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FIVE PRIORITIES FOR THE AIR FORCE'S FUTURE COMBAT AIR FORCE

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Cover: Composite design by Kamilla Gunzinger and Lukas Autenried. XQ-58A Valkyrie developmental UCAV flying with a T-38 Talon trainer (not pictured) over Yuma Training Range as part of its flight capabilities demonstration program in March 2019. Photo courtesy of Kratos and AFRL. MQ-9 Reaper remotely piloted aircraft: U.S. Air Force photo by Lt. Col. Leslie Pratt. B-2 and F-22s: U.S. Air Force photo by Master Sgt. Russ Scalf.

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Executive Summary and Recommendations

In March 2019, CSBA released the results of a study directed by the 2018 National Defense Authorization Act (NDAA) that developed recommendations for a United States Air Force future aircraft inventory.[1] This assessment builds on insights from the study to recommend five priorities that could help the Air Force to align its combat air forces (CAF) with the 2018 National Defense Strategy (NDS).[2] For the purposes of this report, the CAF includes the Air Force's fighters; bombers; electronic warfare; strategic intelligence, surveillance, and reconnaissance (ISR); and battle management and command and control (BMC2) aircraft.[3] Although this report touches on major elements of a potential future CAF, most of its analysis is focused on the capabilities mix and capacity of the Air Force's next-generation fighter and bomber fleets.

Background: Major Air Force CAF Trends

Fighter Forces

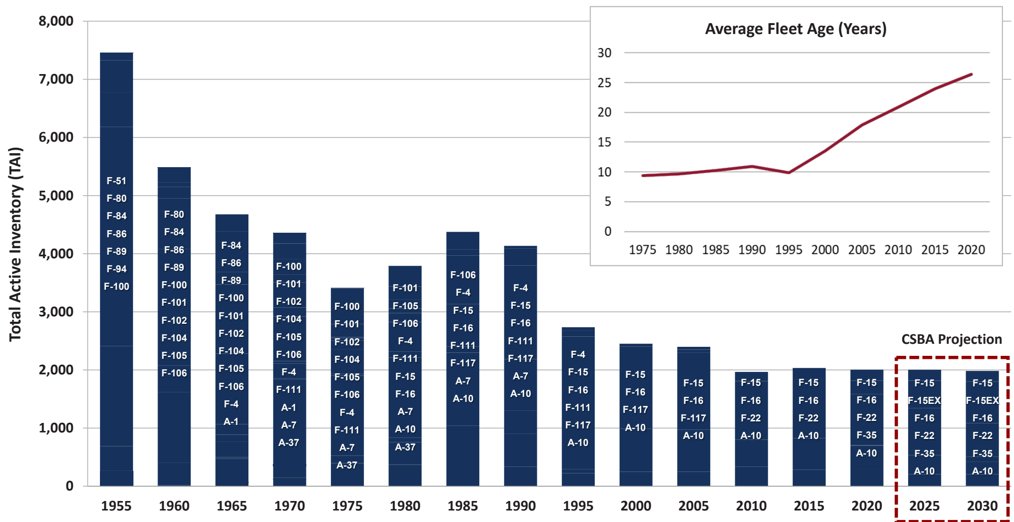
The Air Force has absorbed multiple cuts to the size of its fighter force since the Cold War. By the end of Fiscal Year (FY) 2019, the Air Force operated 55 fighter squadron equivalents, which is about half the size of its 1989 fighter force. Although there have been no major Air Force fighter reductions over the last several years, the force's average age has continued to climb, and maintaining its readiness has become a persistent challenge (see Figure 1).

1 Mark Gunzinger et al., *An Air Force for An Era of Great Power Competition* (Washington, DC: Center for Strategic and Budgetary Assessments, 2019). CSBA's study was one of three independent studies on the Air Force's future aircraft inventory directed by the National Defense Authorization Act for Fiscal Year 2018, P.L. 115-91, 131 Stat. 1283 (2017), Section 1064, "Studies on Aircraft Inventories for the Air Force."

2 Department of Defense (DoD), *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge* (Washington, DC: DoD, January 19, 2018).

3 U.S. Air Force, *Air Force Future Operating Concept: A View of the Air Force In 2035* (Washington, DC: U.S. Air Force, September 2015), available at https://www.af.mil/Portals/1/images/airpower/AFFOC.pdf. The Service's Air Combat Command also provides personnel recovery and combat support forces to U.S. combatant commanders. See Air Force Association, "USAF Almanac 2018," Air Force Magazine, June 2018, p. 60.

FIGURE 1: TRENDS IN THE SIZE AND AVERAGE AGE OF THE AIR FORCE'S FIGHTER INVENTORY



James C. Ruehrmund Jr. and Christopher J. Bowie, *Arsenal of Airpower: USAF Aircraft Inventory, 1950-2016* (Washington, DC: Mitchell Institute for Aerospace Studies, February 2018). The 2025 and 2030 force columns in Figure 1 are CSBA projections.

The most significant cuts to the Air Force's fighter fleet and other forces were driven by a desire to realize a post-Cold War defense budget "peace dividend" and the need to free resources to support overseas contingency operations. Although the budgets and forces of all the Services were reduced, the Air Force absorbed the largest cuts as a percentage of its total obligational authority (TOA) from FY 1989 to the end of FY 2001. Overall, Air Force TOA in its "blue" budget decreased by 31.6 percent over this timeframe compared to a 28.2 percent decrease for the Department of the Navy and 29.2 percent for the Army.[4] This decrease includes a 52 percent drop in the Air Force's total blue procurement budget, which was far greater than the 32 percent and 35.9 percent decrease in the Navy and Army's procurement budgets, respectively.[5] There have only been a few years since 1990 when the Air Force bought new aircraft in significant quantities. This created what has been called an extended aircraft procurement holiday. The Air Force's budget did increase significantly following the September 2001 terrorist attacks on the United States. However, the preponderance of additional resources it received was allocated toward buying capabilities to support

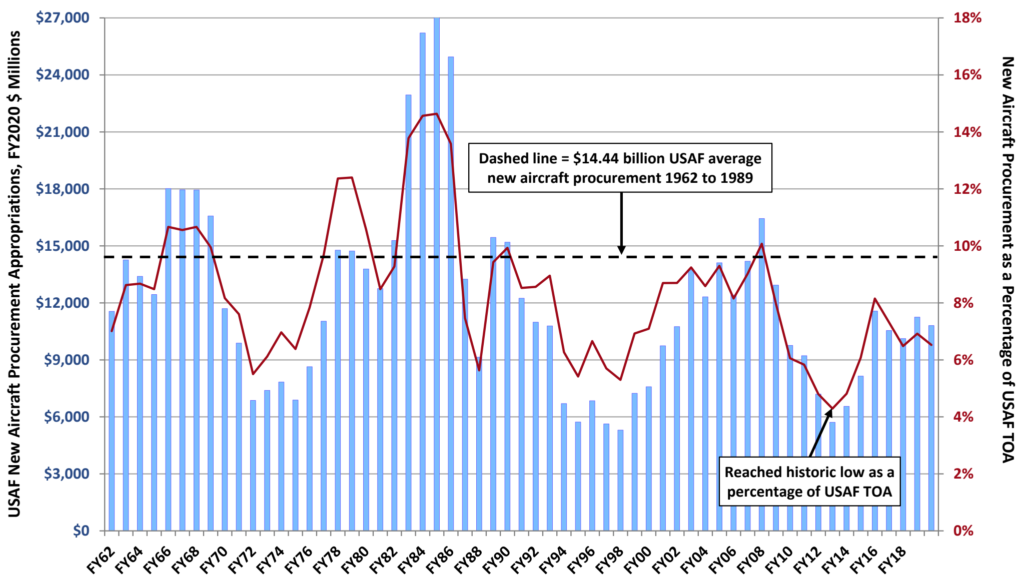
4 The Air Force's "blue budget" excludes pass-through funding for intelligence community programs, special operations forces programs, health care, and other funding requirements over which the Air Force has little control. See Adam J. Hebert, "Beyond the Blue," *Air Force Magazine*, April 2010, p. 22. Air Force blue-only budget data was provided to CSBA to inform its 2019 aircraft inventory study.

5 For a more in-depth analysis of post-Cold War budget trends that helped shape the size and capabilities mix of the current Air Force, see Mark Gunzinger and Carl Rehberg, *Moving Toward the Air Force We Need? Assessing Air Force Budget Trends* (Arlington, VA: Mitchell Institute for Aerospace Studies, December 2019), available at https://03236830-405f-4141-9f5c-3491199c4d86.filesusr.com/ugd/a2dd91_5fd2084d6fe24dd09f94f0ac3c8862e9.pdf.

counterterrorism operations, not new fighters, bombers, and other next-generation systems better suited for great power conflict. The post-September 2001 U.S. defense buildup was followed by another round of budget cuts driven in part by the 2011 Budget Control Act (BCA). Two years after Congress passed the 2011 BCA, the Air Force's new aircraft procurement funding as a percentage of its blue budget reached the lowest level in its history.

Funding for new Air Force fighters and other aircraft increased by roughly 102 percent from FY 2013 ($5.7 billion) to FY 2016 ($11.6 billion) but has since decreased slightly (see Figure 2). For instance, the FY 2020 President's Budget requested funding for 48 F-35As for the Air Force, a decrease from the 56 F-35As appropriated in each of the two previous fiscal years. Even after adding DoD's request to buy "new-old" F-15EXs, the total number of new Air Force fighter aircraft requested in FY 2020 budget proposal falls short of the minimum of 72 per year that is needed to recapitalize its fighter fleet.[6]

FIGURE 2: TRENDS IN THE AIR FORCE'S AIRCRAFT PROCUREMENT FUNDING



6 See Dr. William B. Roper Jr., General James M. Holmes, and Major General David Nahom, testimony before the House Armed Services Committee (HASC), Subcommittee on Tactical Air and Land Forces, U.S. House of Representatives, May 2, 2019, pp. 3–4, available at https://www.congress.gov/116/meeting/house/109348/witnesses/HHRG-116-AS25-Bio-HolmesJ-20190502.pdf. Other official analyses and senior Air Force leaders have said the required fighter procurement rate is closer to 80–100 aircraft per year. Congress may elect to exceed the PB request in FY 2020 and procure 60 F-35A and six F-15EX aircraft for a total of 66 new fighter aircraft, an increase of 12 F-35As from the 48 F-35As requested by DoD. This would be the largest single year procurement of Air Force fighter aircraft since 1991. Senate Appropriations Committee, Defense (SAC-D), Department of Defense Appropriations Bill, 2020, Report 116-00 (Washington, DC: SAC-D, September 2019), p. 150, available at https://insidedefense.com/sites/insidedefense.com/files/documents/2019/sep/09122019_sac.pdf.

Trends in the current readiness of the Air Force's legacy fighters have been just as concerning as their diminished numbers (see Table 1). Lower aircraft mission capable rates have the effect of reducing the total number of sorties a given force is able to generate and sustain in support of flying operations.

TABLE 1: THE AIR FORCE'S 2019 FIGHTER INVENTORY AND RECENT MISSION CAPABLE RATES

	Total Aircraft Inventory (TAI)	Primary Mission Aircraft Inventory (PMAI)	Mission Capable (MC) Rates 2017	Mission Capable (MC) Rates 2018	Estimated PMAI Available Considering MC Rates
F-35A	212	About 70	54.67%	49.55%	35
F-22A	186	123	49.01%	51.74%	62
F-15E	218	138	75.26%	71.16%	98
F-15C/D	235	156	71.24%	71.47%	111
F-16 all blocks	940	About 486	70.22%	70.03%	340
A-10C	281	171	73.76%	72.51%	123
Total	**2,072**	**About 1,144**			**769**

U.S. Air Force, *Fiscal Year 2020 Budget Overview* (Arlington, VA: Headquarters U.S. Air Force, March 2019), p.38, available at https://www.saffm.hq.af.mil/Portals/84/documents/FY20/FY2020%20Air%20Force%20Budget%20Overview%20Book%20Final%20v3.pdf?ver=2019-03-13-082653-843. This source was used for Air Force TAI only to the end of FY 2019. The Air Force's FY 2019 President's Budget Force Structure Data Management (FSDM) database was the primary source used to determine PMAI aircraft inventories for FY 2019 in Table 1. Because the Air Force now considers PMAI data For Official Use Only, CSBA estimated F-16 and F-35A PMAI. The FY 2018 NDAA requires the Air Force to maintain (a minimum of) 1,970 TAI and 1,145 PMAI fighters, including 171 PMAI A-10s. The Air Force procured about 325 "lower block" F-16s (Blocks 25, 30, 32), and about 614 "higher block" F-16s (Blocks 40, 42, 50, and 52) with upgraded capabilities. Many lower block aircraft have already been retired, and remaining lower block F-16s will need to be retired soon due to service life issues.

Sustained high operational tempos over the last two decades, the Secretary of Defense's 2009 decision to halt F-22A acquisition at 187 aircraft, and DoD's decision to delay the F-35A's procurement ramp-up have taken their toll on the fighter force's readiness. As early as 2008–2009, it was evident that every type of legacy fighter in the Air Force's inventory had significant service life issues.[7] Today, two-thirds of the Air Force's remaining force of F-15C/D air superiority fighters are past their designed service lives and must soon be retired, and the average age of the U.S. Air Force total fighter force has reached an unprecedented high of about 28 years (see Table 3).[8] This has increased the cost and effort needed to sustain the force. According to Dr. Will Roper, "A lot of our programs are in sustainment long past the original design life . . . and we're having to do Herculean tasks to keep airplanes flying that should have been retired a long time ago."[9]

7 There was uncertainty at the time over the actual service lives of older model F-16s, F-15C/Ds, and F-15Es and whether some of them could be extended.

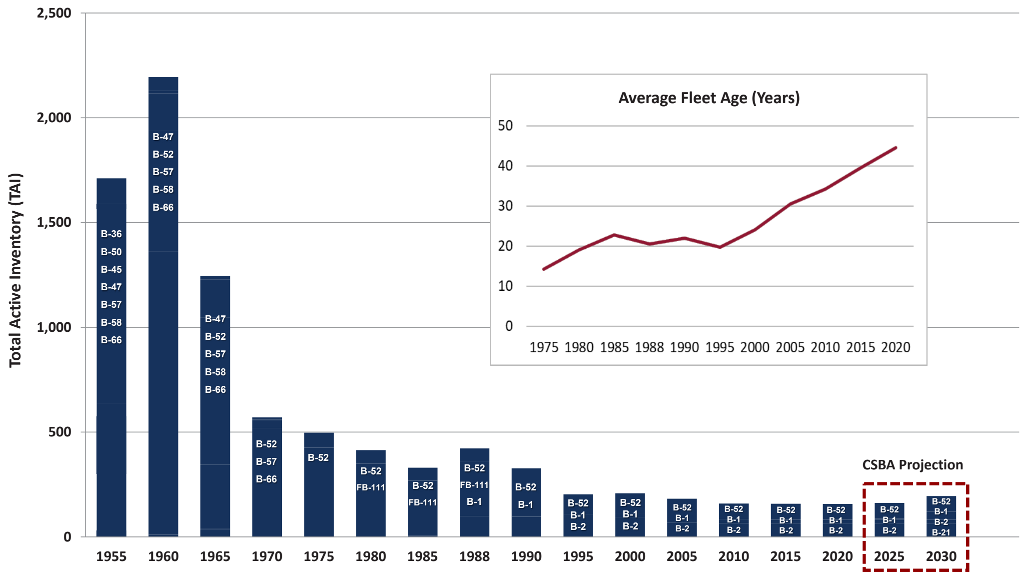
8 Roper, Holmes, and Nahom, testimony before the HASC, Subcommittee on Tactical Air and Land Forces, May 2, 2019, p. 3.

9 Oriana Pawlyk, "The Air Force Is Ready to Scrap Older Aircraft to Prepare for Future Wars," *Military.com*, September 4, 2019.

Bomber Forces

In 1988, the Air Force's bomber fleet consisted of 234 B-52, 98 FB-111, and 90 new B-1B aircraft.[10] Similar to the Air Force's fighter force, the bomber fleet has now reached an all-time low in numbers—157 total aircraft—and an all-time high average age (see Figure 3). The Air Force's B-52H bombers, which were delivered during the Kennedy administration, still constitute more than half of the bomber force. The Service's 62 remaining B-1B bombers are based on 1970–1980s era technologies and are experiencing significant readiness issues, as addressed later in this section.

FIGURE 3: TRENDS IN THE SIZE AND AVERAGE AGE OF THE AIR FORCE'S BOMBER INVENTORY



Ruehrmund and Bowie, *Arsenal of Airpower*.

This smaller and older force trend runs counter to U.S. combatant commanders' growing requirements for Air Force bombers.[11] The long ranges, large payloads, and multi-mission capabilities of bombers are exactly the kind of attributes needed to deter regional actors like North Korea and Iran as well as potential great power aggressors. However, B-52H and B-1B bombers originally designed to penetrate Cold War Soviet air defenses are not capable of penetrating airspace covered by the integrated air defense systems (IADS) fielded by China and Russia. Multiple post-Cold War initiatives to modernize the bomber force and maintain

10 Ruehrmund and Bowie, *Arsenal of Airpower*. The 2025 and 2030 numbers are unofficial CSBA projections.

11 According to the Air Force, "In the last five years, [Air Force Global Strike Command] has gone from supporting one enduring COCOM requirement to an average of 12 annually, a 1,100-percent increase. To meet this level of demand, AFGSC's operation and maintenance personnel and bomber airframes are managed at peak utilization rates." Quote published in John A. Tirpak, "USAF to Retire B-1, B-2 in Early 2030s as B-21 Comes On-Line," *Air Force Magazine*, February 9, 2018.

its ability to penetrate contested areas have fallen victim to the budget axe and competing requirements. Production of stealth B-2s, the Air Force's youngest bomber, was capped by Secretary of Defense Cohen in the late 1990s at 21 total aircraft, far short of the original requirement of 132 B-2s. A second Air Force attempt to procure a next-generation bomber was canceled by Secretary of Defense Gates in 2009 due to his concerns over its cost as well as his desire to allocate more resources toward combat operations in Iraq and Afghanistan. The B-21 program will finally begin to deliver new bombers in the mid-2020s timeframe, almost 30 years after the last B-2 joined the force. The Air Force has said that it will procure at least 100 B-21s.

Similar to its fighter fleet, the Air Force's bombers have suffered from declining mission capable rates (see Table 2). Reduced mission capable rates translate directly to fewer operational sorties, further increasing the Air Force's bomber capacity shortfall. The sustained high operational tempo of the B-1B force, in particular, has reduced its readiness to support new taskings. In August 2019, General Hyten informed the Senate Armed Services Committee that only 6 of 36 PMAI B-1B Lancers were fully mission capable.[12] General Ray, Commander of the Air Force's Global Strike Command, attributed this precipitous decline to deploying 65 to 70 percent of the B-1B force for "more than a decade" to support combat operations, a rate that is far higher than normal.[13]

TABLE 2: THE AIR FORCE'S 2019 BOMBER INVENTORY AND RECENT MISSION CAPABLE RATES

	Total Aircraft Inventory	Primary Mission Aircraft Inventory	Mission Capable (MC) Rates 2017	Mission Capable (MC) Rates 2018	Aircraft Available After Adjusting for 2018 MC Rates
B-52H	75	44	75%	71.82%	31
B-1B	62	36	52.79%	51.75%	18 (Note: 6 in August 2019)
B-2	20	16	53.83%	60.70%	9
Total	**157**	**96**			**Up to 58**

For a more complete listing of Air Force aircraft mission capable rates for FY 2017 and FY 2018, see Stephen Losey, "Aircraft Mission-Capable Rates Hit New Low in Air Force, Despite Efforts to Improve," *Air Force Times*, July 26, 2019.

The shortfall in the Air Force's bomber force capacity has continued to grow over the last two decades, driven in part by force structure cuts, issues with force readiness, and a lack of modernization investment. Although the B-21 program is still in its engineering and manufacturing development (EMD) phase, it is on track for a first flight as soon as December 2021, and operational B-21s could begin to join the force in the mid-2020s timeframe.[14] In the interim,

12 Stephen Losey, "The Air Force's B-1 Bombers Are in More Dire Shape than We Thought," *Air Force Times*, August 2, 2019.

