains at relevant paces over global ranges. The B-2, for example, can close kill chains on the other side of the world from their operating bases in a matter of hours if necessary. Few other military capabilities can match that kind of speed. At the operational level, the stand-in capability, advanced sensing, and information superiority of these stealthy aircraft can accelerate every step of the kill chain, from the initial detection of a target to its engagement and assessment of strike results.

- **Unmatched response times.** The global ranges of the Air Force's penetrating bombers provide strategic kill chain speeds that no other service or allied military can bring to the fight. With an unrefueled combat radius of upward of 3,000 nm, stealthy bombers can respond to deter a threat or create effects in a theater in a matter of hours.[45] This kill chain speed is critically important in peacetime as a deterrent when other capabilities are not be "pre-positioned" in theater.
- **Unique stand-in capability.** The ability of 5th generation aircraft to penetrate inside high-threat areas decreases theater commander response times. The ability to penetrate decreases their range to target areas and, therefore, the time it takes to physically close the kill chain. This is an attribute especially relevant for striking moving and other types of fleeting targets. Physical proximity to these targets also matters because weapon flight times after release must be less than a target's ability to move from its location or take other countermeasures against strikes.
- **Unmatched situational awareness.** Battlespace awareness has a direct impact on the speed of kill chains. 5th generation aircraft have extremely sophisticated sensors, information fusion, and highly advanced pilot-vehicle interfaces (PVI) that accelerate every step of their kill chains to include the cognitive elements of target engagement decisions. High-fidelity, high-trust battlespace awareness empowers warfighters to use their mental capacities to understand the information, make decisions, maneuver, and engage.

The Air Force should retain and modernize their 5th generation aircraft to assure survivable kill chains now and well into the future

As consolidated kill nodes that can independently initiate and close kill chains, 5th generation aircraft can provide survivable kill chains in high-threat and spectrum-contested battlespaces. This is an Air Force advantage that is currently unmatched by China's PLA and other potential adversaries. To maintain this comparative advantage, the Air Force must continue to invest and improve its 5th generation aircraft technologies to offset China's increasingly capable kill chain countermeasures.

- **Improving aircraft survivability.** The Air Force should continue to make investments in modernizing the survivability of its 5th generation aircraft to ensure they remain consolidated kill chain nodes well into the future. Survivability of the platform means the survivability of its kill chains. The opposite is surely true: the loss of a consolidated node means the loss of all its potential kill chains.

- **Improving weapon survivability.** As effective as 5th generation aircraft are, their kill chains become most vulnerable after weapons release because those weapons are not survivable in a highly contested battlespace. Just as the strike aircraft must survive to reach their launch points, their weapons must survive to reach their targets. Improving weapons' survivability against advanced air defenses may require a combination of increasing their speed, designing them with low-observable materials and shapes, and increasing their ability to maneuver in ways that complicate an enemy's ability to intercept them. Enhancing the survivability of munitions, whether air-to-air or air-to-ground, is key to current and future kill chain survivability.

5th Generation Aircraft Facilitate Localized Kill Chains and Mission Execution

As independent, consolidated, and networked kill nodes, 5th and 6th generation aircraft have the unique capability to facilitate localized kill chains and mission execution at the forward edge of the battlespace. The F-22 began pioneering these tactics shortly after it was fielded in the mid-2000s. The Air Force also used its F-22s and their superior situational awareness to direct 4th generation fighters toward targets and away from threats during combat exercises like Northern Edge 2021.[46] Even though these early tactics were coordinated over very high frequency (VHF) radio, the ability of the F-22 to facilitate localized kill chains and mission execution increased the lethality and survivability of the overall force.

As the Air Force looks to the future, it should explore how it can expand opportunities to use the unique physical, informational, and networking attributes of 5th and 6th generation aircraft to act as kill chain force multipliers for all joint force operations. Like how F-22s and F-35s operate with 4th generation fighters and E-3 AWACS today, these aircraft could collaborate with F-15EXs, E-7s, and other capabilities in the Air Force's ABMS to operate in and around contested environments.[47] Only 5th generation aircraft can close kill chains when the spectrum is degraded or locally denied. Only 5th generation aircraft can continue to be resilient, decisive capabilities in this future force, providing kill chain superiority in a highly contested battlespace. Modernization programs that emphasize connectivity could further enhance their contributions to the kill chain competition.