13 Ibid. "Typically, Ray said, the Air Force would commit about 40 percent of a particular bomber or other combat aircraft to deployments, not counting aircraft in depot maintenance, Military.com reported. Instead, he said, the Air Force has committed 65 to 70 percent of its B-1s for more than a decade."

14 Randy Walden, head of the Air Force's Rapid Capabilities Office (RCO), mentioned the B-21 could complete its first flight in December 2021. See John A. Tirpak, "B-21 Taking Shape, Though RCO Hedges on First Flight Date," *Air Force Magazine*, October 24, 2019.

decisions to cut additional legacy bombers or their planned modernization programs to free resources for other priorities, significant unforeseen service life issues with legacy bombers, or unplanned delays to the B-21 program could further decrease the Air Force's remaining long-range strike capacity.

Summarizing the Planned 2030 CAF Inventory

Table 3 summarizes the estimated total inventories and average ages of fighters, bombers, and MQ-9 unmanned aircraft systems (UAS) that will be in the CAF in 2030. As assessed in CSBA's 2019 Air Force aircraft inventory report, this force was sized and shaped by budget constraints and planning assumptions of the past, not the scenarios for great power competition and conflict of the present and future. The average age of the bomber force will be nearing 50 years before the B-21 joins the inventory, and the fighter force is already approaching an unprecedented average age of 30 years. These trends are tangible evidence of the toll taken on the Air Force's CAF by years of inadequate recapitalization and modernization funding.

TABLE 3: ESTIMATE OF THE PLANNED FY30 FIGHTER AND BOMBER AIRCRAFT INVENTORY

Aircraft		2019 TAI	2019 Average Age (Years)	CSBA FY30 TAI Projection	Comments
Bomber Force	**B-52H**	75	58	75	The Air Force plans to retain B-52Hs in the force until about 2050
	B-1B	62	32	42	B-1B retirements may begin in the early 2020s
	B-2	20	25	20	B-2s may be retained until replaced by operational B-21s
	B-21	0	N/A	35+	B-21 first flight may occur as soon as December 2021
	Total	**157**	**44**	**172+**	
Fighter Force	**A-10**	281	38	208	The Air Force plans to restructure its A-10 force to 6 squadrons in 2021 and retain until the early 2030s
	F-16	935	28-plus	625	Assumes F-16s are divested as F-35As are procured
	F-15C/D	234	35	0	Will likely retire earlier than FY19 projection, possibly as early as 2025
	F-15EX	0	N/A	144	Assumes Congress will fund procurement of 144 F-15EX
	F-15E	218	27	218	Assumes all aircraft are sustained and modernized
	F-22A	186	12	186	Assumes all aircraft are sustained and modernized
	F-35A	212	3	762	Assumes a planned procurement rate of 50 per year from 2020 to 2030
	Total	**2,066**	**about 28**	**2,143**	
ISR, Light Strike	**MQ-9**	252	5	252	Not counted by this report as fighter aircraft; new multi-mission UAS could join the force in the 2020s
	Total	**252**	**5**	**252**	

Concerned with the Air Force's diminished force capacity and capabilities, Congress directed the Secretary of Defense to commission three separate, independent studies on a future Air Force aircraft inventory needed to support the 2018 National Defense Strategy.[15] All three

15 DoD, *Summary of the 2018 National Defense Strategy of the United States of America.*

studies concluded the Air Force should modernize and significantly grow the size of its forces, especially its CAF.[16]

In summary, the Air Force has been living off major CAF weapon systems that were, in many cases, designed and delivered during the Cold War. With the exception of a small fleet of 187 stealth F-22s, 21 stealth B-2s, and now a small but growing force of F-35As, the Air Force stopped procuring next-generation fighters and bombers after the Cold War. This report concludes the following five priorities would help close the gap between the Air Force's current combat aircraft force mix and a future CAF that has the capabilities and capacity to support the 2018 NDS. These and other measures needed to recapitalize and modernize the CAF for the future will require increases in the Air Force's annual budgets. Without adequate resources, it is likely that the CAF's current capability and capacity gaps will continue to grow over the next decade.

Recommendations: Five Priorities for the Air Force's Future CAF

The CAF should be sized for great power conflict. Preparing to prevent China and Russia from succeeding in major acts of aggression should be a fundamental force design priority for the Air Force's future CAF. The 2018 NDS initiated a shift of DoD's planning and resource priorities toward this end. However, it also established "what is functionally a one-war force sizing construct" that could increase the risk that a second great power aggressor could take advantage of a major U.S. military response to a conflict in another theater.[17] An Air Force CAF that is sized and shaped to rapidly respond to a second act of great power aggression would reduce this risk. A two-war CAF should also have greater capacity to strike large target sets over long ranges and deep into contested areas, which is another key recommendation of all three 2018 NDAA Air Force aircraft inventory studies. Increasing the CAF's long-range penetrating strike capacity would help deny operational sanctuaries to China, Russia, and other aggressors.

16 The Air Force submitted a classified report on the results of its study to Congress. For an unclassified summary of the Air Force's study, see U.S. Air Force, *Fiscal Year 2018 National Defense Authorization Act (NDAA) Section 1064 Study: Aircraft Inventories for the Air Force* (Washington, DC: U.S. Air Force, March 2019), p. 3, available at http://airforcemag.com/DocumentFile/Documents/2019/Air%20Force%20FY18%20NDAA%20Section%201064%20Study.pdf. The MITRE Corporation and CSBA also completed studies as directed by the 2018 NDAA. For an unclassified executive summary of MITRE's report, see "MITRE U.S. Air Force Aircraft Inventory Study Executive Summary," MITRE Corporation, 2019, available at http://www.airforcemag.com/DocumentFile/Documents/2019/MITRE-USAF-Aircraft-Inventory-Study.pdf.

17 According to the report of the National Defense Strategy Commission, "The United States now faces five credible challengers, including two major-power competitors, and three distinctly different geographic and operational environments. This being the case, a two-war force sizing construct makes more strategic sense today than at any previous point in the post-Cold War era. Instead, the NDS adopts what is functionally a one-war force sizing construct and recommends only modest increases in force capacity, an approach that is likely to create severe strategic and operational vulnerabilities for the United States." Eric Edelman and Gary Roughead, *Providing for the Common Defense: The Assessment and Recommendations of the National Defense Strategy Commission* (Washington, DC: U.S. Institute of Peace, 2018), p. 35, available at https://www.usip.org/sites/default/files/2019-07/providing-for-the-common-defense.pdf.

Procure additional advanced stealth aircraft and fund survivability improvements for select CAF platforms. The current CAF predominately consists of 4^{th} generation non-stealth aircraft that are not suitable for operations in future contested threat environments. Low radar cross-sections and other stealth technologies have become a requirement for aircraft that must operate in contested and highly contested threat environments. Over the next 20 years, the Air Force should accelerate the purchase of aircraft with next-generation stealth capabilities. This should include aircraft such as B-21 bombers, F-35As, a new multi-mission Penetrating Counterair/Penetrating Electronic Attack (PCA/PEA) aircraft, and penetrating unmanned ISR systems. The Air Force should also continue to fund its B-2 Defensive Management System Modernization (DMS-M) program that addresses shortfalls in the bomber's Defensive Management System. Maintaining the B-2's ability to penetrate contested threat environments would help sustain a capable U.S. bomber force until significant numbers of B-21 bombers become operational and hedge against a potential B-21 program schedule slippage. Other CAF priorities should include maintaining the survivability of the F-22 and procuring next-generation weapons, including a family of hypersonic weapons, that could significantly increase the lethality of the Air Force's offensive operations.

Maintain the Air Force's ability to generate combat power forward. The Chinese and Russian militaries have time and distance advantages in areas on their countries' peripheries where their governments aspire to increase their influence or control. Both continue to increase their capacity to launch large-scale precision air and missile attacks against airbases and other operating locations that U.S. air forces now depend on to generate combat sorties. A major objective of the 2018 NDS is to create the capacity for robust U.S. force postures in the Western Pacific and Europe that can deter or respond rapidly to Chinese and Russian aggression.[18] A future CAF capable of supporting joint operations to deter or deny China or Russia the ability to achieve a *fait accompli* in these regions should be able to generate strike sorties from bases located in areas that are at less risk of high-density missile attacks *and* generate counterair and other combat sorties from dispersed networks of closer in theater airbases.[19] These are not "either-or" options. The Air Force should increase its capacity to operate from airbases that are located in more distant, lower-threat areas. At the same time, schemas that would overweight the Air Force's CAF sortie generation operations toward far more distant airbases early in a conflict with China or Russia could erode DoD's ability to assure America's allies and partners. In both cases, maintaining the CAF's ability to generate combat power will require DoD to field higher capacity airbase defenses against large-scale air and missile attacks. The Air Force would need additional resources and personnel end strength should it be given greater responsibility for the airbase defense mission.

18 A *fait accompli* strategy is designed to rapidly achieve objectives before an opponent can effectively mobilize and deploy its forces. See Michael S. Gerson, "Conventional Deterrence in the Second Nuclear Age," *Parameters*, Autumn 2009, available at https://ssi.armywarcollege.edu/pubs/Parameters/articles/09autumn/gerson.pdf.

19 The First Island Chain in the Western Pacific follows the Japanese island of Kyushu down the Ryukyus to the north of Taiwan, runs west toward Luzon, then south along Palawan to Singapore. The Second Island Chain includes the northern Marianas and the Volcano Islands, runs south to Guam, then down to Palau and New Guinea.

Develop and employ UAS for a wider set of missions in a broader set of threat environments. The Air Force's CAF lacks capacity to support high-end combat operations, sustain homeland defense, and meet other requirements of the 2018 National Defense Strategy simultaneously. This lack of capacity will likely persist well into the 2030s until new CAF capabilities can be delivered in scale. To reduce the risk caused by this shortfall, the Air Force should develop new concepts for employing existing and future UAS, including MQ-9s, lower-cost attritable UAS, and other unmanned systems that could be delivered in the near term. In the long term, more advanced UAS designs that are capable of penetrating contested environments could team with manned stealth aircraft to conduct counterair, long-range standoff area surveillance, strikes, electronic warfare, and other combat operations in addition to performing ISR and light strike missions.

Accelerate the development of Air Force next-generation force multipliers. The Air Force's future force multipliers should include next-generation hypersonic weapons, cruise missiles with counter-electronics HPM payloads capable of attacking multiple targets per weapon, advanced engines that will increase the range and mission endurance of CAF aircraft, and the datalinks needed to support multi-domain operations in contested environments. Replacing legacy Air Force BMC2 aircraft such as the E-3 Airborne Warning and Control System (AWACS) and E-8 Joint Surveillance Target Attack Radar System (JSTARS) with joint all-domain BMC2 architectures would also increase the effectiveness and resiliency of the entire joint force in future operations.

Report Organization

Chapter 1, "Size the CAF for Great Power Conflicts: Capacity Counts," compares major recommendations of the three Air Force aircraft inventory studies directed by Section 1064 of the 2018 NDAA. It then recommends a force sizing construct and major shifts in the Air Force's future force mix that would better prepare it to support great power competition and conflict.

Chapter 2, "Create a More Survivable CAF," assesses major trends that are driving the need for the Air Force to develop and acquire next-generation capabilities for operations in contested and highly contested threat environments.

Chapter 3, "Generate Air Combat Power Forward," addresses concepts and capabilities that would improve the Air Force's ability to generate combat power forward during great power conflict, including dispersing its forces and fielding new capabilities to defeat air and missile threats to U.S. and allied airfields in the Indo-Pacific and Europe.

Chapter 4, "Exploit the Force Multiplying Potential of Current and Future UAS," assesses a number of new and existing unmanned aircraft and concepts for their employment that would help reduce the Air Force's capacity shortfalls as it transitions to a CAF better suited for great power competition and conflict.

Chapter 5, "Prioritize the Development of Other Future Force Multipliers," focuses on new capabilities such as hypersonic weapons, advanced aircraft engines, and multi-domain command and control (MDC2) capabilities that could enhance the combat potential of the Air Force and, potentially, reduce aircraft sortie, weapons, and logistics requirements.

CHAPTER 1

Size the CAF for Great Power Conflict: Capacity Counts

CSBA's 2019 report *An Air Force For An Era of Great Power Competition* assessed major force planning and resource trends that shaped the Air Force's aircraft inventory since the Cold War.[20] This chapter offers additional details regarding significant procurement trends and provides context for assessing initiatives that could better align the Air Force's CAF with the 2018 NDS. The chapter then assesses the CAF's current long-range capacity and recommends force structure changes that would increase its ability to "mass precision at range" by conducting precision strikes deep into contested areas to deny operational sanctuaries to aggressors. Increasing the Air Force's capacity to project power over long ranges would also help reduce the CAF's reliance on theater airbases that are increasingly vulnerable to large-scale Chinese and Russian air and missile attacks.

USAF Force Planning Construct Recommendations

Comparing Major Insights from Three 2019 Air Force Aircraft Inventory Studies

The FY 2018 NDAA directed the Secretary of Defense to "Provide for the performance of three independent studies of alternative aircraft inventories through 2030, and an associated force-sizing construct, for the Air Force."[21] These studies were completed in early 2019 by the Air Force, MITRE Corporation, and CSBA. Although each used a different study methodology, many of their recommendations were identical or nearly so. All three studies concluded the future CAF should be more survivable, lethal, and have greater capacity to operate over longer ranges, especially for operations to defeat Chinese aggression in the Indo-Pacific region. All

20 Gunzinger et al., *An Air Force for An Era of Great Power Competition*. See also "MITRE U.S. Air Force Aircraft Inventory Study Executive Summary."

21 National Defense Authorization Act for Fiscal Year 2018, "Studies on Aircraft Inventories for the Air Force," p. 131 STAT. 1576–1577, available at https://www.congress.gov/115/plaws/publ91/PLAW-115publ91.pdf.

three recommended the Air Force should continue to develop next-generation families of systems for counterair, strike, and other missions rather than revert to traditional platform-centric acquisition approaches to developing the future force. These families of systems should exploit new operating concepts and technologies, including multi-domain command and control operations, manned-unmanned teaming, artificial intelligence, and new weapons suitable for contested threat environments.

Perhaps most importantly, the three studies recommended the Air Force increase the *size* of its force structure. The Air Force and MITRE Corporation based their assessments on a force sizing construct that was derived from the 2018 NDS.[22] The Air Force's study assessed maximum aircraft inventory requirements for both of the two categories of potential force demands labeled "competition" and "war" (see Figure 4). For instance, the "war" category of operations, as illustrated by the right-hand column in Figure 4, includes force structure that may be needed to defend the U.S. homeland, deter nuclear and non-nuclear strategic attack, defeat aggression by one major power such as China or Russia, deter opportunistic aggression in a second theater, and disrupt terrorism and weapons of mass destruction (WMD) threats. The greatest total demand for force structure in either of the two categories determined the number of operational squadrons for various elements (fighters, bombers, missile squadrons, etc.) in the Air Force's proposed 2030 force (see Figure 5).

FIGURE 4: AIR FORCE STUDY FORCE SIZING CONSTRUCT

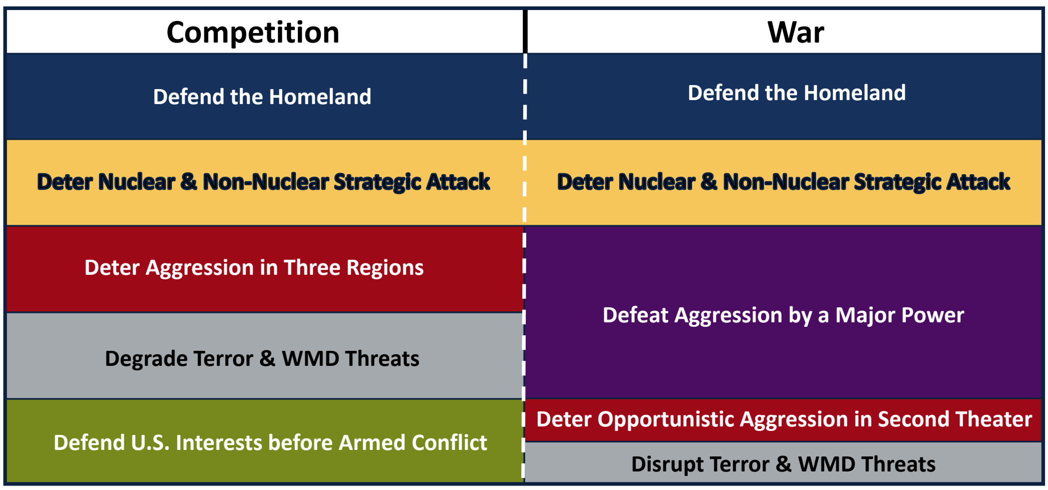


Figure 4 is from the Air Force's unclassified summary of its study. See U.S. Air Force, *Fiscal Year 2018 NDAA Section 1064 Study: Aircraft Inventories for the Air Force*, p. 3.

22 DoD uses a force sizing construct to define the types, number, and frequency of operations the U.S. military should be sized and shaped to support in the future. DoD's force sizing constructs include other major planning assumptions such as personnel rotation guidelines for long-term operations and assumptions for reserve component mobilization timing that impact DoD's capability and capacity requirements.

FIGURE 5: AIR FORCE GRAPHIC ON ITS 2030 "THE AIR FORCE WE NEED"

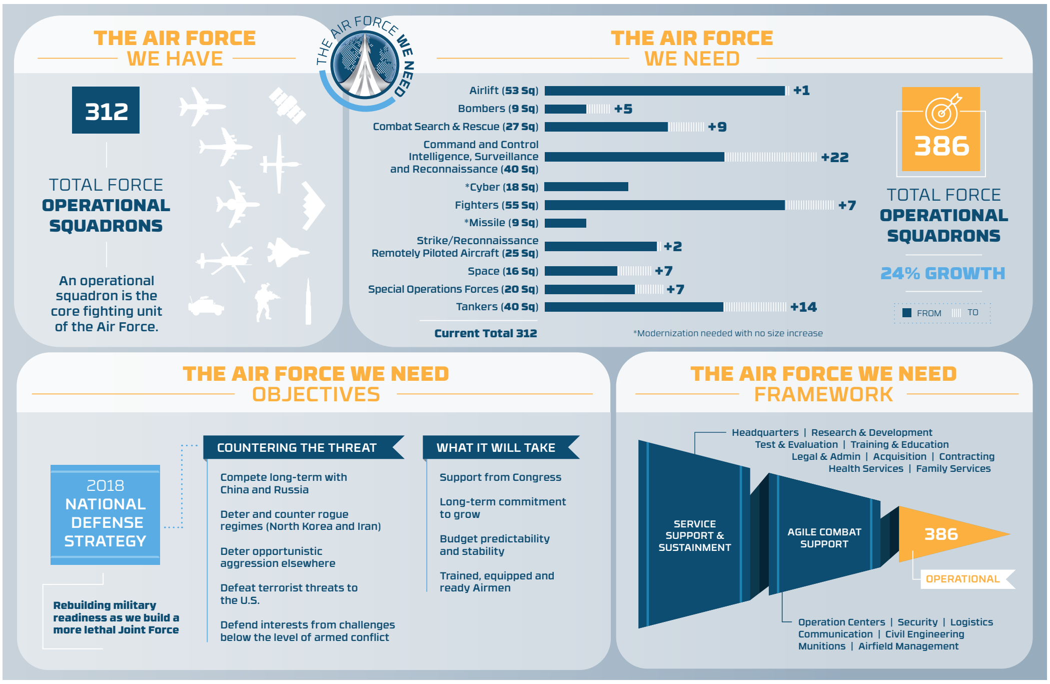


Figure 5 is from the U.S. Air Force's unclassified briefing materials on its inventory study.

CSBA's study recommended a force sizing construct that was similar to the Air Force and MITRE's constructs with the major exception that it recommended sizing and shaping the Service's future forces to defeat aggression by *two* great powers nearly simultaneously while sustaining strategic deterrence and defending the U.S. homeland (see Table 4). This construct is consistent with the National Defense Strategy Commission's recommendation that a DoD "two-war force sizing construct makes more strategic sense today than at any previous point in the post-Cold War era."[23]

23 Edelman and Roughead, *Providing for the Common Defense*, p. 35.

TABLE 4: CSBA'S RECOMMENDED FORCE SIZING CONSTRUCT FOR THE AIR FORCE

Primarily shape and size the force to support these scenarios/mission areas	Description
Sustain strategic deterrence	Includes air forces withheld from overseas deployments to support strategic deterrence during great power conflict
Defend the U.S. homeland	Missions include aerospace control, other air operations to deter or counter aggression against the U.S. homeland, and support to civil authorities in the event of a catastrophic event in the homeland
Conduct operations as part of the Joint Force to defeat major acts of aggression by China and Russia nearly simultaneously	Example force planning scenarios: Conflict to defeat a major Chinese act of aggression in the Indo-Pacific region and conflict with Russia to defend or secure the sovereignty of a NATO ally Note: Major conflict could be preceded by Chinese or Russian gray zone aggression that escalates to high-end warfare
... then assess the resulting force to determine its ability to support the following scenarios/mission areas	**Description**
Conflict with a regional aggressor	Example: Countering aggression by Iran or North Korea
Long-term peacetime competition	Includes a level of effort over time to deter or counter great power aggression in the gray zone that falls short of outright conflict
Counterterror operations	A level of effort to sustain multiple small, widely dispersed counterterror operations that require rotational forces

CSBA's study recommended that the Air Force sustain a credible, secure, and reliable nuclear enterprise of mission-ready bombers, ICBMs, tankers, and other force structure to deter attacks on the United States and its allies. It also recommended the Air Force's aircraft inventory should have sufficient capacity for missions in the U.S. homeland, such as defending its sovereign airspace against unauthorized aircraft and airstrikes, and, in the future, defeating limited cruise missile attacks. Requirements for strategic deterrence and homeland defense should be additive to force capacity needed to defeat great power aggression.

Force capacity for two nearly simultaneous great power conflicts. CSBA's proposed force sizing construct would require the Air Force to organize, train, and equip forces to defeat Chinese and Russian acts of aggression nearly simultaneously. China and Russia are strengthening ties between their militaries and have announced their intent to increase their joint military exercises and training.[24] It is plausible that China might someday be willing to take advantage of a U.S. military deployment to defeat a major act of aggression by Russia to launch a military offensive in another theater, or vice versa. CSBA's recommended force planning construct is also based on the likely character of potential great power conflicts and the forces that U.S. combatant commanders could request to defeat Russian or Chinese aggression. In contrast to the other military Services, the Air Force possesses unique, indispensable capabilities that will be required in both theaters. For example, whereas the

24 See, for example, "China, Russia Pledge to Deepen Military Cooperation," *Xinhua News*, September 5, 2019; and Jeremy Page, "China Promises Further Military Cooperation with Russia," *The Wall Street Journal*, July 24, 2019.

Army will undoubtedly play a major role in a European conflict with Russia, the Navy's role in a conflict that occurs along NATO's eastern frontier may be ancillary. Similarly, the Navy and Marine Corps will play a major role in an Indo-Pacific conflict with China, but the Army will likely not need to provide a commensurate level of forces to support joint operations that occur primarily in the air, sea, and space domains. In other words, the Army's "pacing threat" that will drive most of its future force requirements will likely remain a major hybrid conflict with Russia in Europe.[25] Similarly, the Marine Corps' pacing threat for future force planning should remain future conflict with China.[26] In both theaters, however, Air Force CAF and other forces will be essential. Force planning assessments that assume a major conflict with China and a second conflict with Russia occurring in overlapping timeframes would help the Air Force determine force capacity needed to respond to one conflict and have sufficient forces ready to rapidly deploy to deter or if necessary prevent a second opportunistic great power aggressor from achieving a *fait accompli*.

Other operational challenges shown in the white-colored rows in Table 4 would require force structure to support operations related to long-term great power competition, counter the aggression of lesser regional powers such as Iran or North Korea, and support counterterror operations. In many instances, a two-war Air Force should be able to execute these additional operational requirements. However, in some cases, this assumption may not hold. A force sized for homeland defense, strategic deterrence, and defeating the aggression of two great power aggressors should be tested against these and other potential "lesser included" operational cases since the latter could drive requirements for special operations forces and other niche Air Force capabilities.

Sizing the CAF's Fighter Forces for Great Power Conflict

The Air Force now has 56 fighter squadron equivalents of 21 PMAI aircraft each, which is about half the size of its fighter force at the end of the Cold War. Over the last 25 years, the Air Force has funded multiple modifications, upgrades, and service life extension programs (SLEPs) to sustain its legacy fighters. Upgrades have greatly improved the capabilities of Air Force A-10s, F-15s, and F-16s that were first designed more than 40 years ago. However, it is unlikely that additional modifications would significantly increase their ability to operate in

25 "We see Russia as our pacing threat, if you will. So we look to them in terms of their formations, their tactics or equipment, those things that they would bring to bear against us. But the long-term threat is clearly China." From "And the Army Goes Rolling Along," transcript of an interview with Secretary of the Army Mark T. Esper, Aspen Security Forum, July 21, 2018, available at https://aspensecurityforum.org/wp-content/uploads/2018/08/ASF-2018-And-the-Army-Goes-Rolling-Along.pdf.

26 In answer to a Senate Armed Services Committee question, "What are the key areas in which the Marine Corps must improve to provide the necessary capabilities and capacity to the Joint Force to prevail in a potential conflict with Russia?" General Berger responded, the "same basic answer applies to the one we provided for China because capabilities designed for the pacing threat will address all lesser included actors, including Russia." "Senate Armed Service Committee Advance Policy Questions for Lieutenant General David Berger, USMC Nominee for Appointment to the Grade of General and to be Commandant of the Marine Corps," April 30, 2019, available at https://www.armed-services.senate.gov/imo/media/doc/Berger_APQs_04-30-19.pdf.

contested environments. Even newly manufactured, so-called 4th generation-plus variants of legacy fighter designs will lack the degree of survivability needed to operate in future threat environments without the risk of suffering significant attrition. In aggregate, the Air Force's current fighter force lacks the capacity and degree of survivability that would be needed in future high-end conflicts with China or Russia.

All three 2018 NDAA Section 1064 independent aircraft inventory studies concluded the Air Force must increase the size of its fighter force and pursue next-generation systems to support the 2018 National Defense Strategy (see Table 5). The Air Force concluded it should grow its fighter force to 62 squadrons over the next decade based on the "expected threats and warfighting challenges it assessed in the years 2025 through 2030."[27] Although more specific recommendations were not included in the Air Force's unclassified study summary, Table 5 lists several initiatives in its FY 2020 budget request that would help place it on the path toward its objective, "The Air Force We Need." MITRE, in its study, explicitly recommended the Air Force continue to ramp-up F-35A production and pursue a variant of the Service's future T-X trainer aircraft for homeland defense, light strike, and possibly other missions. MITRE also recommended the Air Force allocate additional resources to increase the mission capable rates of its current fighters to 80 percent, which would have the net effect of increasing its fighter capacity in the near term.

TABLE 5: FIGHTER FORCE RECOMMENDATIONS FROM THREE INDEPENDENT STUDIES ON THE AIR FORCE'S FUTURE AIRCRAFT INVENTORY

	The Air Force's "The Air Force We Need"	MITRE Corporation	Center for Strategic and Budgetary Assessments
Pacing threat	• Major conflict with China	• Major conflict with China	• Major conflicts with China and Russia
Future fighter force size	• 62 fighter squadrons (+7 squadrons increase from 55 squadrons in 2019)	• Generally consistent with the Air Force's force size recommendation • Should include 15 squadrons of a T-X trainer armed variant to supplement the homeland defense mission after 2030	• 65 fighter squadrons (+10 squadrons, about +210 PMAI)
New Acquisition	Note: based on the FY20 budget • 48 F-35A in FY20 • Develop a Next Generation Air Dominance (NGAD) aircraft as part of a family of systems for counterair • Attritable UAS that team with manned aircraft for counterair and other missions	• F-35A procurement as planned by the Air Force up to 54 per year • Do not reduce F-35A procurement to pay for other force modernization • Procure enough next-generation F-15s to completely replace aging F-15C/Ds • Procure about 400 T-X trainer variants for homeland defense and foreign sales, most would come after 2030	• Procure up to 70 F-35A per year • Develop and procure PCA/PEA (NGAD) as part of a future counterair family of systems as soon as feasible • Procure armed variant of the T-X trainer to support homeland defense operations and foreign sales
Retirements	• None specified in the Air Force's unclassified report	• Retire a mix of A-10Cs and F-16C/D at the rate of F-35A deliveries • Retire non-re-winged A-10s and oldest F-16C/Ds first • Retire aging F-15C/Ds	• Retire F-15C/Ds as planned, consider using some F-35As for counterair missions • Reduce A-10 force to 208 TAI by 2030, do not procure a direct A-10 replacement • Retire F-16s as F-35As replace them

27 U.S. Air Force, *Fiscal Year 2018 NDAA Section 1064 Study: Aircraft Inventories for the Air Force*, p. 4.

CSBA recommended that the Air Force should have about 65 operational fighter squadrons in its future (2035-plus) force, three more squadrons than USAF's "The Air Force We Need." Table 6 summarizes CSBA's recommendations through 2030 for the Air Force's fighter inventories. **The inventories in Table 6 are a waypoint to CSBA's proposed future force, not a recommended end state.** Overall, CSBA recommended the Air Force fund a more aggressive F-35A acquisition profile over the next decade compared to both MITRE and the Air Force's acquisition profile. Procuring F-35As at a faster rate would accelerate the fielding of a 5th generation CAF and reduce overlap with programs to acquire other new Air Force weapon systems, including B-21 bombers. Additional F-35As could also help fill the gap in the Air Force's air superiority forces caused by its planned retirement of F-15C/D fighters in the 2020s.[28] Ultimately, a future family of capabilities for counterair, which should include a multi-mission PCA/PEA aircraft, will be needed to ensure the Air Force can achieve the degree of air superiority required to support the joint force in operations against great power aggressors.

TABLE 6: A WAYPOINT TO THE FUTURE (2035-PLUS) CAF: SIZING THE FIGHTER FORCE THROUGH 2030 (TOTAL ACTIVE INVENTORY)

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
A-10	281	281	251	221	208	208	208	208	208	208	208	208
F-16 (illustrative drawdown)	935	915	895	875	845	815	785	755	715	685	655	625
F-15C/D (illustrative drawdown)	234	200	170	140	110	80	50	25	0	0	0	0
F-15E	218	218	218	218	218	218	218	218	218	218	218	218
F-22A	186	186	186	186	186	186	186	186	186	186	186	186
F-35A	171	221	281	351	421	491	561	631	701	771	841	911
PCA/PEA (notional ramp)	0	0	0	0	0	2	4	8	16	24	36	50
Total	**2,025**	**2,021**	**2,001**	**1,991**	**1,988**	**2,000**	**2,012**	**2,031**	**2,044**	**2,092**	**2,144**	**2,198**

Increase the CAF's Capability to Mass Precision from Range

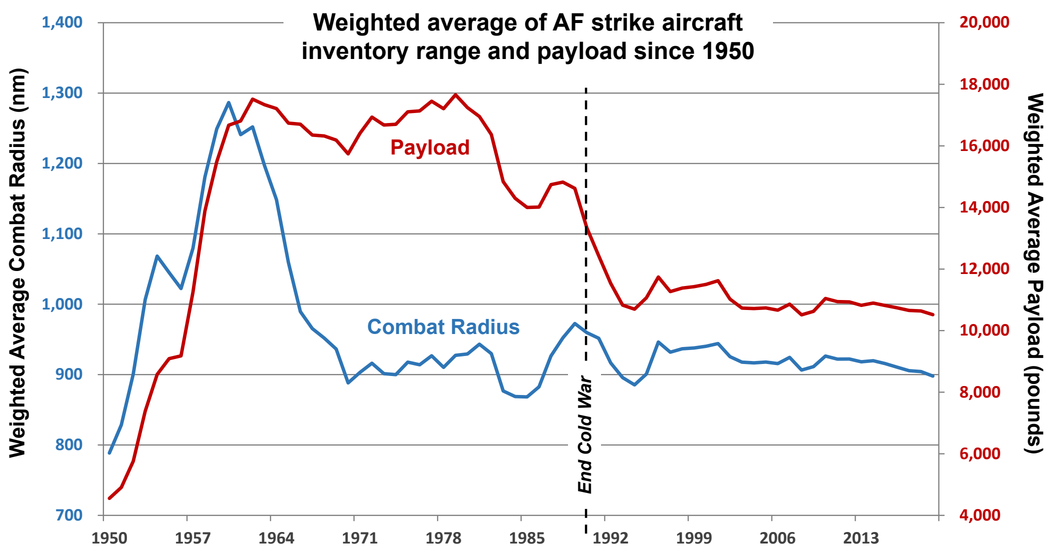
The ability to strike a large number of targets located throughout a battlespace and deep into an adversary's territory as necessary with precision is a core U.S. Air Force mission.[29]

28 Due to DoD's decision to cap F-22 procurement at 187 aircraft, F-15C/Ds have remained in the force far longer than originally planned. This has led to significant issues with the aircraft's sustainability. Jeremiah Gertler, "Defense's 30-Year Aircraft Plan Reveals New Details," *In Focus*, Congressional Research Service, October 9, 2018, available at https://fas.org/sgp/crs/weapons/IF10999.pdf.

29 The Air Force's core missions are air and space superiority; global strike; intelligence, surveillance, and reconnaissance; rapid global mobility; and command and control. The Air Force's vision is to maintain a global strike force capable of "holding any target on the planet at risk and, if necessary, disabling or destroying it promptly—even from bases in the continental United States." "Global strike missions include a wide range of crisis response and escalation control options, such as providing close air support to troops at risk, interdicting enemy forces, inserting special operations forces, and targeting an adversary's vital centers." U.S. Air Force, *Global Vigilance, Global Reach, Global Power for America* (Washington, DC: U.S. Air Force, 2015), p. 8, available at https://www.af.mil/Portals/1/documents/af%20events/2015/newGV_GR_GP_PRINT.pdf.

Since the Cold War, improvements in the Air Force's ability to mass precision effects over long ranges have been the result of what has been called the revolution in precision strike. As assessed in CSBA's report, *Sustaining America's Precision Strike Advantage,* the advent of precision-guided munitions (PGMs) "changed the way America prefers to conduct strike operations."[30] The report also addresses reasons why the Air Force decided to shift the weight of its combat aircraft force mix toward shorter-range, smaller-payload capacity fighters in the aftermath of the Cold War (see Figure 6). These reasons included assumptions that U.S. forces could quickly deploy large numbers of fighters to distant theaters at the start of a regional conflict and that there would continue to be few threats to U.S. fighter bases located close to regional aggressors such as Iran and North Korea. For its future force planning purposes, DoD also adopted overarching operating concepts for theater wars similar to those used during Operation Desert Storm in 1991. These planning assumptions and concepts reduced the need to use long-range, large-payload bombers to attack target sets after U.S. fighter forces completed their deployments into a theater within a few weeks. Most of these assumptions and concepts are no longer valid given emerging threat environments and DoD's strategic shift toward preparing to defeat great power aggression in Europe and across the vast expanse of the Indo-Pacific theater, rather than lesser regional militaries.[31]

FIGURE 6: TRENDS IN CAF STRIKE INVENTORY AND TOTAL PAYLOAD CAPACITY



30 Mark Gunzinger and Bryan Clark, *Sustaining America's Precision Strike Advantage* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015).

31 For more in-depth analysis of DoD and Air Force post-Cold War force planning assumptions, see Mark Gunzinger, Bryan Clark, David Johnson, and Jesse Sloman, *Force Planning for the Era of Great Power Competition* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

Grow the size of the U.S. bomber force. All three independent studies recommended the Air Force should grow the size of its bomber force to support the 2018 NDS. The Air Force concluded it should increase its bomber force from 9 to 14 squadrons over the next decade. In a conflict against China, the large payload capacities of penetrating B-2, B-21, and non-stealth bombers would help compensate for reduced sortie rates resulting from operating across the great distances of the Indo-Pacific region. A force mix rebalanced toward bombers that can fly thousands of miles unrefueled would also reduce the CAF's overall requirements for aerial refueling capacity. High-volume penetrating and standoff bomber strikes could also help blunt a Russian invasion of a NATO ally and fill shortfalls in joint fires capacity until U.S. surge forces can arrive in theater. Overall, a larger force of penetrating bombers with long endurance and large weapon payloads would increase the Air Force's capacity to persist in the battlespace and launch strikes against emergent mobile or relocatable targets such as mechanized ground forces, missile TELs, and ground-based IADS. Long-range, low-observable B-21 bombers capable of penetrating a battlespace from multiple aspects could also impose costs on an adversary by forcing it to defend in-depth, rather than focus its defenses on a few air avenues of approach along its periphery.

Table 7 compares future bomber force recommendations from all three Air Force aircraft inventory studies directed by the 2018 NDAA. The Commander of the Air Force's Global Strike Command has said the Air Force would need about 225 total bombers to support the 2018 NDS.[32] This could require the Air Force to procure about 150 new bombers, assuming it still plans to keep its B-52Hs in the force until approximately 2050, and retire its B-1 and B-2 bombers as B-21s replace them.[33] The MITRE Corporation's recommendations are generally consistent with the Air Force's bomber vector, with the possible exception that it also recommended the Air Force not retire any of its legacy (B-2, B-1, and B-52) bombers "until there are at least 50 operational B-21 bombers in the inventory in the mid-2030s."[34]

32 Colin Clark, "More B-21s Likely; B-1s to Carry Up to 8 Hypersonic Weapons," *Breaking Defense*, September 17, 2019.

33 "Once sufficient B-21 aircraft are operational, the B-1s and B-2s will be incrementally retired. Delivery and retirement timelines are dependent on the B-21 production and delivery schedules." Secretary of the Air Force for Public Affairs, "Air Force Outlines Future of Bomber Force," February 12, 2018, available at https://www.af.mil/News/Article-Display/Article/1438634/air-force-outlines-future-of-bomber-force/.

34 "MITRE U.S. Air Force Aircraft Inventory Study Executive Summary," p. 7.

TABLE 7: BOMBER FORCE RECOMMENDATIONS FROM THREE INDEPENDENT STUDIES ON THE AIR FORCE'S FUTURE AIRCRAFT INVENTORY

	The Air Force's "The Air Force We Need"	MITRE Corporation	Center for Strategic and Budgetary Assessments
Pacing threat	• Major conflict with China	• Major conflict with China	• Major conflicts with China and Russia
Key long-range strike recommendations	• Require a larger proportional increase for bombers and other long-range capabilities	• Shift toward long-range operations/ use of distant airbases • Priority = bombers and bomber basing	• The Air Force should rebalance its CAF in favor of long-range penetrating bombers
Future bomber force size	• 14 bomber squadrons (increase from current 9 squadrons) • Retire B-1s starting in the early 2020s • Retire B-2s as they are replaced by B-21s	• Similar recommendation to the Air Force, but keep the B-2 into the 2030s and do not retire B-1Bs until about 50 B-21s are operational • Increase mission capable rates of legacy bombers	• 24 bomber squadrons (383 Total Aircraft Inventory)
B-21 acquisition	• Procure a future force of more than 100 B-21s	• Accelerate production if possible, increase planned buy beyond 100 aircraft	• If possible, accelerate production to 5 to 10 aircraft per year by late 2020s and increase total planned buy

CSBA's study recommended the Air Force grow its bomber capacity to support the force sizing construct in Table 4. This could require a future force of 383 TAI bombers in the future (2035-plus) force consisting of 20 B-2, 75 B-52H, and 288 B-21 bombers, which translates to a force of 266 Primary Mission Aircraft Inventory (PMAI) bombers that are fully resourced to support operations. The notional 2030 inventory in Table 8 is a waypoint toward this future force.