5th Generation Fighters are the Bridge to NGAD

5th generation fighters will be important to the Air Force's overall force design as a bridge to the service's NGAD family of systems. Revolutionary new programs like the NGAD rarely stay on schedule, and a contractor has not yet been awarded a production contract for this cornerstone capability. Even the B-21 bomber program, which drew heavily on existing technologies and was very tightly scoped to avoid delays, took seven years from contract award to unveiling.[48] This reinforces the need for the Air Force to retain and modernize its entire F-22 force until fully operational NGAD systems join the force in meaningful quantities. The F-35, because it is still in production, should also be increased by procuring it at the maximum rate possible to ensure the Air Force will provide the kill chain capacity theater commanders require, especially in contested areas.

While much is classified about the NGAD and its family of systems, public statements made by Secretary Kendall and other senior leaders indicate that the NGAD may not be as consolidated a kill chain as are previous "exquisite" stealthy combat aircraft.[49] It is not unreasonable to expect that NGAD will be a true multifunction node that prioritizes connectivity, information fusion, and localized mission and kill chain execution over consolidation. Even so, 5th generation fighters will continue to pioneer the operational relationships, dependencies, and tactics needed to shape NGAD operations. With the right modernization path, continuing to develop F-22 and F-35 operations could decrease risk in the development of important elements of NGAD operations, including CCA concepts of employment and other tactics, techniques, and procedures, potentially accelerating NGAD integration into the force.

The best and most effective force structure for the future is not wholly disaggregated or wholly consolidated. A more effective U.S. Air Force force design would consist of a mix of disaggregated systems that are networked into distributed kill chains managed by ABMS.

Summary

The F-35 is in production and operational now. In fact, the F-35 is the *only* major element of the future force that is fielded and has a sizable cadre of experienced and ready warfighters. Even as the Air Force must remain committed to developing a disaggregated force that constructs distributed kill chains, the F-35 is the only piece of this future operational system that is real and exists today. **This is the primary kill chain advantage that the Air Force must rely upon to hedge against risk in the present and long into the future.** Yet the service is not procuring F-35s at an optimum rate of at least 80 aircraft per year as previously planned, even as it continues to divest legacy force structure. Soon, B-21s will also be an important part of this equation and should also be procured at scale.

In summary, while the F-22 and B-2 were never procured in the quantities the nation needed, the Air Force should retain both these aircraft and aggressively invest in their sustainment, readiness, and modernization. Like the F-35, their capabilities can still dominate in the highest-risk environments. Retaining the F-22 and B-2 would help mitigate the looming capability and capacity gaps the Air Force faces as it transforms into its future force design. Continuing to modernize and enhance the connectivity of these 5th generation aircraft will contribute to the Air Force's kill chain dominance. Operating these advanced aircraft as consolidated nodes in the near-term can help to develop and mature the technologies and operational concepts that the Air Force needs to build to survive while buying down developmental risk.

Conclusion and Recommendations

As the Air Force moves toward developing a more disaggregated force design, 5th and eventually 6th generation aircraft will be key to ensuring resilient kill chain closure because of their ability to independently complete the F2T2EA process in a spectrum-contested environment. The best and most effective force structure for the future is not *wholly* disaggregated or *wholly* consolidated. A more effective U.S. Air Force force design would consist of a mix of disaggregated systems that are networked into distributed kill chains managed by ABMS. As part of this operational system, 5th and 6th generation aircraft will continue to be critical multifunction nodes and consolidated, independent kill chain closers. This mix would provide the best balance between complexity and resiliency.

While the Air Force's current kill chains have proven incredibly effective over the last 20 years of permissive, low-intensity conflict, it must evolve its operational systems to create kill chains that have the scale, scope, speed, and survivability to prevail against the PLA's warfighting strategy of system destruction. The PLA understands the asymmetric advantage that airpower provides, and instead of pursuing attrition warfare, the PLA plans to systematically disrupt, deconstruct, and destroy the Air Force's kill chains. It will do this by targeting key nodes and networks, disrupting the operational relationships of kill chains, and delaying kill chain closure to outpace a theater commander's operations.

The Air Force must take action today to evolve its kill chains into an operational system that can prevail in high-intensity peer conflicts against this strategy of system destruction. This does not mean simply hardening and doubling down on current kill chains. As senior leaders and force planners consider developing new force designs, technologies, and operational concepts to win in a Pacific conflict scenario, they must keep the principles of kill chain superiority in mind. Kill chain scale and scope will be crucial to prosecuting the volume of targets across the expansive battlespace over the duration that the Air Force must operate. The scale and scope imply certain physical attributes of this future force. Range, payload, persistence, and quantity are also attributes that the Air Force should seek to maximize. Kill chain speed is another consideration that Air Force must achieve to win, and this means not only the time required to close a kill chain from detection to effect and assessment but also the speed at which the Air Force can connect and construct real-time, ad hoc kill chains against targets. In short, speed includes not just execution but construction. Kill chains that take years to construct through extended modernization cycles will not outpace adversary efforts to spoil them. Finally, kill chains must be survivable against and through adversary attacks. While platform, network, and weapon survivability all play a piece in this, the kill chain itself must be designed to be survivable through attrition and network degradation—especially for consolidated kill chain or multifunction nodes.

There are actions the Air Force should take in the near-to-mid-term to begin securing the kill chain advantage, even as it works toward transforming its force design for the longer term.

Near-to-mid-term Recommendations for the Air Force

1. **Maximize F-35 and B-21 production rates.** The F-35 is the only U.S. 5th generation aircraft in production today that can provide a kill chain advantage now and long into the future. To achieve kill chain scale and scope and mitigate risk in this decade, the Air Force should maximize the rate at which it procures its F-35As. The B-21 will soon require similar consideration.
2. **Aggressively invest in modernizing and improving the range and survivability of the F-35 and F-22 as a bridge to NGAD.** By making key investments in the entire F-22 force and F-35s, the Air Force can increase the survivability of its kill chains as well as their reach. The Air Force needs advanced kill chain capability in the present that is capable of pioneering and maturing key concepts as the service develops NGAD.
3. **Invest in the development and high-quantity production of advanced, survivable air-to-air and air-to-ground weapons suitable for 5th and 6th generation combat aircraft operations.** Developing advanced, survivable weapons would dramatically impact the

scale and survivability of U.S. kill chains. Increasing the number of kill chains that 5th generation aircraft can complete per sortie will have a direct impact on the timing and mission effectiveness of a campaign operation. Enhancing the survivability of these weapons would address one of the most vulnerable parts of the kill chain since legacy weapons designed for permissive environments of the past are increasingly vulnerable to China's advanced air and missile defenses.

4. **Map out and connect the right sensors, platforms, and weapons for highly effective kill chains in and across mission elements.** Not everything needs to be connected to everything all the time. Current kill chains are sub-optimized because these kill chain mission threads are not well understood and are often not connected. The Air Force should better understand and then connect its forces as an operational system so that it can increase the scale, scope, and survivability of its kill chains.
5. **Develop advanced networks and invest in connectivity across the force.** Enhancing the connectivity of 5th generation aircraft with other aircraft and strike capabilities across the force will empower them to be both consolidated and multifunction nodes that increase the scale, scope, and speed of a theater commander's kill chain operations.

Mid-to-far-term Recommendations for the Air Force

1. **Create automated tools that can support air battle managers to rapidly identify, validate, evaluate, and construct kill chains.** A disaggregated kill chain presents tremendous complexity to battle managers, especially when the physical, locational, and informational characteristics of each node are "in play." In a highly dynamic battlespace, battle managers need automated or intelligent tools to facilitate the real-time identification of kill chain options for target pairing. Without such tools, kill chains will be rigid, limited, and slow, unable to respond in a changing and contested environment.
2. **Accelerate the development and fielding of collaborative combat aircraft as part of a family of systems for 5th and 6th generation aircraft operations.** By increasing the absolute quantity of platforms in the battlespace, CCAs have the potential to increase the number and reach of the Air Force's 5th and 6th generation kill chains. Quantity also provides survivability to these kill chains because these family-of-systems formations can maintain kill chain continuity through light or moderate attrition.
3. **Develop and launch a space-based sensing and data transport layer.** A highly proliferated LEO sensing and communication layer will be essential to winning kill chain competitions against a peer adversary. The unique attributes of the space domain, when populated with high-volume sensing and communication constellations, can dramatically boost the scale, scope, speed, and survivability of air-based kill chains.
4. **Accelerate the development of NGAD as an advanced multifunction node for highly contested battlespaces and procure at high rates and in high quantities.** The Next Generation Air Dominance family of systems will be a cornerstone of the Air Force's future force and combat operations that will boost all elements of kill chain superiority. Yet the DOD has a poor record of ensuring the Air Force receives the resources it

> needs to acquire a sufficient capacity of advanced systems, even for programs that are foundational to future joint combat operations. For over 30 years in a row, the Air Force has received less funding than either the Army or the Navy.[50] The Air Force must develop and field the NGAD family of systems in robust quantities along with the F-35 and B-21 if it is to maintain its kill chain advantage over China.