TABLE 8: A WAYPOINT TO THE FUTURE (2035-PLUS) CAF: SIZING THE BOMBER FORCE THROUGH 2030 (TOTAL ACTIVE INVENTORY)

	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
B-21 (assumes increased annual procurement rates)	0	0	0	0	0	3	6	11	16	21	29	37
B-1B with an illustrative retirement schedule	62	62	62	62	62	62	62	62	62	57	52	42
B-2	20	20	20	20	20	20	20	20	20	20	20	20
B-52H	75	75	75	75	75	75	75	75	75	75	75	75
Total	**157**	**157**	**157**	**157**	**157**	**160**	**163**	**168**	**173**	**173**	**176**	**174**

Assuming annual B-21 production can ramp to a range between five and ten aircraft per year by the late 2020s, a total of 37 TAI B-21s could be in the force by 2030. The B-2 will remain the Air Force's only means to deliver large weapons by air over long ranges to defeat hard and deeply buried targets in contested areas until significant numbers of B-21s become operational sometime in the 2030s. Both B-2s and B-52Hs will constitute the airbreathing leg of the nuclear triad until B-21s are certified as nuclear-capable. As shown in Table 8, the Air Force should gradually retire its B-1Bs as new B-21s join the force. While B-1Bs have been a workhorse in overseas contingency operations over the last decade, they cannot penetrate contested or highly contested environments. However, B-1B retirements should occur on a schedule that would not increase DoD's existing shortfalls in long-range strike capacity.

Rebuilding the Air Force's Capacity for Maritime Strike

The Air Force's capacity to support the joint maritime fight has generally increased or decreased depending on the nature of emerging naval threats.[35] In the early part of the post-Cold War period, there was little need for USAF airpower to conduct maritime dominance operations. Given that the PLA Navy is maturing its surface navy and fielding the means to launch anti-ship attacks at sea and from the shore, there is a growing need for land-based airpower to conduct maritime strike operations. Air Force bombers that can carry large payloads of AGM-158C Long Range Anti-Ship Missiles (LRASMs) could degrade Chinese naval forces operating inside the First Island Chain and attrite Chinese forces attempting an amphibious invasion of Taiwan and other areas China claims as its sovereign territory.[36] The Air Force should acquire a significant number of LRASMs for future maritime strike missions and plan to integrate them on its B-2s and, eventually, B-21 bombers to hold at risk PLA Navy ships operating in contested areas.

FIGURE 7: QUICKSTRIKE ER WITH TAILFINS TO EXTEND ITS RANGE

Source: https://www.thedrive.com/the-war-zone/23705/b-52-tested-2000lb-quickstrike-er-winged-standoff-naval-mines-during-valiant-shield

35 David A. Deptula, *Bombers for Maritime Strike: An Asymmetric Counter to China's Navy* (Arlington, VA: Mitchell Institute for Aerospace Studies, February 2019), available at http://www.mitchellaerospacepower.org/maritimestrike.

36 Ibid; Thomas G. Mahnken, Travis Sharp, Billy Fabian, and Peter Kouretsos, *Tightening the Chain: Implementing a Strategy of Maritime Pressure in the Western Pacific* (Washington, DC: Center for Strategic and Budgetary Assessments, 2019), pp. 66–67.

There are emerging requirements for additional naval mining capacity that could help reduce the freedom of action of Chinese or Russian naval forces in a future conflict. Quickstrike ER mines and potential variants carried by Air Force stealth bombers could greatly increase the joint force's capacity in the near term to deny critical maritime areas to enemy navies.[37] The Quickstrike ER is a modified general-purpose bomb with tailfins that increase its glide range after release from an aircraft (see Figure 7). It may be possible to add jet engines to air-launched mines to further extend their range and help keep the aircraft launching them outside the lethal radius of some enemy defensive systems.[38]

Summary

After decades of force structure cuts and deferred or canceled modernization programs, the Air Force's CAF has reached a point where it lacks the capacity needed to support the National Defense Strategy. Modest growth in the size of the Air Force's fighter fleet could be achieved by accelerating F-35A procurement over the next decade and developing a multi-mission PCA/PEA aircraft and other next-generation capabilities. As it grows its combat capacity, the Air Force should rebalance its CAF in favor of penetrating bombers that can deliver large payloads of weapons on targets in contested and highly contested areas. Increasing the size of the nation's bomber force over the long term is one of the most significant findings of the congressionally directed studies led by the Air Force, MITRE, and CSBA. Although some legacy CAF aircraft should be retired over the next decade, the Air Force should carefully balance the value of reducing its current capacity for long-range strike to achieve near-term savings with the additional risk this could create until new B-21s join the force. In the interim, the Air Force should continue to acquire long-range strike munitions, such as JASSM-ERs and its variants, and pre-position them in storage facilities that are hardened against enemy attacks in theater locations that will ensure they are immediately available to support combat operations. Increasing the size of the CAF without ensuring new aircraft will have adequate weapons to deliver them would be a step toward a hollow force. Finally, the Air Force should regenerate its ability to conduct maritime denial operations. A future CAF capable of conducting anti-ship strikes and offensive mining missions could greatly improve the joint force's ability to deny freedom of action to China's and Russia's navies and prevent them from supporting operations to achieve a rapid *fait accompli*.[39]

37 Quickstrike-ER munitions could give B-52 bombers the "unprecedented ability to lay down entire minefields over wide areas, in a single pass, with pinpoint accuracy, and all while standing-off at over 40 miles away." Tyler Rogoway, "B-52 Tested 2,000lb Quickstrike-ER Winged Stand-off Naval Mines During Valiant Shield," *The War Zone*, September 20, 2018, available at https://www.thedrive.com/the-war-zone/23705/b-52-tested-2000lb-quickstrike-er-winged-standoff-naval-mines-during-valiant-shield.

38 Michael W Pietrucha, "Twenty-First Century Aerial Mining," *Air & Space Power Journal*, March-April 2015, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a617836.pdf.

39 Mahnken, Sharp, Fabian, Kouretsos, *Tightening the Chain*.

CHAPTER 2

Create a More Survivable CAF

Chapter 2 assesses examples of major trends that are driving the need to increase the survivability of the Air Force's CAF. The chapter begins by highlighting some of the key developments in Russian and Chinese weapons systems that threaten to erode America's airpower advantage. It then addresses the suitability of the current CAF to operate in future contested environments. A final section summarizes how emerging threats should inform the Air Force's development of CAF weapon systems capable of supporting operations in a high-end great power conflict. The future CAF should include major new capabilities such as a Penetrating Counter Air/Penetrating Electronic Attack aircraft (also called a Next Generation Air Dominance or NGAD aircraft), penetrating UAS for ISR, and a force of penetrating B-21 bombers.

The Evolving Threat Environment

The future CAF should be prepared to operate in areas covered by advanced IADS that China, Russia, and others have created to contest U.S. air superiority and increase freedom of maneuver for their own air, land, and maritime forces. More than a network of surface-to-air missile launchers, an IADS is a composite of air and missile defense systems that includes active and passive sensors, weapons, battle management networks, and associated personnel and infrastructure.[40] Although they vary in their configuration and effectiveness, the most capable IADS create dense, overlapping networks of surface-to-air and air-to-air threats that are highly mobile and use measures such as passive sensing, camouflage and deception, and electronic warfare to reduce their risk of being detected and engaged. In such highly contested environments, the CAF should be prepared to continuously counter threats from multiple domains.

40 Joint Chiefs of Staff (JCS), *Countering Air and Missile Threats*, Joint Publication 3-01 (Washington, DC: JCS, April 21, 2017), p.IV-7; and Peter W. Mattes, *System of Systems: What, Exactly, is an Integrated Air Defense System?* (Arlington, VA: Mitchell Institute for Aerospace Studies, June 2019), available at http://www.mitchellaerospacepower.org/iads.

Advanced Integrated Air Defense Systems

Russia and China are improving the sophistication, coverage, and density of their IADS. For instance, once integrated with the 40N6 long-range missile, Russian S-400 SAM systems may have engagement ranges of up to 400 km against non-stealth aerodynamic targets and be capable of intercepting ballistic missiles traveling at speeds of up to Mach 16.[41] Whereas the 40N6 missile is designed to hold high-value targets at risk at very long ranges, S-400 systems are capable of launching a multitude of different SAMs including the medium-range Russian 48N6 and short-range 9M96 families of missiles that are cheaper and can better maneuver to intercept agile targets such as fighter aircraft and cruise missiles.[42] Coupled with a 92N6 Grave Stone target engagement radar, a single S-400 battery may be capable of engaging up to ten targets simultaneously, launching two missiles per target to increase the probability of successful engagements.[43] Beyond greater lethality, advanced SAMs such as the S-400 have built-in redundancy and are designed to be integrated into larger, overlapping, and layered air defense networks to improve their effectiveness and survivability.

Layered ground-based air defenses of the kind developed by China and Russia incorporate multiple weapon systems that are optimized to defeat various types of threats and help offset any particular system's weaknesses. Layered defenses include multiple SAM batteries of different classes that create overlapping fire zones, which can be controlled by a single battle management complex that prioritizes threats, deconflicts potential target engagements, and calculates optimal firing solutions.[44] Shorter-range systems supplement limited inventories of strategic SAMs and free them to concentrate on engaging high-value air targets over long ranges. Russian tactical SAMs tasked with protecting maneuver forces can also help fill gaps in the larger air defense network.[45] Chinese and Russian advanced IADS are more resilient to counterattacks compared to the threat systems U.S. air forces encountered during conflicts with lesser adversaries over the last 25 years. Russian S-400 SAMs typically deploy with the Pantsir self-propelled anti-aircraft gun and missile system that is optimized to engage incoming bombs, anti-radiation missiles, UAS, cruise missiles, and other threats.[46] Modern Chinese and Russian air defenses are highly mobile, allowing them to quickly reposition to create an optimum network as conditions in the battlespace evolve. Critical system

41 Sean O'Connor and Jon Hawkes, "The S-300P and S-400: Russia's Strategic Defenders," *Jane's by IHS Markit* briefing, April 5, 2018.

42 Justin Bronk, *Next Generation Combat Aircraft: Threat Outlook and Potential Solutions* (London: Royal United Services Institute, November 2018), p. 8, available at https://rusi.org/sites/default/files/20181101_next_generation_combat_aircraft_web.pdf.

43 Sean O'Connor, Konrad Muzyka, and Huw Williams, "Analysing Russia's SAM Capabilities: Deployments, Capabilities, and Future Prospects," *Jane's by IHS Markit* briefing, August 31, 2017.

44 O'Connor and Hawkes, "The S-300P and S-400."

45 O'Connor, Muzyka, and Williams, "Analysing Russia's SAM Capabilities."

46 Defense Intelligence Agency (DIA), *Russia Military Power: Building a Military to Support Great Power Aspirations* (Washington, DC: DIA, 2017), p. 80, available at https://www.dia.mil/portals/27/documents/news/military%20power%20publications/russia%20military%20power%20report%202017.pdf.

components including missile transporter erector launchers (TELs), radar units, and support vehicles that can relocate within minutes enable "shoot and scoot" tactics to reduce their vulnerability to counterattacks, particularly to U.S. strikes that use weapons with longer flight times.

China and Russia place considerable emphasis on electronic warfare (EW) measures to degrade the effectiveness of U.S. sensors, datalinks, and precision-guided weapons. To complicate detection and targeting by U.S. sensor networks, Chinese and Russian air defense units can utilize a combination of countermeasures such as jammers to interfere with radars and radios, visual and emitting decoys to produce false targets, and camouflage to obscure potential targets.[47] Chinese and Russian advanced air defense radar units are digital and can use frequency hopping to frustrate an enemy's signal analysis-based jamming and direction-finding techniques.[48] Modern communication mediums and networks also provide redundancy and the passage of data irrespective of a unit's echelon or span of control, preventing air defense units from being isolated from the rest of their networks.[49] Conversely, lower echelon air defense units have organic sensors to detect and cue threat engagements independent of centralized, integrated C2 networks. Collectively, these capabilities reduce the ability of an enemy to attack weak links in an IADS.

Advances in Threat Sensors and Post-Processing Capabilities

Russian and Chinese IADS include networks of ground-based, airborne, maritime, and space-based multi-phenomenology sensor and communication systems that improve the range, density, and sophistication of their surveillance operations. Advances in sensor resolution, post-processing power, data storage capacity, and fusing information from sensors in multiple domains have improved their ability to locate, track, and engage airborne threats.[50] Both Russia and China exploit the strategic depth of their home territory to create sensor and communication networks that enable them to engage U.S. forces before they can do the same.[51] Operating from their own territory reduces constraints on the size, weight, and power generation capabilities of their sensor networks compared to U.S. sensor networks that must deploy to a fight. Taking advantage of their recent successful gray zone operations, Russia is deploying sensors and weapons in Crimea, and China has deployed sensors and weapons on

47 For more information, see Mark Gunzinger and Bryan Clark, *Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses* (Washington, DC: Center for Strategic and Budgetary Assessments, 2016).

48 Bronk, *Next Generation Combat Aircraft*, p. 7.

49 Mattes, *System of Systems*, p. 8.

50 Justin Bronk, "Technological Trends," in Peter Roberts, ed., *The Future Conflict Operating Environment Out to 2030* (London: Royal United Services Institute, June 2019), available at https://rusi.org/sites/default/files/201906_op_future_operating_enviroment_web.pdf.

51 For more information, see Bryan Clark and Mark Gunzinger, *Winning the Airwaves: Regaining America's Dominance in the Electromagnetic Spectrum* (Washington, DC: Center for Strategic and Budgetary Assessments, 2017).

islands it has occupied or created in the South China Sea.[52] Both are simultaneously pursuing a variety of early warning and control aircraft, UAS, aerostats, and balloons that will better detect low-altitude airborne targets at standoff distances.[53]

Advanced digital signal processing and the introduction of active electronically scanned array (AESA) radar technologies have significantly improved the detection range and resolution of Chinese and Russian radars that operate in lower frequency bands.[54] Combined with passive sensors and other technologies discussed below, radars that operate in lower frequency bands could improve China and Russia's ability to detect some low-observable aircraft designs.[55] Due to their poor resolution and other limitations, earlier generation low-frequency radars could not develop target quality tracks. However, advances in signal processing have enabled pulse compression techniques that improve the range resolution of low-frequency radars, and the introduction of AESA technologies have improved their directional resolution.[56] Russia and China have incorporated low-frequency AESA radars on AEWC aircraft and ground-based systems such as the Russian Nebo-M and the Chinese JY-27A.[57] These capabilities could improve the ability of Chinese and Russian defenses to vector intercept fighters to a threat aircraft's location, cue higher frequency fire-control radars, or provide mid-course guidance updates to surface-to-air missiles after launch without losing a threat track (see Figure 8).[58] These systems also leverage low probability of intercept/low probability of detection (LPI/LPD) waveforms and electronic protection capabilities to reduce the effectiveness of U.S. electronic detection and jamming techniques.[59]

52 "Chinese Power Projection Capabilities in the South China Sea," Asia Maritime Transparency Initiative, Center for Strategic and International Studies, available at https://amti.csis.org/chinese-power-projection/; and Masao Dahlgren, "Russia Plans Early Warning Radar in Crimea by 2020," Missile Threat, Center for Strategic and International Studies, June 26, 2019, available at https://missilethreat.csis.org/russia-plans-early-warning-radar-in-crimea-by-2020/.

53 Vladimir Karnozov, "Russia's Next-gen A-100 AWACS Begins Acceptance Trials," *Aviation International News*, February 12, 2019, available at https://www.ainonline.com/aviation-news/defense/2019-02-12/russias-next-gen-100-awacs-begins-acceptance-trials; Mike Yeo, "China Ramps Up Production of New Airborne Early Warning Aircraft," *Defense News*, February 5, 2018; and Elsa Kania, *The PLA's Unmanned Aerial Systems: New Capabilities for a "New Era" of Chinese Military Power* (Montgomery, AL: China Aerospace Studies Institute, 2018), available at https://www.airuniversity.af.edu/Portals/10/CASI/Books/PLAs_Unmanned_Aerial_Systems.pdf.

54 Dan Katz, "Physics and Progress of Low-Frequency Counterstealth Technology," *Aviation Week & Space Technology*, August 25, 2016.

55 Arend G. Westra, "Radar versus Stealth: Passive Radar and the Future of U.S. Military Power," *Joint Forces Quarterly* 55, 2009.

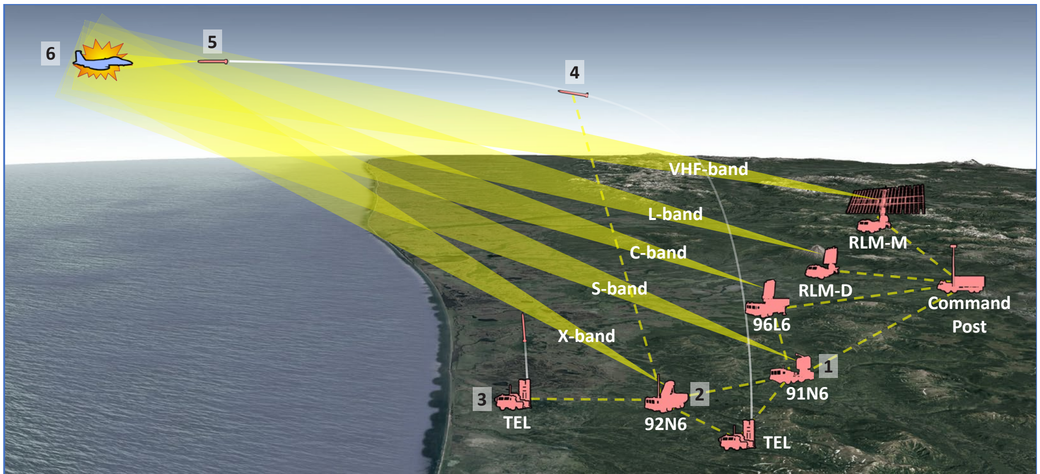
56 DIA, *China Military Power: Modernizing a Force to Fight and Win* (Washington, DC: DIA, 2019), p. 86. AESA radars offer other advantages including near instantaneous target updates, advanced radar modes, large search volumes, and the ability to stare at a target or track multiple targets simultaneously.

57 Carlo Kopp, "NNIIRT 1L119 Nebo SVU / RLM-M Nebo M: Assessing Russia's First Mobile VHF AESAs," *Air Power Australia*, updated October 2012, available at https://www.ausairpower.net/APA-Nebo-SVU-Analysis.html; Sean O'Connor, "China Expands Deployment of JY-27A Anti-stealth Radar Systems," *Jane's Defence Weekly*, May 28, 2019; and Nikolai Novichkow, "Phazotron-NIIR Readies New AESA Radar for Russian Fighter Trials," *Jane's International Defence Review*, November 20, 2018. Russia and China are equipping fighters with higher-frequency AESA radars.

58 Katz, "Physics and Progress of Low-Frequency Counterstealth Technology."

59 Mark Barrett and Mace Carpenter, *Survivability in the Digital Age: The Imperative for Stealth* (Arlington, VA: Mitchell Institute for Aerospace Studies, July 2017).