Adapting U.S. kill chains to be able to prevail against the PLA will not be easy or cheap. Recommendations in this report identify lines of effort that the DAF should pursue to enhance kill chain lethality today and in its future force. They will also require additional budget increases for the DAF. Ramping up F-35 production without additional resources, for example, would have ripple effects across the DAF enterprise, from military construction to depots to training. Developing and integrating advanced network connectivity across the force would also be challenging. The past is littered with failed efforts and lost time on DOD programs that were descoped or even abandoned entirely due to a desire to reduce defense spending. This has had a devastating effect on today's force structure, which is too small and too old to meet the demands of our National Defense Strategy.

This report's recommendations are not "quick kill" fixes that can be achieved by simply trading off current force capacity. More importantly, Senior DOD leaders must consider the ultimate cost of *not* pursuing kill chain dominance as it develops its future force design. A defeat at the hands of a peer adversary would have devastating long-term consequences for the security of the United States and its allies and partners. ✪

Endnotes

1 "2022 USAF & USSF Almanac: Equipment," *Air & Space Forces Magazine*, July 1, 2022. The Air Force's total aircraft inventory dropped below 8,000 for the first time in its history in 2003 and has not recovered since. Congressional floors have limited the Air Force from shrinking even further, but the failure of the Air Force to aggressively recapitalize key fleets has resulted in the service extension of legacy platforms, creating a force that is the oldest it has ever been.

2 These steps may be completed so quickly as to appear instantaneous to the warfighter, or technology may enable flexibility in how and when they are accomplished in the process. Regardless, each step must be performed to complete any kill chain.

3 Air Land Sea Space Application (ALSSA) Center, *Multi-Service Tactics, Techniques, and Procedures for Dynamic Targeting* (Hampton, VA: ALSSA Center January 2022); and U.S. Air Force, *Targeting*, AFPD 3-60 (Washington, DC: U.S. Air Force, November 2021). Military communities among the services have developed their own kill chain language to describe the same process. Army Special Forces, for example, use a model of Decide, Detect, Deliver, Assess (D3A), while other elements of the Army use Find, Fix, Finish (F3) and various permutations such as Find, Fix, Fight, Finish (F4); Find, Fix, Fire, Finish, Feedback (F5); or Find, Fix, Finish, Exploit, Analyze, Disseminate (F3EAD). The Navy broadly describes kill chains as the "detect to engage sequence," more recently decomposing this process to Prepare/Configure, Search, Detect, Track, ID, Launch, Control, Weapon, Assess, Defend. These different models seek to capture the unique perspective and nuances of how these communities operate and, in doing so, reflect how their operators experience the kill chain through their unique technological and tactical lens. For discussions on various interpretations of the kill chain, please see: Charles Faint and Michael Harris, "F3EAD: Ops/Intel Fusion "Feeds" The SOF Targeting Process," *Small Wars Journal*, January 31, 2012; John A. Tirpak, "Find, Fix, Track, Target, Engage, Assess," *Air & Space Forces Magazine*, July 1, 2000; Raj Agrawal and Christopher Fernengel, "The Kill Chain in Space: Developing a Warfighting Mindset," *War on the Rocks*, October 24, 2019; Mike Benitez, "It's About Time: The Pressing Need to Evolve The Kill Chain," *War on the Rocks*, May 17, 2017; and Tyson Wetzel, "Information-Centric Operations: Airpower Strategy for the 21st Century," The Strategy Bridge, October 15, 2017.

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14 Author interview with Johnny Duray.

15 Conversation with Mark Gunzinger, January 12, 2023. See also Col Chris Buckley, USAF, Chief of Weapons Development & Requirements, "The End of the Kill Chain: The Weapons We Need to Arm the Air Force the Nation Needs," briefing to Weapons Pitch Day Conference on July 20–21, 2022, slide 4.

16 See Mark Gunzinger and Bryan Clark, *Winning The Salvo Competition: Rebalancing America's Air and Missile Defenses* (Washington, DC: The Center for Strategic and Budgetary Assessments, 2016); and Mark Gunzinger, *Affordable Mass: The Need for a Cost-Effective PGM Mix for Great Power Conflict* (Arlington, VA: The Mitchell Institute for Aerospace Studies, November 2021).

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