FIGURE 8: ILLUSTRATING THE INTEGRATED USE OF LOW-FREQUENCY RADARS TO DETECT AND CUE AN AIR INTERCEPT



1. 91N6 'Big Bird' target acquisition and battle management radar generates target track/receives data from early warning sensors such as the multi-wavelength 55Zh6M Nebo-M surveillance radar system (RLM-M VHF-band; RLM-D L-band), and 96L6 battery-level C-band target acquisition radar
2. 92N6 'Grave Stone' target engagement radar locks on and tracks potential target, performs identification friend or foe (IFF) interrogation
3. Two missiles launched from TELs against a verified target
4. Missiles receive initial guidance and midcourse updates via command link
5. Missiles use own seekers and external updates for endgame guidance
6. 92N6 performs damage assessment and cues target reengagement if necessary

Russia and China also leverage their knowledge of local environments to exploit multi-static passive detection techniques. Passive listening systems triangulate the location of emitters using multiple passive electronic support measures (ESM) arrays.[60] Such systems typically consist of a central site containing signal processing equipment and an ESM receiver as well as at least two additional sites with ESM receivers that relay the signals they receive to a central site to triangulate the location of potential targets. Examples of such systems include the Russian Moskva-1, the Chinese DWL-002, and the Czech Vera-NG.[61] Similar to lower frequency radars, the modular nature of Russian and Chinese air defense C2 systems allow for the integration of information from passive systems to facilitate target engagements.[62]

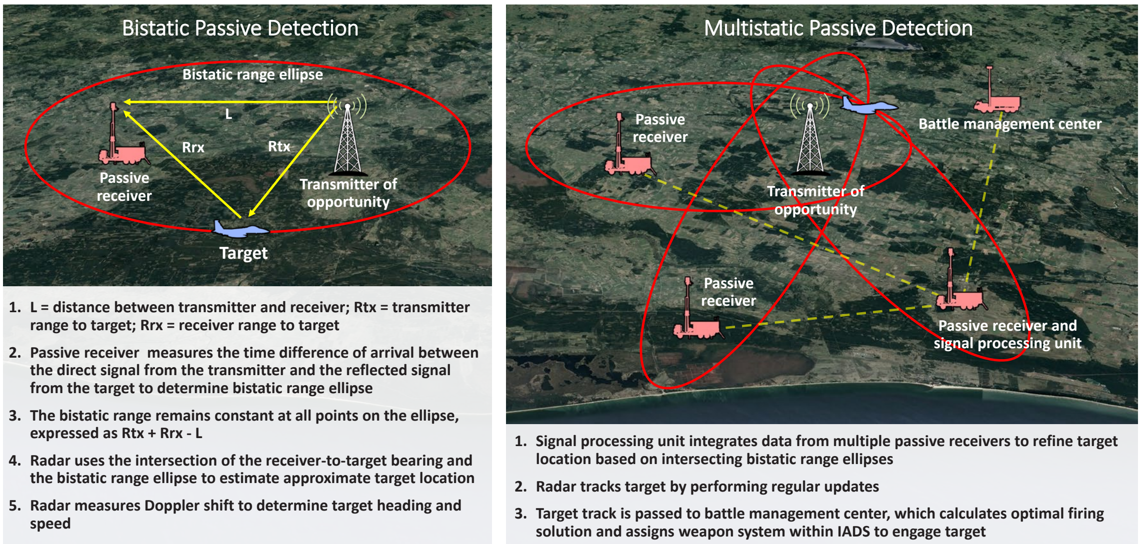
60 Dimitrios Oikonomou, Panagiotis Nomikos, George Limnaios, and Konstantinos Zikidis, "Passive Radars and Their Use in the Modern Battlefield," *Journal of Computations & Modeling* 9, no. 2, 2019.

61 Mark Cazalet and Samuel Cranny-Evans, "All Quiet on the Eastern Front: EW in Russia's New Generation Warfare," *Jane's International Defence Review*, February 28, 2018; and Ankit Panda, "How Effective is China's New Anti-Stealth Radar System, Really?" *The Diplomat*, October 6, 2014, available at https://thediplomat.com/2014/10/how-effective-is-chinas-new-anti-stealth-radar-system-really/.

62 Bronk, *Next Generation Combat Aircraft*, pp. 8-9; and Carlo Kopp, "Warsaw Pact/Russian/PLA Emitter Location Systems/ELINT Systems," *Air Power Australia*, May 2008, updated April 2012, available at http://www.ausairpower.net/APA-Warpac-Rus-PLA-ESM.html#mozTocId286118.

Using passive EM receivers to detect ambient electronic energy emanating from non-cooperative transmitters of opportunity that is reflected off target aircraft is another emerging approach (see Figure 9).[63] Advances in hardware, computer processing, and improved models of the local electromagnetic spectrum and meteorological environments can improve the ability of an enemy to integrate data from different passive receivers, cancel signal interference, differentiate faint signals from ghost returns, and establish a track on a potential target suitable to launch an intercept.[64] Such passive sensors would complicate U.S. efforts to detect, jam, target with anti-radiation weapons, and otherwise suppress IADS threats.

FIGURE 9: ILLUSTRATING PASSIVE COHERENT LOCATION OF AIRCRAFT



Adapted from Westra, "Radar versus Stealth," pp. 139–140.

Passive airborne sensors are also being rapidly developed and fielded to complement and, in some instances, displace complex active systems like airborne radar. For example, China and Russia are investing in passive infrared search and track (IRST) sensors that have super-cooled lenses that detect thermal radiation emitted from aircraft, particularly from their engines, exhaust plumes, and aircraft skin due to flying at high speeds through the atmosphere.[65] Both countries have experience building IRST sensors and related airborne data networking capabilities. They have also sought to develop long-wave IRST systems that have the ability to detect faint thermal signals over extended ranges. The performance of early

63 J.R. Wilson, "New Frontiers in Passive Radar and Sonar," *Military & Aerospace Electronics*, February 8, 2016, available at https://www.militaryaerospace.com/communications/article/16709052/new-frontiers-in-passive-radar-and-sonar. In multi-static systems, radars determine target locations based on intersecting bistatic range ellipses, and measure Doppler shift to determine a potential threat aircraft's heading and speed. Westra, "Radar versus Stealth," p. 140.

64 Bronk, "Technological Trends," p. 61.

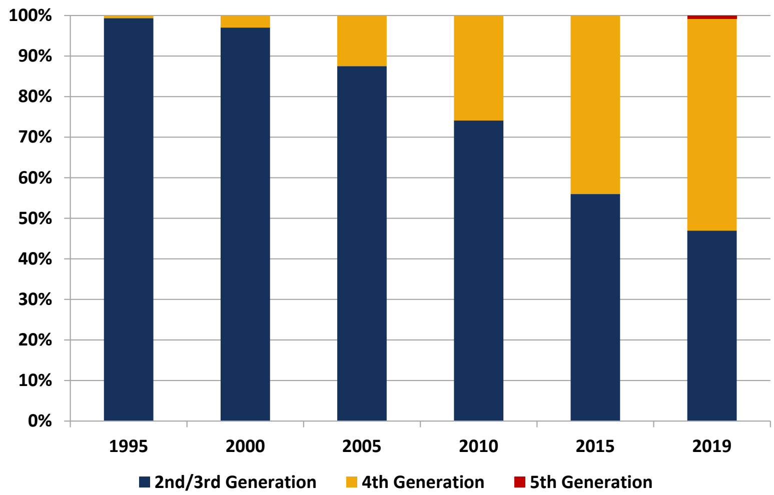
65 Wilson, "New Frontiers in Passive Radar and Sonar."

long-wave IRST systems was hampered by their poor resolution, ghost returns, and clutter.[66] However, advances in computer processing, high-speed networking of data from multiple airborne sensors, and advanced sensor fusion algorithms could allow future long-wave IRST to generate intercept-quality information on threats.[67]

In summary, China and Russia's growing ability to fuse and cross-reference data from networks of multi-domain, multi-phenomenology sensors and then provide air defense commanders with real-time situational awareness is becoming a pacing threat for the Air Force. The future CAF should be capable of operating in these types of threat environments where enemies will employ multi-domain networks of sensors to simultaneously scan areas from a range of aspects and over many frequency bands using both active and passive techniques. This will require the Air Force to modernize its CAF rather than continue to rely on legacy combat aircraft that were originally designed for far more benign threat environments.

Modernizing IADS Counterair Capabilities

FIGURE 10: TRENDS IN PLA AIR FORCE FIGHTER AIRCRAFT GENERATIONS



Data for this figure was drawn from IISS's *The Military Balance*. For an overview of the general characteristics of Chinese 4th generation and 5th generation aircraft, see DIA, *China Military Power*, p. 86.

China and Russia are also fielding advanced fighter aircraft to contest U.S. air operations. China, in particular, is rapidly modernizing its PLA Air Force (PLAAF), transitioning it to a predominately 4th generation force while also developing and fielding low-observable 5th generation fighters (see Figure 10). New fighters such as the J-20 feature modern radar tracking and targeting capabilities, sensor fusion, integrated electronic warfare systems, and advanced datalinks.[68]

66 David Schmieder and James Teague, "The History, Trends, and Future of Infrared Technology," *Defense Systems Information Analysis Center Journal* 2, no. 4, Fall 2015.

67 DM Chan, "IRST Gives Super Hornets Counter-stealth Capability," *Asia Times*, September 2, 2019.

68 Office of the Secretary of Defense (OSD), *Military and Security Developments Involving the People's Republic of China 2019*, Annual Report to Congress (Washington, DC: DoD, May 2, 2019), p. 57.

China is fielding advanced air-to-air missiles such as its short-range PL-10 that has an imaging infrared seeker and thrust-vector control capability. PL-10s will soon be integrated with helmet-mounted displays to facilitate rapid missile locks on airborne targets.[69] Increasingly capable Chinese beyond-visual-range air-to-air missiles (BVR AAM) such as the PL-15 and PL-21 feature ramjet engines and AESA radar seekers.[70] The combination of airborne early warning and command and control aircraft with advanced sensors that can cue low-observable J-20s carrying BVR AAMs will improve the PLAAF's ability to engage high-value aircraft assets (HVAAs) such as U.S. aerial refueling tankers and BMC2 platforms over long ranges. China is also increasing its emphasis on improving its air combat tactics, techniques, and procedures. The PLAAF is shifting its training away from highly scripted scenarios toward training that better represents potential combat conditions, and it is experimenting with various artificial intelligence (AI) applications for controlling unmanned aircraft swarms, providing decision aids for commanders, and creating higher fidelity simulations and training for pilots.[71]

Although Russian Aerospace Forces have had less success developing and fielding operational 5th generation fighters, they retain a significant fleet of 4th generation Flanker fighter series and MiG-31 aircraft. These combat platforms can launch salvos of air-to-air missiles that have a mix of semi-active and active RF seekers, passive RF seekers, and IR seekers to complicate U.S. countermeasures.[72] Russia continues to pursue concepts and capabilities to conduct long-range air-to-air engagements against high-value force enablers such as AWACS and tanker aircraft using BVR AAMs, such as the K-100 launched by Flanker series aircraft, and the hypersonic R-37 (NATO nomenclature AA-X-13/AA-13 Arrow), designed to be launched by MiG-31s.[73]

69 Douglas Barrie, "It's Not Your Father's PLAAF: China's Push to Develop Domestic Air-to-Air Missiles," *IISS Military Balance Blog*, February 21, 2018, available at https://www.iiss.org/blogs/military-balance/2018/02/not-your-fathers-plaaf.

70 See John Stillion, *Trends in Air-to-Air Combat: Implications for Future Air Superiority* (Washington, DC: Center for Strategic and Budgetary Assessments, 2015); and Jeffrey Lin and P.W. Singer, "This New Ramjet Engine Could Triple the Range of Chinese Missiles," *Popular Science*, June 12, 2017, available at https://www.popsci.com/chinas-new-ramjet-engine-triple-range-missiles/. AESA is a type of phased array antenna consisting of a matrix of small, solid state transmit/receive modules each capable of generating its own signal, allowing AESA radars to produce multiple, simultaneous radar beams at different frequencies to perform multiple functions simultaneously.

71 Jana Allen and Kenneth Allen, *The PLA Air Force's Four Key Training Brands* (Montgomery, AL: China Aerospace Studies Institute, 2018), pp. 23–24; and Brendan S. Mulvaney, "China's Military Reforms and Modernization: Implications for the United States," testimony before the U.S.-China Economic and Security Review Commission, February 15, 2018, available at www.uscc.gov/sites/default/files/Dr%20Mulvaney%20testimony%20to%20USCC%2015%20Feb%202018%20PLA%20Air%20Force.pdf.

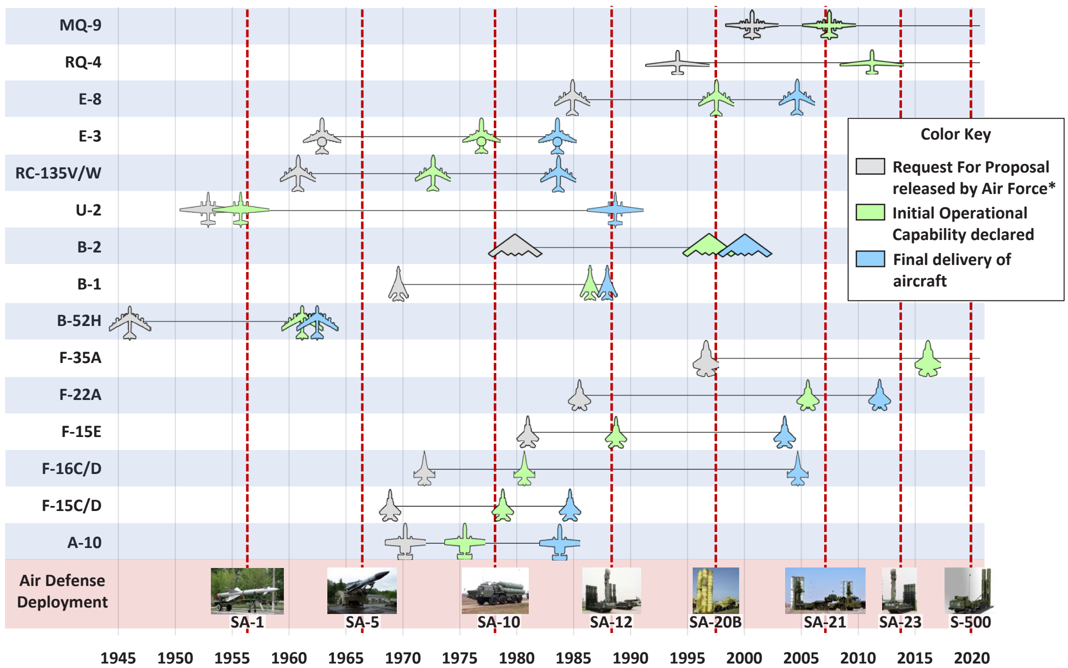
72 Carlo Kopp, "The Russian Philosophy of Beyond Visual Range Air Combat," *Air Power Australia*, March 25, 2008, updated April 2012, available at http://www.ausairpower.net/APA-Rus-BVR-AAM.html.

73 Kyle Mizokami, "The Navy Wants to Give Its Bigger Planes a Way to Shoot Down Missiles," *Popular Mechanics*, May 9, 2018, available at https://www.popularmechanics.com/military/aviation/a20634418/navy-interceptor-for-larger-planes/.

CAF Capabilities Designed for Threat Environments of the Past

The current CAF predominately consists of aging, non-stealth aircraft that are not suitable for operations in contested and highly contested threat environments. This force structure is largely the result of decisions to cancel or prematurely truncate CAF modernization initiatives to develop and procure new weapon systems for high-end operations against modern IADS, such as the F-22 and B-2 programs. In addition to program cost, the primary justification for these decisions was based on a belief that low-observable aircraft would not be needed in significant numbers to support contingency operations against regional aggressors like Iraq or North Korea. Although reasonable in the immediate aftermath of the Cold War, this assumption is no longer valid.

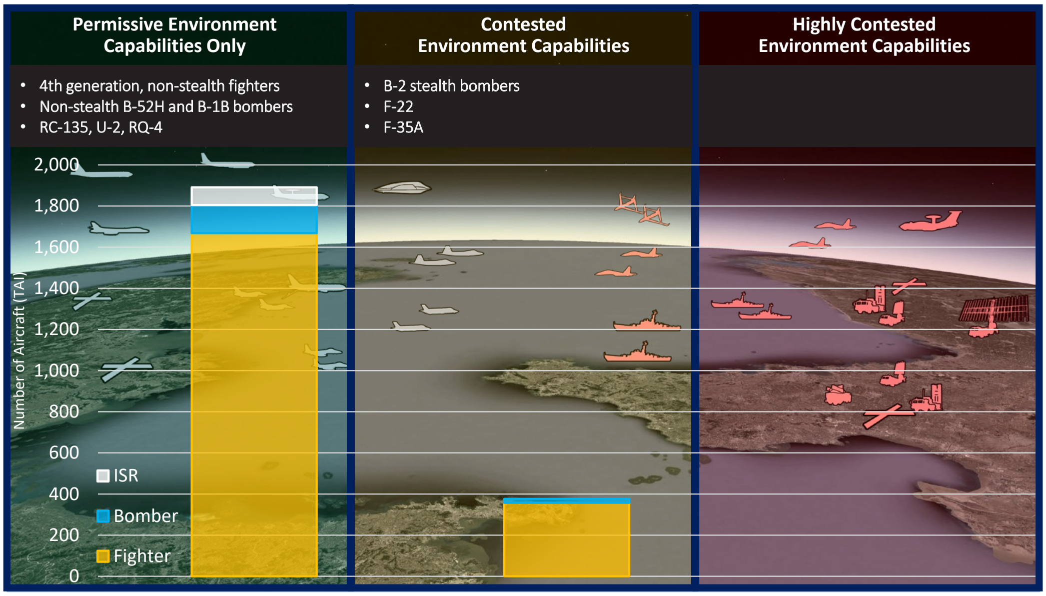
FIGURE 11: CAF CAPABILITIES DESIGNED FOR THREAT ENVIRONMENTS OF THE PAST



*Request for Proposal dates in Figure 11 are for the initial variant of an aircraft, and the initial operating capability and final delivery dates are for aircraft variants in the force.

Advanced avionics, new mission systems, and other software or add-on hardware upgrades have made the Air Force's legacy combat aircraft more capable than when they first rolled off the production line. However, whereas sensors can be improved and software can be made more robust, non-stealth aircraft cannot be made significantly stealthier. This imposes significant operational constraints on the current CAF because robust aircraft signature management, although alone not a silver bullet solution, has become a prerequisite for air operations in contested and highly contested environments.[74] Except for a small number of low-observable B-2s, F-22s, and a growing number of F-35As in the force, today's CAF cannot penetrate contested and highly contested environments without risking significant attrition (see Figure 12).

FIGURE 12: CHARACTERIZING THE SURVIVABILITY OF THE AIR FORCE'S 2019 CAF AIRCRAFT



Maintaining this CAF mix would hinder the Air Force's ability to execute its core missions in support of the 2018 National Defense Strategy. At the outset of a great power conflict, most of the Air Force's current non-stealth force would be relegated to fighting on the periphery of the battlespace, lobbing standoff attack weapons into contested areas. BMC2 and ISR platforms would be required to operate at significant standoff ranges that would severely diminish their effectiveness, degrading their ability to generate sufficient situational awareness and identify emerging targets of significance.[75] When targets are finally identified, the extended weapon flight times associated with this scheme would reduce the CAF's ability to suppress fleeting targets such as mobile IADS weapon systems and facilities. Long weapons flight times would also diminish the CAF's ability to conduct high-volume strikes, provide close air support, and perform other time-sensitive missions. Finally, the payload constraints of long-range standoff weapons could limit their effectiveness against hardened or deeply buried targets. In sum, relying primarily on expensive long-range standoff weapons to strike tens of thousands of

74 David A. Deptula, Lawrence A. Stutzriem, and Heather R. Penney, "Ensuring the Common Defense: The Case for Fifth Generation Airpower," *Mitchell Institute Policy Papers*, April 2019, available at http://docs.wixstatic.com/ugd/a2dd91_662dd97d81c34910a970569ea97d1cf2.pdf.

75 Alan J. Vick, Richard M. Moore, Bruce R. Pirnie, and John Stillion, *Aerospace Operations Against Elusive Ground Targets* (Santa Monica, CA: RAND Corporation, 2002), pp. 64–66.

potential targets in a future air campaign against a great power adversary could be prohibitively expensive. Eventually, non-stealth aircraft might be able to operate closer to the contested battlespace as U.S. forces degrade an enemy's IADS and other access-denial threats. However, rolling-back an enemy's advanced IADS would require a significant amount of time to achieve, time that the enemy could use to achieve a *fait accompli* or consolidate their gains.

Capabilities for a Future, More Survivable CAF

DoD and Congress should prioritize building an Air Force CAF that can operate in future threat environments rather than permissive environments of the past. In the most stressing and plausible scenarios for conflict with Russia or China, the U.S. military will not have time to marshal a large force into a theater of operations before launching a counteroffensive to roll back enemy area-denial capabilities, establish all-domain dominance, and then reverse an enemy's gains.[76] This sequential approach would create opportunities for Russia or China to exploit their time-distance advantage to achieve their campaign objectives before the United States and its allies could effectively respond. Instead, the future CAF should be capable of conducting operations at the start of hostilities to blunt attacks and deny a Russian or Chinese *fait accompli*. This approach will require the CAF and other U.S. forces to fight "in and through enduringly contested operational environments" without achieving the degree of domain dominance to which they have grown accustomed to in conflicts of the past.[77]

Stealth Will Be the Price of Admission for Operations in Contested Environments

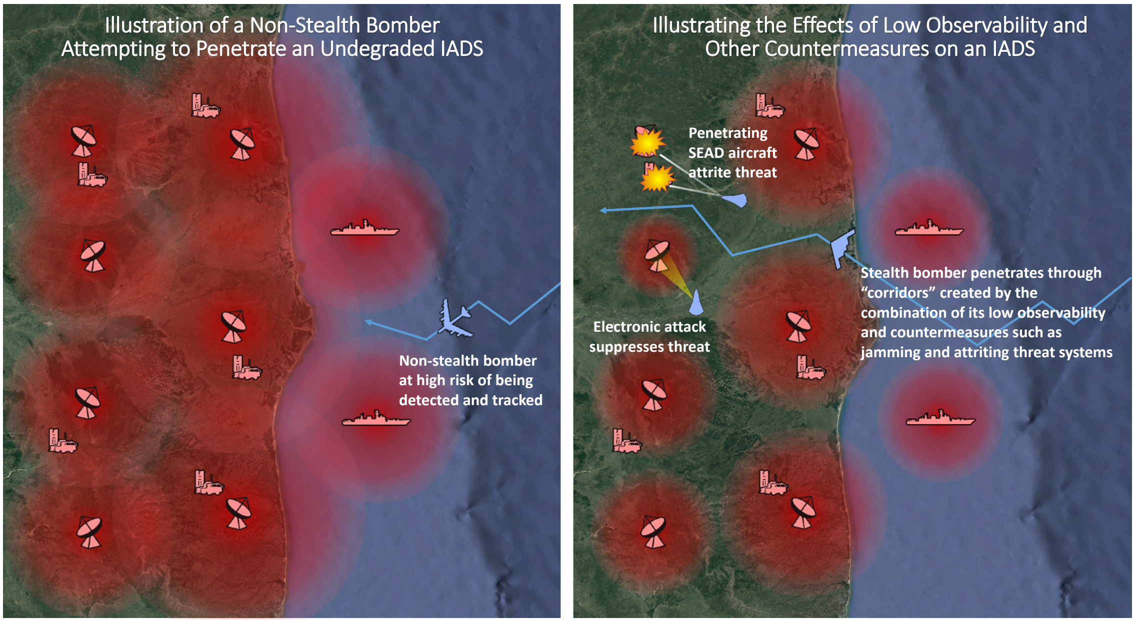
Advances in stealth technologies will continue to provide a significant margin of survivability for future CAF capabilities. Stealth aircraft have low observable features such as radar energy-absorbing materials, specially designed outer mold lines, and other capabilities that reduce its signature. Low-observable technologies reduce ranges at which air platforms can be detected and engaged; they do not render them invisible to sensors. Although in certain instances low-observable aircraft designs and treatments alone may be sufficient to allow them to penetrate enemy air defenses, these features are most effective when combined with other countermeasures. As shown in Figure 13, the survivability of a stealth aircraft is the result of a combination of attributes that includes controlling the signatures they create in the electromagnetic spectrum, detecting threats then modifying an aircraft's flight path to avoid the most lethal areas, supporting electronic attacks, and other countermeasures that reduce an enemy's ability to complete an intercept kill chain.[78]

76 For more information, see Gunzinger et al., *An Air Force for An Era of Great Power Competition*, pp. 59–65.

77 Elbridge A. Colby, Director of the Defense Program, Center for a New American Security, testimony before the Senate Armed Services Committee Hearing on Implementation of the National Defense Strategy, January 29, 2019, available at https://www.armed-services.senate.gov/imo/media/doc/Colby_01-29-19.pdf.

78 Kill chain refers to the steps in the "find, fix, track, target engage, assess" (F2T2EA) chain of actions that are accomplished by a system or system-of-systems to successfully destroy a target or set of targets.

FIGURE 13: LOW OBSERVABILITY AND OTHER STEALTH TACTICS REDUCE SENSOR DETECTION RANGES AND IMPROVE AN AIRCRAFT'S ABILITY TO PENETRATE



For example, F-35 survivability is, in part, the product of its low-observable design combined with automated, multi-spectral sensors that generate highly accurate, real-time threat pictures. An F-35's fused information of the battlespace can improve a pilot's ability to engage threats or determine changes to flight profiles that would reduce the signature an F-35 presents to threats.[79] An ongoing upgrade to the B-2's Defensive Management System (DMS) provides that bomber with similar capabilities. Low observability also facilitates concepts to cooperatively use multiple systems to improve the survivability of penetrating aircraft. For instance, the reduced signatures of low-observable aircraft combined with advanced processing and other capabilities make it easier for off-board low-power electronic jammers to effectively counter adversary sensors.[80] Another technique is to use multiple low-observable aircraft to conduct electronic attacks against some threats, cycling active emissions between aircraft to reduce the probability they will be detected and engaged.

79 Deptula, Stutzriem, and Penney, "Ensuring the Common Defense," p. 21.

80 Barrett and Carpenter, *Survivability in the Digital Age*, p. 20.

Next-Generation Weapon Systems Are Needed for Operations in Future Contested and Highly Contested Environments

Key capability attributes for future CAF platforms. The "hider-finder" competition between air defense sensors and low-observable aircraft will be an ongoing dynamic; adversaries will continue to study and attempt to develop countermeasures to U.S. combat aircraft and operating concepts.[81] More generally, Russia and China will continue to mature and expand their multi-domain networks of sensors that can simultaneously scan areas from a variety of aspects over many frequency bands using combined active and passive techniques. This will make it increasingly challenging for aircraft of all classes to avoid detection. Consequently, the long-term ability of the Air Force's CAF to penetrate and survive in contested and highly contested environments will depend on the Service's ability to continuously develop and field new combat aircraft that include the following attributes.

- More advanced outer mold line designs. Because the "shape," or more accurately the outer mold line (OML), of an aircraft accounts for the majority of its low observability, the decision to incorporate low-observable OML features must be made during an aircraft's design phase.[82] Advanced algorithms and other technologies needed to develop and manufacture next-generation stealth OMLs is a significant advantage of the U.S. defense industry. However, it is very difficult, likely prohibitively so, to modify OMLs of existing non-stealth aircraft such as F-15s, F-16s, and legacy bombers to significantly improve their stealth characteristics. This is a key reason why the Air Force should develop and field a new generation of combat aircraft rather than attempt to further modify decades-old aircraft designs as it has been compelled to do for budgetary and other reasons since the end of the Cold War.[83]

- All-aspect broadband signature control. All-aspect signature control will become increasingly important for aircraft survivability as advances in computing power continue to reduce sensor fusion and data processing challenges that have hindered adversary systems from operating beyond traditional fire control radar bands and generating engagement tracks. As is evident from concepts for next-generation aircraft, all-aspect broadband signature control may require blended wing tail-less designs that have fewer discrete edges. Advances in materials science should yield materials with reduced and more controllable emissivity properties at different wavelengths, which will improve the ability to design these aircraft.

81 The "hider-finder" competition comprises the whole range of capabilities needed to detect, track, and engage aircraft on the one hand, as well as capabilities to hide, conceal, obscure, deceive, or blind integrated air defense systems on the other.

82 For the first in an excellent series of articles on stealth and stealth aircraft designs, see Dan Katz, "Measuring Stealth Technology's Performance," *Aviation Week & Space Technology*, June 26, 2016.

83 For an assessment of budget constraints and other factors that shaped the Air Force's current CAF, see Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*

- LPI/LPD communications and datalinks. Advancements in the sensitivity and capability of adversary passive sensors have made high-power omnidirectional radio emissions and datalinks a significant vulnerability for aircraft that must penetrate contested areas. Next-generation platforms should have LPI/LPD communications systems that can be directionally focused and have low-power and narrow beamwidths to reduce their risk of detection.

- Advanced sensor suites. Even with improved LPI/LPD communications and datalinks, it is likely that a great power adversary will be able to deny communications in some localized areas of contested battlespaces. In such degraded communications environments, it will be important for future CAF aircraft to also have an organic capability to actively and passively detect, track, and engage targets. Next-generation combat aircraft with multi-spectral, multi-phenomenology sensor suites with ranges greater than those available on current systems would help ensure they will be able to sense and counter threats before threats can target them.

- Multi-domain interoperability. To fully take advantage of information collected by the aforementioned advanced sensor suites, the Air Force should increase its ability to share data across its CAF and other joint capabilities through a distributed, all-domain, self-healing network to improve shared situational awareness and battlespace management and command and control. This degree of interoperability will enable the CAF to create effects in multiple domains at an operational tempo that adversaries cannot match.

Need for a Penetrating Counter Air/Penetrating Electronic Attack Aircraft. The PCA/PEA aircraft recommended by CSBA's 2019 Air Force aircraft inventory report should be capable of a range of counterair missions, including defeating airborne threats and conducting suppression of enemy air defenses/destruction of enemy air defenses (SEAD/DEAD) operations. In addition to the above attributes, the PCA/PEA aircraft should have sufficient payload capacity for offensive and defensive weapon systems. Future self-defense capabilities could include mission systems for multi-spectral electronic attacks, the ability to carry multiple air-to-air Small Advanced Capabilities Missiles (SACM), and on-board directed energy weapons. The capability to sprint at supersonic speeds to help defeat airborne threats may also be important. Integrating more fuel-efficient adaptive engine technologies into a PCA/PEA design could help reduce tradeoffs between large weapons payloads, speed, long range, and other performance attributes. These engines are addressed in Chapter 5.

Accelerate F-35A procurement. Given the F-35A's stealth features, the fact that it is the only Air Force low-observable combat aircraft in production, and its declining unit costs, CSBA's 2019 Air Force aircraft inventory report recommended increasing its procurement as quickly as possible to at least 70 aircraft per year. DoD should also mature and field Block 4 software for its F-35A fighters to outpace emerging Chinese and Russian air-to-air and surface-to-air threats.[84] Other than the B-21, there are no other alternatives to the F-35A in the near to medium term that will help close the capability and capacity gaps between the Air Force's current CAF and 2018 NDS requirements for a more survivable force.

Modernize and expand the stealth bomber force. To ensure it will have the capacity needed to conduct large-scale strikes in contested and highly contested environments, the Air Force should rebalance its combat forces in favor of long-range, penetrating bombers. The long-range, penetrating strike capacity needed to help deter and, if necessary, defeat great power aggression in two separate theaters nearly simultaneously could require the Air Force to more than double its planned buy of B-21s. Maintaining the B-2's ability to penetrate contested threat environments would reduce risk until a significant number of operational B-21s are in the force. This would require the Air Force to continue the B-2 Defensive Management System Modernization (DMS-M) program. The program will address shortfalls in the B-2's Defensive Management Suite Threat Emitter Location System that "detects, identifies, and locates enemy radar systems and provides real-time threat avoidance, threat warning, and threat situational awareness information to the aircrew."[85] DMS-M upgrades are needed to avoid reductions in the B-2's "operational capability and survivability."[86] Continued improvement of the B-2's stealth qualities under the ongoing Low Observable Signature and Supportability Modifications (LOSSM) program could further enhance B-2 survivability and availability, while the integration of weapons for SEAD/DEAD, maritime strikes, and stand-in attacks could enable it to support new concepts of employment.

Increase penetrating ISR (P-ISR) UAS capacity in the future force. Unmanned persistent penetrating airborne ISR platforms would reduce the joint force's reliance on increasingly vulnerable overhead sensor networks and increase its ability to adapt to the dynamic conditions of the future battlespace. Future P-ISR UAS would help other aircraft and weapons operating in contested airspace receive current information on the disposition of enemy forces, emerging threats, and mobile/relocatable targets. Multiple P-ISR UAS combined with sensors and datalinks on F-35As, B-21s, and PCA/PEA aircraft could reduce the nodality of the Air Force's future multi-domain battle networks, improving their resiliency to enemy countermeasures.

84 John A. Tirpak, "Keeping the F-35 Ahead of the Bad Guys," *Air Force Magazine*, October 2019.

85 DoD, "B-2 Defensive Managements System–Modernization (B-2 DMS-M)," Selected Acquisition Report, December 2017, available at https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/18-F-1016_DOC_04_AF_B-2_DMS-M_SAR_Dec_2017.pdf.

86 Ibid.

Summary

Blunting a great power adversary's attacks and preventing it from achieving a *fait accompli* will require the Air Force to conduct operations from the outset of hostilities in contested and highly contested areas. The current CAF mix predominantly consists of aging, non-stealth aircraft that are not suitable for operations in environments characterized by continuous or near-continuous threats from multiple aspects and domains. Furthermore, sequential operational concepts that rely on a traditional IADS rollback campaign or conducting strikes largely from standoff distances until threats are suppressed could give a great power aggressor the time it needs to achieve its campaign objectives.

A future CAF mix that is more capable of penetrating and operating in contested environments on night one of a major conflict is needed to address these challenges. In the near term, this should entail maximizing the acquisition of 5th generation capabilities such as the F-35A and upgrading the B-2 and F-22 fleets as needed to maintain their survivability. In the long run, outpacing emerging threats will also require the Air Force to develop and procure a new generation of systems including a PCA/PEA aircraft, penetrating unmanned ISR aircraft, and a significantly larger force of penetrating bombers capable of operating in highly contested environments.

Independent of advancements that will improve the survivability of the Air Force's CAF in the air, the CAF will remain highly vulnerable when on the ground if it fails to improve its theater airbase defenses against air and missiles attacks. CSBA's 2019 Air Force aircraft inventory study detailed how Chinese or Russian salvos of precision weapons could strike U.S. theater airbases and cripple the Air Force's ability to generate combat sorties.[87] Chapter 3 assesses the need to develop more resilient force postures in the Indo-Pacific and Europe that will ensure the Air Force can generate timely combat power in great power conflicts.

87 CSBA's 2019 Air Force aircraft inventory report provides a more comprehensive overview of the threats to future U.S. air operations. See Gunzinger et al., *An Air Force for An Era of Great Power Competition*, pp. 36–52.

CHAPTER 3

Generate Air Combat Power Forward

China and Russia continue to seek increased influence over major areas located along their periphery. China has demonstrated its strategic ambitions in the South China Sea by establishing military facilities on natural and artificial islands that extend its overwatch of shipping lanes critical to global commerce. Russia has used military, paramilitary, and irregular forces to illegally occupy areas in the sovereign state of Georgia, invade and occupy Crimea, and support a conflict in eastern Ukraine. A major objective of the 2018 NDS is to create the capacity for robust U.S. force postures in the Western Pacific and Europe that can deter or respond rapidly to Chinese and Russian aggression.[88] U.S. bases in Europe and the Western Pacific currently lack adequate defenses against salvos of ballistic missiles, cruise missiles, unmanned aircraft, and other threats that China or Russia could employ in the opening stages of a conflict. The vulnerability of these bases erodes the credibility of the U.S. forward posture and diminishes its ability to assure and defend America's allies and partners.

Chapter 3 addresses ways the Air Force could improve its ability to generate combat power forward while under attack by a great power aggressor. Without adequate air and missile defenses, the Air Force's ability to generate combat power from its forward bases would be greatly diminished. Schemas that would redeploy a significant portion of U.S. forward-stationed forces to more distant locations at the outset of a crisis with China or Russia might greatly reduce the risk they will be attrited by air and missile attacks. However, plans to withdraw U.S. forces from forward bases could weaken America's ability to deter aggression and assure allies, and it could embolden revisionist great power competitors.

88 A *fait accompli* strategy is designed to rapidly achieve objectives before an opponent can effectively mobilize and deploy its forces. See Michael S. Gerson, "Conventional Deterrence in the Second Nuclear Age," *Parameters*, Autumn 2009, pp. 32–48, available at https://ssi.armywarcollege.edu/pubs/Parameters/articles/09autumn/gerson.pdf.

Approaches for Creating a More Resilient Air Force CAF Posture

Chinese and Russian forces are well aware that the most efficient approach to attriting an opposing air force is to attack it where it is most vulnerable: on the ground before it can sortie aircraft.[89] A primary mission of the PLA Rocket Force (PLARF) is to suppress "enemy air force air bases, airfields, and missile defense (air defense) systems."[90] Using long-range missiles and other means to degrade NATO's air forces and airbase operations is also a key element of Russia's warfighting strategy. Chinese or Russian attacks could greatly degrade the Air Force's ability to generate combat power from its forward airbases that currently lack sufficient air and missile defenses. The potential loss of a significant number of the Air Force's combat aircraft on the ground would be all the more challenging given the present diminished size of its CAF. For instance, the loss of small numbers of high-value combat aircraft such as low-observable F-22As could cripple the Air Force's ability to control and exploit the air domain during the opening stages of a great power conflict.

The 2018 NDS prioritizes creating more resilient forward postures in the Indo-Pacific and Europe that consist of "forces that can deploy, survive, operate, maneuver and regenerate in all domains while under attack."[91] The Air Force is debating the best approach for countering emerging threats to its forward airbases and forces. One option is to increase its ability to generate air combat power from bases located in lower-risk areas, such as the Second Island Chain in the Pacific and even the continental United States. Another approach is to improve the Air Force's ability to disperse its forward-based forces and defend its theater airbases against air and missile attacks. These are not "either-or" options. The future CAF should have increased capacity to operate aircraft with long ranges and large payloads from more distant bases *and* generate significant combat power from forward bases in Japan, elsewhere along the First Island Chain, and in Europe.

Some Disadvantages of Redeploying CAF Forces from their Forward Airbases in a Crisis

Redeploying Air Force combat aircraft from forward bases that lack air and missile defenses at the outset of a crisis to distant bases located further from Chinese or Russian air and missile threats would reduce their ability to suppress the Air Force's combat sortie generation operations. On the surface, this may appear to be a logical approach for a Service that has touted its ability to conduct combat operations over long ranges. However, shifting toward generating the preponderance of Air Force combat sorties from the Second Island Chain or even

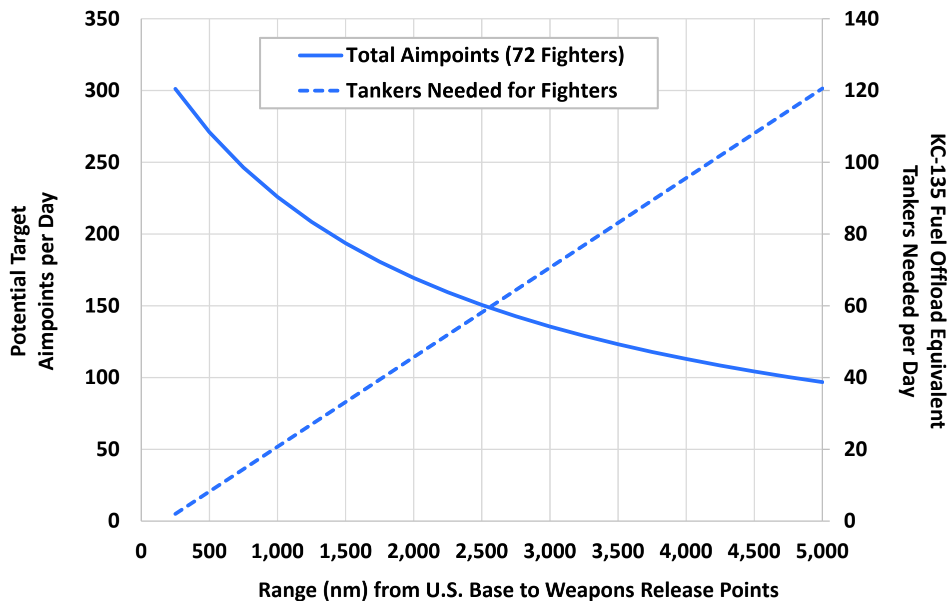
89 Oriana Skylar Mastro and Ian Easton, *Risk and Resiliency: China's Emerging Air Base Strike Threat* (Arlington, VA: Project 2049, November 8, 2017), p. 3. This was discussed in more detail in Carl Rehberg and Mark Gunzinger, *Air and Missile Defense at a Crossroads: New Concepts and Technologies to Defend America's Overseas Bases* (Washington, DC: Center for Strategic and Budgetary Assessments, 2018), pp. 8–14.

90 Thomas Shugart and Javier Gonzalez, *First Strike: China's Missile Threat to U.S. Bases in Asia* (Washington, DC: Center for a New American Security, June 2017), pp. 4–6.

91 DoD, *Summary of the 2018 National Defense Strategy of The United States of America*, p. 6.

more distant locations in the Indo-Pacific during the opening stages of a conflict with China, and from non-continental bases during a conflict with Russia, would have significant operational impacts. For instance, operating the Air Force's fighter aircraft from airbases in Guam, Australia, and other distant locations in the Indo-Pacific would greatly reduce their daily sortie rates and increase the strain on the Service's aerial refueling force. Analysis and real-world experience have proven there can be an exponential reduction in combat sortie generation rates for aircraft that must operate over very long ranges.[92] Sustaining these very long-range operations over time would also require additional crews, aerial refueling tankers, and other supporting capabilities.

FIGURE 14: ILLUSTRATING THE IMPACT OF INCREASING MISSION DISTANCES ON WEAPONS DELIVERY POTENTIAL AND AERIAL REFUELING REQUIREMENTS



This figure assumes each F-35A carries two JDAM-like weapons internally. Turn times between fighter sorties are assumed to be four hours, and cruise speed at altitude is 0.85 Mach.

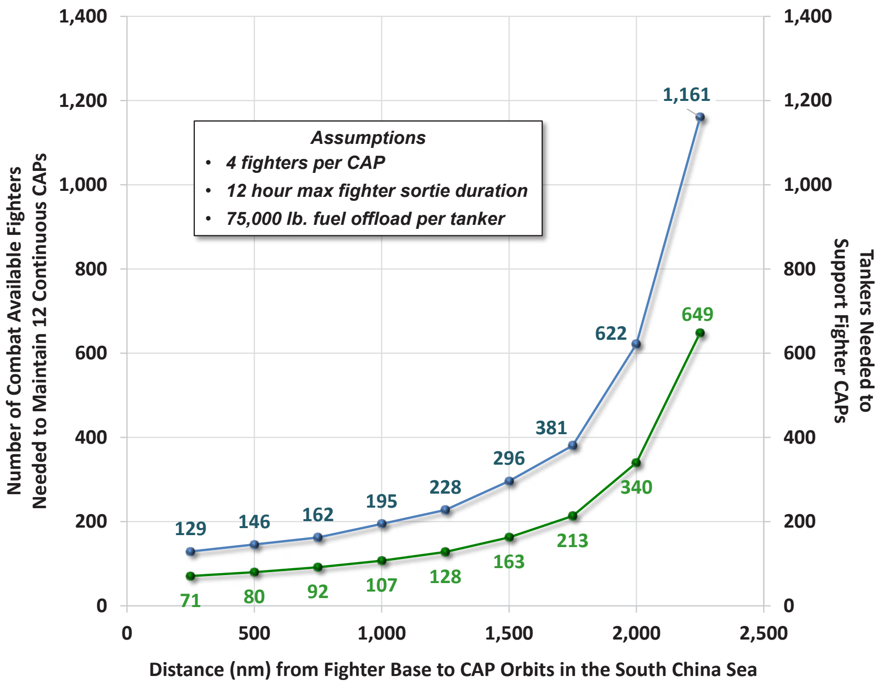
As shown in Figure 14, operating from more distant airfields would require Air Force fighters to fly longer duration sorties, which would reduce the number of sorties a given deployed force could generate per day. This would have the effect of reducing the number of weapons the force could deliver on an enemy target set, as well as reduce the time available for fighters to perform counterair, close air support, and other missions. The solid line in Figure 14 shows

92 For example, a force of about 20 B-52s based in Saudi Arabia dropped about two and a half times the tonnage of weapons as 48 B-52s deployed to the United Kingdom, Diego Garcia, and Morón Air Base in Spain, and they did so without the need for aerial refueling. See "Conduct of the Persian Gulf War (CPGW)," Pursuant to Title V of the Persian Gulf Conflict Supplemental Authorization and Personnel Benefits Act of 1991 (Public Law 102-25), April 1992, p. T-2, available at https://archive.org/details/ConductofthePersianGulfWarFinalReporttoCongress/page/n561; and Eliot Cohen, *Gulf Air Power Survey*, volumes 1–5 (Washington DC: U.S. Government Printing Office, 1993), volume 5, available at https://media.defense.gov/2010/Sep/27/2001329816/-1/-1/0/AFD-100927-065.pdf.

how the number of aimpoints a force of 72 combat available F-35A fighters carrying two internal weapons can strike per day decreases as the range between their bases and weapons release points increase. The dashed line in Figure 14 illustrates the increase in aerial refueling requirements as fighter mission distances increase.

Similar patterns emerge when plotting fighter on-station requirements. Figure 15 illustrates how increased ranges from fighter bases to an operational area such as the South China Sea reduce fighter time on station in combat air patrols (CAPs) and the number of tankers (green line) needed to sustain operations.

FIGURE 15: ILLUSTRATING THE NUMBER OF FIGHTERS AND AERIAL REFUELING TANKERS NEEDED TO SUPPORT 12 CONTINUOUS COMBAT AIR PATROLS IN THE SOUTH CHINA SEA



To help put this in context, Air Force fighters that stage from airbases located in northern Australia would need to fly nearly 1,600 nm to reach a CAP location in the vicinity of the Spratly Islands in the South China Sea. Maintaining four fighters continuously on station at that range would require more than a full squadron of 24 mission-ready fighters. Accounting for historic aircraft mission capable rates, a requirement to sustain 12 CAPs at equivalent ranges could exceed the Air Force's entire inventory of F-15Cs and F-22s. Demand for air refueling to support these CAP missions could also exceed the current capacity of the Air Force's tanker force.

Maintain the Ability to Generate Air Combat Power Forward

Maintaining U.S. air forces at forward bases is a key element of a strategy to deter great power aggression and assure U.S. allies and partners. The 2018 NDS established a new DoD construct for conventional deterrence that includes posturing a "contact" layer of forces in regions of high strategic value, a "blunt" force layer, a "surge" layer, and a homeland security layer.[93] The primary purpose of the contact layer is to deter aggression that falls below the level of armed conflict or hybrid warfare. Blunt forces, which could be located in or out of a theater, would rapidly supplement contact forces and conduct initial combat operations to degrade, delay, and deny adversaries from achieving their initial campaign objectives. Follow-on surge forces would comprise additional global or CONUS-based forces that could be quickly moved into the theater to provide decisive combat power, reinforcing the blunt layer and initiating counterattacks from a variety of directions.

Future U.S. contact and blunt air forces postured in the Indo-Pacific and Europe must have the right mix of capabilities and appropriate capacity to deter China or Russia from attempting a *fait accompli*. If that fails, they must be able to impose initial costs sufficient to cause an aggressor to immediately reconsider and reverse its actions, and then seamlessly integrate with surge forces that would rapidly deploy into the theater to help defeat the aggressor.[94] While they may be a key component in the opening stages of a conflict, contact and blunt forces forward-based in the Indo-Pacific and Europe also help reassure U.S. allies and partners that are critical to U.S. national security and prosperity.

Increase the CAF's Capacity to Project Power from Range

Growing the size of the bomber force would improve the Air Force's ability to project power over long ranges from airfields located in areas that face less risk of high-density air and missile attacks. Since the end of the Cold War, the Air Force dramatically reduced the size of its bomber fleet, its primary means of delivering large payloads of weapons on targets over very long ranges. In 1988, the Air Force had a total aircraft inventory of 422 bombers, including B-52s, B-1Bs, and FB-111 fighter-bombers.[95] Today, the Air Force has a total of 157 bombers, of which only 20 are low-observable B-2s. This diminished force has the capacity to generate fewer than 60 bomber combat sorties per day after accounting for aircraft mission capable rates as assessed in Chapter 1.[96] Consequently, projecting power over very long ranges using a current CAF that is still heavily weighted toward shorter-range fighters is not a viable solution. To counter great power aggression in the Indo-Pacific and in Europe, the Air Force should rebalance its mix of CAF strike forces toward long-range, large-payload bombers. It

93 Susanna Blum, "How the United States Can Get More Bang For Its Buck," *War on the Rocks*, February 1, 2018.

94 Ross Babbage, *Stealing A March: Chinese Hybrid Warfare in The Indo-Pacific: Issues and Options for Allied Defense Planners*, volume I (Washington, DC: Center for Strategic and Budgetary Assessments, 2019), pp. 1–3.

95 Ruehrmund and Bowie, *Arsenal of Airpower*, p. 22.

96 The estimate of 60 sorties per day is based on open source bomber mission capable rates listed in Table 2 in this report.

should also complement this larger bomber force with fighter forces that can operate from airbases located inside areas covered by Chinese or Russian A2/AD threats. These forward-located fighters should be preferentially used to conduct counterair sorties and other combat missions in support of penetrating and standoff strike aircraft. In either case, the Air Force's future theater airbases should be capable of countering air and missile threats, as addressed in the next section.

Improving Posture Resiliency: A Prerequisite for Both Approaches

U.S. main operating airbases in the Indo-Pacific and Europe are now optimized to conduct efficient operations in peacetime, not wartime.[97] As early as 2006, DoD identified the need to increase the resiliency of its theater bases to counter emerging air and missile threats.[98] More recently, the 2018 NDS called for "transitioning from large, centralized, unhardened infrastructure to smaller, dispersed, resilient, adaptive basing that include active and passive defenses."[99] As the Air Force seeks to balance its future mix of long-range power projection and forward-postured combat forces, it must undertake an aggressive program to enhance passive and active defense capabilities of its close-in *and* more distant theater airbases.

Unfortunately, in the past, the types of capabilities that would increase the resilience of the Air Force's theater bases have not competed well with other priorities. The following six lines of effort could help improve base resiliency. Individually, each will help reduce the impact of air and missile salvos against the Air Force's airbases and facilitate faster recovery after an attack. In combination, these lines of effort could greatly increase an aggressor's cost of action by substantially increasing the number of weapons it requires to achieve desired effects on a target set. For example, depriving an adversary the ability to use weapons with submunitions that can cripple multiple soft targets such as unreinforced airbase facilities could force it to use a much larger number of unitary weapons instead to achieve similar effects across the airbase. This calculus might actually forestall an attack or, at a larger scale, a conflict.

97 Rehberg and Gunzinger, *Air and Missile Defense at a Crossroads*, p. 8.

98 For example, see DoD's 2006 Quadrennial Defense Review report to Congress: DoD, *Quadrennial Defense Review* (Washington, DC: DoD, 2006), p. ix, available at https://archive.defense.gov/pubs/pdfs/QDR20060203.pdf. The 2018 NDS describes posture resilience as "forces that can deploy, survive, operate, maneuver and regenerate in all domains while under attack." DoD, *Summary of the 2018 National Defense Strategy of the United States of America*, p. 6.

99 DoD, *Summary of the 2018 National Defense Strategy of the United States of America*, p. 6. The Air Force has described adaptive basing as "an enterprise-level approach to force employment and force development that ensures USAF capability to project power into and operate from bases in contested and highly contest environments." This description was taken from an unclassified briefing titled "What is Adaptive Basing?" given to CSBA by the Air Force's Air Force Warfighting Integration Capability organization.

Six Posture Resiliency Lines of Effort[100]

Improve threat detection and warning. Threat detection and warning capabilities include strategic and tactical systems that provide the joint force with awareness of the battlespace, advanced indications of possible attacks, and warnings of actual attacks on U.S. bases.[101] Although the U.S. military has developed a relatively robust warning system for aircraft and ballistic missile threats (especially ICBMs), there are shortfalls in its ability to detect and provide warning of cruise missile and UAS attacks.[102] The Air Force could modify some of its current capabilities, possibly including current UAS such as the MQ-9, and procure high-altitude long-endurance UAS and future space-based multi-spectral sensors capable of detecting non-ballistic missile threats.[103]

Increase the Air Force's ability to conduct dispersed operations. The concept of dispersing forces that may be subject to major air and missile attacks is not new. Japanese surprise attacks on U.S. airbases in the Pacific during the opening stages of World War II proved the folly of concentrating aircraft at airbases that are virtually undefended.[104] Throughout most of the Cold War, the Air Force continually refined and exercised its ability to operate from a distributed network of airfields and opportune locations in Europe to offset Warsaw Pact massed fires. The Air Force is now working toward regenerating its capability to operate from dispersed postures in the Indo-Pacific region and in Europe. Decades of force concentration in search of increased operations efficiencies must be selectively rolled back in favor of decentralization and redundancy. This will likely be a difficult and costly endeavor, especially in the Indo-Pacific, where significant improvements to widely dispersed airfields and supporting logistics infrastructure may be needed.[105]

100 Some of these lines of effort are informed by a series of 2008–2009 "Pacific Vision" wargames and CJCS Joint Publication 3-01, *Countering Air and Missile Threats*, April 21, 2017, available at https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_01_pa.pdf?ver=2018-05-16-175020-290. Pacific Vision was played by experts from the RAND Corporation's Project Air Force, the U.S. Air Force, CSBA, and other organizations. See *RAND Project Air Force (PAF) Annual Report 2009* (Santa Monica, CA: RAND Corporation, 2009), pp. 5–7, available at https://www.rand.org/content/dam/rand/pubs/annual_reports/2009/RAND_AR7145.pdf.

101 Some refer to detection and warning described here as "indications and warning" (I&W).

102 Thomas K. Hensley, Lloyd P. Caviness, Stephanie Vaughn, and Christopher Morton, "Understanding the Indications and Warning Efforts of U.S. Ballistic Missile Defense," *Joint Forces Quarterly* 78, 3rd Quarter, 2015, available at https://ndupress.ndu.edu/JFQ/Joint-Force-Quarterly-78/Article/607660/understanding-the-indications-and-warning-efforts-of-us-ballistic-missile-defen/; There is no comparable indications and warning article for non-ballistic missiles defenses.

103 See, for example, see Rehberg and Gunzinger, *Air and Missile Defense at a Crossroads*; and Gunzinger et al., *An Air Force for An Era of Great Power Competition*. Armed MQ-9s or other UAS equipped with directed energy or kinetic interceptors could also help counter cruise missile attacks and other threats to airbases.

104 Alan J. Vick, *Air Base Attacks and Defensive Counters: Historical Lessons and Future Challenges* (Santa Monica, CA: RAND Corporation, 2015).

105 Aaron Mehta, "Esper Calls for New Basing Investments in the Pacific," *Defense News*, August 27, 2019. Also see Miranda Priebe, Alan J. Vick, Jacob L. Heim, and Meagan L. Smith, *Distributed Operations in a Contested Environment: Implications for USAF Force Presentation* (Santa Monica, CA: RAND Corporation, 2019), pp. 9–23, available at https://www.rand.org/content/dam/rand/pubs/research_reports/RR2900/RR2959/RAND_RR2959.pdf.

Creating more dispersed force postures requires more than just developing new airfields or adapting additional existing airfields for military use. Regaining the ability to conduct dispersed air operations in future contested areas will require the Air Force to develop new operating concepts, tactics, techniques, and procedures and then regularly exercise these capabilities. Over the last few years, the Air Force has experimented with concepts such as the F-22 Rapid Raptor 2.0 that deploys small numbers of F-22 fighters accompanied by a C-17 airlift aircraft to small and sometimes austere bases to conduct distributed operations.[106] Other concepts the Air Force and other Services have explored or are developing include adaptive basing; posturing air forces in "clusters" of airbases to facilitate mutual logistics and missile defense operations; the Marine Corps' expeditionary advanced base operations (EABO); and several variations of these concepts.[107] However, the corresponding logistics concepts and efforts to define material requirements needed to support these novel force posture approaches are still in their infancy.

Executing effective dispersed operations will require the Air Force to invest in a variety of enabling capabilities, including additional air mobility systems and logistics infrastructure. In particular, the Air Force will require additional resilient logistics infrastructure at more locations, as well as new logistics assets to support distributed operations at scale.[108] Although the Air Force has experimented with using air mobility aircraft to support refueling and rearming of small numbers of fighter aircraft on the ground, it is unlikely these approaches will scale to support bulk supply demands for a large number of forces at multiple locations. The U.S. military may need to acquire a larger number of maritime and ground logistics assets such as additional Afloat Pre-positioned Fleet ships, sealift tankers, and systems capable of transferring fuel and bulk supplies at scale, such as Offshore Petroleum Distribution Systems and Inland Petroleum Distribution Systems.[109]

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106 Priebe, Vick, Heim, and Smith, *Distributed Operations in a Contested Environment*, p. 18. Also see Amy McCullough, "Rapid Raptor 2.0," Air Force Magazine News, March 6, 2017.

107 For a basic description of the adaptive basing concept, see Airman 1st Class JaNae Capuno, "Gunfighter Flag 18-3, Adaptive Basing," Air Combat Command, July 24, 2018, available at https://www.acc.af.mil/News/Tag/117666/adaptive-basing/. For a description of expeditionary air base operations, see Jim Lacey, "The Dumbest Concept Ever Just Might Win Wars," *War on the Rocks*, July 29, 2019. A recent RAND report proposed three categories for future U.S. Air Force bases that address tradeoffs between the advantages and disadvantages of dispersed operations and improving airfield resiliency. See Priebe, Vick, Heim, and Smith, *Distributed Operations in a Contested Environment*, pp. 9–23.

108 United States Transportation Command, "Mobility Capabilities and Requirements Study (MCRS) 2018, Executive Summary," February 8, 2019, available via https://www.airforcemag.com/PDF/DocumentFile/Documents/2019/MobilityCapabilitiesRequirementsStudy2018.pdf. See also Courtney Albon, "New Mobility Requirements Study Projects No Growth in DOD Airlift, Tanker Capacity," *Inside Defense*, February 5, 2019.

109 For an assessment of potential future maritime logistics requirements, see Timothy A. Walton, Ryan Boone, and Harrison Schramm, *Sustaining the Fight: Resilient Maritime Logistics for A New Era* (Washington, DC: Center for Strategic and Budgetary Assessments, 2019).

Increase the number of theater operating locations for CAF operations. DoD should continue to expand the number of locations and improve infrastructure needed to support distributed CAF operations in the Indo-Pacific and Europe. Sufficient basing and infrastructure are key to conducting effective distributed operations during a great power conflict. This is especially true in the Indo-Pacific, given the expansive size of the operating area and the relatively small number of U.S. main operating bases in theater. Increasing the number of the CAF's operating locations would also help decrease China's or Russia's ability to concentrate their missile attacks on a small number of airfields. Based on multiple wargames led by CSBA over the last decade, future CAF operations would also benefit by increasing the number of airfields that Air Force aerial refueling tankers can use to support combat air operations.

Improve airbase hardening. Hardened aircraft shelters are the most visible means of increasing the resiliency of the Air Force's theater bases. Congress appropriated resources for two new large hardened hangars at Andersen AFB on Guam. Other than these two hangars, the U.S. military has done little to harden its Indo-Pacific bases against potential Chinese air and missile attacks over the last two decades.[110] From 2000 to 2014, DoD increased the number of its hardened aircraft shelters by 2.5 percent, whereas from 2000 to 2012, the People's Liberation Army increased its hardened shelters by almost 240 percent, from 92 to 312.[111] Of the U.S. military's 200-some hardened aircraft shelters in the Indo-Pacific, most are in South Korea and would be impractical for use in a South China Sea conflict. Additional hardening throughout the theater is also needed to protect personnel, fuel infrastructure, communications nodes, munitions, and other resources critical to sustaining airbase operations while under attack. Similar hardening and other resiliency improvements are needed for bases that would be used by U.S. forces in Europe during a conflict with Russia.

110 David Lewton, "The Dragon Pours Concrete," *Air Force Magazine*, December 2014.

111 Ashley Townshend, Brendan Thomas-Noone, and Matilda Stewart, *Averting Crisis: American Strategy, Military Spending and Collective Defence in the Indo-Pacific* (Sydney: United States Studies Centre, August 19, 2019), p. 56, available at https://www.ussc.edu.au/analysis/averting-crisis-american-strategy-military-spending-and-collective-defence-in-the-indo-pacific.

Improve rapid airfield damage repair capabilities. In addition to hardening critical base facilities, the Air Force should improve its capacity to conduct rapid airfield damage repair (RADR).[112] Repairing runways that have been damaged by air and missile attacks is the most widely recognized aspect of RADR. New capabilities to facilitate RADR operations include small specialized UAS and other systems that can rapidly assess damage and determine the most expeditious way to repair a runway, as well as Mine Resistant Ambush Protected vehicles equipped with a laser and other capabilities to eliminate unexploded ordinance. A variety of new materials and techniques to rapidly repair runway damage are also under development.[113] Air Force airbases should also have backup systems for providing the electricity, water, and fuel required to generate combat power and resupply the base while under attack. Although there have clearly been major improvements in the Air Force's RADR capabilities, additional resources will be needed for these and other improvements to create a more resilient forward posture.

Develop active kinetic and non-kinetic air and missile defenses. In 2018, CSBA released a report that made eight recommendations for developing and fielding active airbase defenses.[114] The report concluded the Air Force should take advantage of new technologies that will provide high-capacity defenses against air and missile threats. Some of these technologies include non-developmental UAS that can be modified for air and missile defense missions, affordable long-range air-to-air missiles capable of intercepting ballistic missiles, and possibly hypersonic glide vehicles, and airborne and ground-based directed energy weapons to counter cruise missiles and UAS threats.[115] Studies on the tradeoffs between the cost and effectiveness of various active airbase defenses, passive defenses, requirements for basing new force structure, and basing forces at greater ranges from land-based Chinese and Russian missile threats would help inform the Air Force's future base resiliency investments.

112 RADR focuses on improving the resiliency of airbase infrastructure as well as the timely repair and regeneration of airfield operations. It includes developing, testing, and certifying equipment; materials; and tactics, techniques, and procedures for the rapid assessment and repair of damaged runways and other airfield facilities. See Benjamin Raughton, "Dirt Boys Restore Taxiway in 23 hrs Despite Record Heat," *Air Force Civil Engineer Center News*, August 20, 2018, available at https://www.afcec.af.mil/News/Article-Display/Article/1610721/dirt-boys-restore-taxiway-in-23-hrs-despite-record-heat/. RADR is replacing older capabilities developed in the 1990s that are commonly referred to as rapid runway repair (RRR) capabilities.

113 Jess Echerri, "New Sensors Expected to Speed Up ADR Process," *Air Force Civilian Engineer Center News*, June 2, 2015, available at https://www.afcec.af.mil/News/Article-Display/Article/871470/new-sensors-expected-to-speed-up-adr-process/; and Joseph Tevithick, "USAF Bomb Disposal Units Will Soon Get Laser-Armed Trucks to Rapidly Clear Mined Airfields," *The War Zone*, August 24, 2018, available at https://www.thedrive.com/the-war-zone/23120/usaf-bomb-disposal-units-will-soon-get-laser-armed-trucks-to-rapidly-clear-mined-airfields. This is an extremely important capability and critical to protecting personnel.

114 Rehberg and Gunzinger, *Air and Missile Defense at a Crossroads*.

115 This is not an exhaustive list. See U.S. Air Force, *Innovation for Advantage: USAF Air Force Blue Horizons Annual Report 2018-2019* (Maxwell AFB, AL: Center for Strategy and Technology, August 2019). Whereas this report is not available to the public, for general information on Blue Horizons, see https://www.airuniversity.af.edu/CSAT/.

Clarifying Responsibilities for Future U.S. Airbase Air and Missile Defense

Although DoD's development of new air and missile defense technologies is progressing, transitioning them to acquisition programs remains a challenge. To a large extent, uncertainty over which Service or other DoD organization should accept responsibility for funding acquisition programs for airbase active defense capabilities remains a barrier to their procurement. In particular, DoD has not clarified which Service or Services should have the primary responsibility for organizing, training, and equipping forces for theater airbase cruise missile defense operations. A current DoD directive requires all of the Services to provide their unique capabilities for missile defense without elaborating on what these capabilities are. It also directs the Army to organize, train, and equip forces to "conduct air and missile defense to support joint campaigns and assist in achieving air superiority;" the Navy to organize, train, and equip to "conduct ballistic missile defense;" and the Air Force to organize, train, and equip to "conduct offensive and defensive operations, to include appropriate air and missile defense, to gain and maintain air superiority and air supremacy as required."[116] This ambiguous guidance has been a contributing factor to the long-term debate between the Air Force and the Army over which should have the primary responsibility for theater airbase air and missile defense.

Given the magnitude of the threat, DoD should clarify the Services' responsibilities for airbase defense. Since missile defense is a core mission of the Army, it should continue to improve its capability and increase its capacity against non-ballistic missile threats in the Indo-Pacific and European theaters. Another approach would be to assign the Air Force increased responsibility to detect and track salvos of ballistic missiles, hypersonic glide vehicles, cruise missiles, and other missile threats. The Air Force could also be assigned responsibility for acquiring passive and active airbase defenses against small UAS, and it should share responsibilities with the Army and other U.S. force providers for active airbase defenses against larger UAS, ballistic missiles, and cruise missiles. The Air Force would need additional funding and end strength for these increased responsibilities.[117]

116 DoD, *Functions of the Department of Defense and Its Major Components* (Washington, DC: DoD, December 21, 2010), pp. 28–34, available at http://www.dtic.mil/whs/directives/corres/pdf/510001p.pdf.

117 Group 1 and 2 UAS are small aircraft that weigh less than 55 pounds and fly below 3,500 feet above ground level (AGL) at less than 250 knots airspeed. Group 3 UAS have a maximum gross weight of less than 1,320 pounds and operate below 18,000 feet mean sea level (MSL) at less than 250 knots airspeed. Group 4 UAS have a maximum gross weight of more than 1,320 pounds and operate below 18,000 feet MSL at any airspeed. Group 5 UAS have a maximum gross weight of more than 1,320 pounds and operate above 18,000 feet MSL at any airspeed. DoD, FY2009-2034 *Unmanned Systems Integrated Roadmap* (Washington, DC: DoD, April 6, 2009), pp. 96–97, available at https://www.globalsecurity.org/intell/library/reports/2009/dod-unmanned-systems-roadmap_2009-2034.pdf.

Summary

Maintaining the Air Force's ability to generate air combat power to defeat great power aggression will hinge on its ability to improve the resiliency of its forward posture. The 2018 NDS established airbase resiliency as a critical means to assure U.S. allies and partners while inhibiting a great power aggressor from achieving a *fait accompli*. Developing a forward posture that is "more resilient and survivable" will require the Air Force, other Services, and U.S. Combatant Commands to develop new operating concepts supported by robust investments in active and passive air and missile defenses, logistics infrastructure, and other capabilities to increase the resiliency of their forces and bases.[118] Failing to do so will further degrade the credibility of the U.S. military's forward posture and its ability to engage great power aggressors. Simultaneously, the Air Force should continue its force structure investments to enhance its ability to project combat power from range. A properly balanced mix between the Air Force's long-range power projection and forward-deployed forces would maximize strategic challenges for an adversary, bolster U.S. regional allies and partners, and preserve decision-space for U.S. policymakers.

118 For recommendations that would improve the resiliency of DoD's regional posture, see Edelman and Roughead, *Providing for the Common Defense*, pp. 34–35.

CHAPTER 4

Exploit the Force Multiplying Potential of Current and Future UAS

The Air Force is in a conundrum. It must recapitalize its CAF, but it cannot retire sufficient quantities of its current CAF aircraft to fund necessary acquisition programs without accepting an excessive degree of risk.[119] The Air Force tried that approach several times in recent decades, divesting significant numbers of CAF aircraft in the hope that it would eventually receive funding to procure next-generation replacements. These CAF "redux" initiatives may have saved some resources in the near term, but they did not yield savings that were sufficient to modernize the force.[120] Implementing a similar cut to the CAF at this time without assurances of a significant budget increase to acquire new next-generation capabilities could risk further widening the gap between the Air Force's combat capacity and 2018 NDS requirements.

Whereas modernization is critical, and increased high-end manned aircraft capacity is required, unmanned systems continue to represent a significant but not-yet-fully exploited opportunity. Spurred by new operational concepts, unmanned systems that are now operational or that could soon join the force could help reduce the Air Force's capacity shortfalls by increasing the number of effective sorties it can launch. In particular, the Air Force could use low-cost attritable and recoverable UAS to support multi-domain BMC2, airbase defense,

119 Townshend, Thomas-Noone, and Stewart, *Averting Crisis*.

120 Air Force procurement of new aircraft reached a historic low as a percentage of its total obligational authority in 2013 and has since remained well below levels needed to develop the Service's proposed "The Air Force We Need." See Gunzinger and Rehberg, *Moving Toward the Air Force We Need?*

counterair, and other missions.[121] This chapter addresses a number of these UAS and introduces concepts for their employment that could help reduce the Air Force's shortfalls in combat capacity as it transitions to a force better suited for great power competition. Some current-generation UAS, either off-the-shelf or with some feasible modifications, could perform a broader range of high-priority missions than in the past. Additionally, UAS are historically cheaper to procure and operate than manned aircraft, which could allow the Air Force to better focus resources on future capabilities and missions not suitable for UAS.

Rethinking Roles and Missions for UAS

Military innovation in the aerospace domain entails creating news ways for airmen to employ their existing and future capabilities as well as developing cutting-edge technologies.[122] Conversely, the failure to develop new operating concepts and organizational structures can prevent militaries from realizing the full potential of new technologies in the battlespace.[123] For instance, over the last two decades, the U.S. military has used unmanned aircraft such as the MQ-1 Predator and MQ-9 Reaper almost exclusively for ISR and light attack missions.[124] UAS such as the Predator-C/Avenger, future variants of the Navy's MQ-25 aerial refueling UAS, or iterations of developmental aircraft such as the X-47B could perform a much broader range of missions.[125] This is not a distant vision; some current UAS and new capabilities that could soon join the force have the potential to support gray zone deterrence operations, defend theater airbases and other U.S. military installations from missile attacks, and increase the Air Force's capacity to deliver large numbers of weapons and create other effects in the battlespace over long ranges.

UAS Support for Gray Zone Deterrence Operations

Deterring Chinese and Russian aggression is more than simply preparing to defeat their militaries in open combat. Both countries are pursuing strategies that rely on proxy and paramilitary forces, special operations forces, and other non-traditional means. These strategies are focused on destabilizing neighboring governments, degrading regional alliances, and

121 A 2014 CSBA report assessed how "multi-mission, penetrating, and semi-autonomous UAVs teamed with manned aircraft acting as airborne battlespace controllers could extend the reach of the CAF and increase the density of weapons it can place in target areas." See Mark Gunzinger and David Deptula, *Toward A Balance Combat Air Force* (Washington, DC: Center for Strategic and Budgetary Assessments, 2014).

122 U.S. Air Force, *Innovation for Advantage: USAF Blue Horizons Annual Report 2017-2018* (Maxwell AFB, AL: Center for Strategy and Technology, August 2018). Whereas this report is not available to the public, for general information on Blue Horizons, see https://www.airuniversity.af.edu/CSAT/.

123 Thomas G. Mahnken, *Technology and the American Way of War Since 1945* (New York: Columbia University Press, 2008).

124 For a more comprehensive study on this topic, see Thomas P. Ehrhard, *Air Force UAVs: The Secret History* (Arlington, VA: Mitchell Institute for Aerospace Studies, 2010). Also see Chloe Thompson, "The Advent of the UAV Era," *American Foreign Policy Council* 20, November 2017, pp. 23–24.

125 These UAS were called "Multi-mission UAS" (MM-UAS) in CSBA's 2019 report *An Air Force for an Era of Great Power Competition*.

ultimately expanding China or Russia's control over territories along their peripheries. They are also designed to achieve their hegemonic objectives while remaining below a threshold of violence that would typically result in a military response by the United States and its allies. Deterring this gray zone aggression is, therefore, a key component of great power competition.

CSBA's *An Air Force for an Era of Great Power Competition* recommended the Air Force's UAS structure might be ideally suited to help deter this gray zone aggression. The extended mission endurance of many contemporary UAS, their capacity to carry a variety of sensor and weapons payloads, and their smaller ground footprint relative to manned aircraft are attributes that are well-suited for U.S. operations in the gray zone. MQ-9 Reapers, for instance, have been an unqualified success in conducting counterterror missions and other irregular warfare operations over the last dozen years. Reapers are equipped with a Multi-Spectral Targeting System (MTS) that has a TV camera, infrared sensor, laser range finder, and a laser designator that can direct laser-guided weapons precisely to a target. They can carry laser-guided Hellfire missiles for air-to-ground anti-personnel and anti-armor strikes and, in the future, weapons for other missions such as the Miniature Air-Launched Decoy (MALD) and MALD-Jammer.

These non-stealth long-endurance UAS combined with smaller attritable UAS—discussed in the next section—could help detect, identify, track, and expose acts of gray zone aggression and other malign behavior by China or Russia. Unlike low-observable aircraft or space-based ISR assets, the high visibility of a robust wide-area persistent surveillance network enabled by non-stealth reconnaissance UAS could support a "deterrence by detection" strategy.[126] Air Force MQ-9s are already stationed in Poland to support deterrence operations along NATO's eastern frontier. According to a U.S. Air Force in Europe press release, these MQ-9s are "providing intelligence, surveillance and reconnaissance in support of U.S. foreign policy security" and "valuable force protection data to the U.S. and international partners."[127] The Air Force has suggested other uses for the MQ-9 that are suitable for operations in the gray zone (see Figure 16).

The MQ-9 is just one example of how mature UAS could be configured to support operations in the gray zone and otherwise. The MQ-9 also has one of the lowest operating costs per flying hour—about 25 percent the cost per flying hour of an A-10—and a mission capable rate of about 90 percent that exceeds the mission capable rate of nearly every other aircraft in the Air Force's inventory.[128] Although the MQ-9 is not a low-observable weapon system designed for operating in contested areas, it could perform missions to deter gray zone aggression in

126 This will be discussed in a forthcoming CSBA publication by Thomas G. Mahnken, Billy Fabian, Travis Sharp, and Grace B. Kim on innovative concepts for deterring Great Power aggression.

127 Preston Cherry, "MQ-9 Detachment Becomes Fully Operational," *U.S. Air Forces in Europe and Air Forces Africa News*, March 4, 2019, available at https://www.usafe.af.mil/News/Article-Display/Article/1773928/mq-9-detachment-becomes-fully-operational/.

128 Stephen Losey, "Aircraft Mission-Capable Rates Hit New Low in Air Force, Despite Efforts to Improve," *Air Force Times*, July 26, 2019.

peacetime. It could also operate in permissive environments during great power conflict to help free 4^{th} generation and 5^{th} generation combat aircraft for higher-end missions.

FIGURE 16: MQ-9 AT A POLISH AIRFIELD AND POTENTIAL FUTURE MQ-9 MISSIONS

- **Support to peacekeeping and counter-narcotic operations**
- **Coastal and border surveillance**
- **Embargo enforcement**
- **Weapons tracking**
- **Convoy/raid overwatch**
- **Combat search and rescue**
- **Humanitarian/disaster assistance**

The list of potential MQ-9 missions in Figure 16 is from "MQ-9 Reaper," U.S. Air Force factsheet, September 23, 2015, available at https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104470/mq-9-reaper/. In addition to these missions, MQ-9s could serve as communications relay nodes, provide standoff wide-area surveillance in permissive environments, and detect and track various air and missile threats.Picture from https://www.airforcetimes.com/news/your-air-force/2019/03/05/air-force-mq-9-reaper-drones-based-in-poland-are-now-fully-operational/

Improving Resiliency of the Air Force's Forward Posture

The size, weight, and power capacity of MQ-9-class UAS give them the ability to host large aperture advanced sensors such as AESA radars or other electronic support systems that could provide a standoff surveillance capability similar to contemporary large manned ISR aircraft.[129] UAS equipped with appropriate sensors could help defend theater airbases from air and missile attacks by conducting persistent wide-area surveillance of areas where an enemy might launch missile salvos and providing initial detection and warning of missile attacks on U.S. theater bases.[130] These UAS could team with other unmanned aircraft equipped with solid-state high energy lasers (HELs) to form an outer layer of defenses against cruise missile salvos, swarms of armed UAS, and other airborne threats to U.S. bases.[131] Multi-mission UAS like the Predator-C Avenger or a modified variant of the MQ-25 could support defensive counterair combat air patrols or protect the operations of U.S. and allied high-value aircraft in permissive and lightly contested environments. It may be possible to integrate AIM-9X, counter-UAS missiles—or possibly even longer-range AIM-120 AMRAAM air-to-air missiles—on UAS to give them a kinetic capability to defeat some airborne threats.[132]

Reducing the "footprint" of personnel, forces, and infrastructure stationed at forward airbases is another way to improve the resilience of the Air Force's posture. For example, the new Automatic Takeoff and Landing Capability (ATLC) for UAS will improve the Air Force's ability

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129 Tyler Rogoway, "USAF Officially Retires MQ-1 Predator While MQ-9 Reaper Set to Gain Air-To-Air Missions," *The War Zone*, March 9, 2018, available at https://www.thedrive.com/the-war-zone/19122/usaf-officially-retires-mq-1-predator-while-mq-9-reaper-set-to-gain-air-to-air-missiles.

130 See Rehberg and Gunzinger, *Air and Missile Defense at a Crossroads*; and Gunzinger et al., *An Air Force for An Era of Great Power Competition*.

131 Ibid.

132 Ibid.

to sustain MQ-9s with less logistical support and smaller on-site ground crews. Rather than requiring an aircrew and control station in theater to launch and recover the UAS, crews can execute these tasks from remote locations, including locations in the United States. This automated capability will help the Air Force "reduce required aircrew manpower and LRE launch and recovery element] footprints."[133] Some future attritable UAS, assessed in the next section, will be able to launch and recover *without* the need to use a runway, further improving the resiliency of the Air Force's posture and complicating Chinese and Russian offensive counterair strike planning.

Potential Attritable UAS and Their Applications

Developing new concepts for employing current and emerging UAS capabilities alongside manned aircraft could increase the Air Force's combat capacity and reduce risk during future air operations in permissive and contested environments. Acquiring attritable UAS could also reduce the Air Force's overall aircraft operating and support (O&S) expenditures. O&S savings over time could help fund other CAF modernization priorities.

What Are Attritable UAS?

For the purposes of this report, attritable UAS have significantly lower unit procurement costs relative to manned aircraft if manufactured in significant quantities. The airframe and engine for an attritable UAS such as the developmental Valkyrie could cost about $2.5 million, with a goal of around $2.0 million for each fully integrated aircraft if more than 100 are procured. Additional avionics, sensors, and weapons could increase the unit cost of some attritable UAS to $8.0 million. Attritable UAS may cost less than 10 percent to operate and sustain compared to Air Force manned fighters and would require a small number of flight hours in peacetime for training and exercises with manned aircraft (see Table 9 at the end of this section).

The Air Force and other DoD organizations have launched multiple initiatives to develop attritable UAS. In 2016, the Air Force Research Laboratory (AFRL) funded several attritable UAS development programs under its Low Cost Attritable Aircraft Technology (LCAAT) umbrella program. One of LCAAT's primary objectives is to "break the escalating cost trajectory of tactically-relevant aircraft."[134] By using better design tools, leveraging commercial

133 See "GA-ASI Demonstrates Latest Automatic Takeoff and Landing Capability Using SATCOM Data Link for MQ-9B RPA," *AUVSI News*, January 24, 2018, available at https://www.auvsi.org/industry-news/ga-asi-demonstrates-latest-automatic-takeoff-and-landing-capability-using-satcom-data; and General Atomics-ASI, "USAF Completes First Auto-Land Using MQ-9 Block 5: Signals USAF's Move Towards Increased Flight Automation for RPA," *Jane's by IHS Markit*, September 17, 2018.

134 88th Air Base Wing Public Affairs, "AFRL XQ-58A Completes Second Successful Flight," *U.S. Air Force News*, June 17, 2019, available at https://www.af.mil/News/Article-Display/Article/1877980/afrl-xq-58a-uav-completes-second-successful-flight/.

manufacturing, and vertically integrating production and manufacturing processes, it may be possible to field some attritable UAS by 2023 or earlier.[135]

The following bullets identify a number of Air Force and Defense Advanced Research Projects Agency (DARPA) initiatives associated with the development of attritable UAS:

- Low Cost Attritable Strike Demonstrator (LCASD). An AFRL program to develop a UAS with sufficient range and payload for less than $3 million each. LCASD was part of the LCAAT program.
- Skyborg. An Air Force Strategy Development Planning Experimentation initiative to demonstrate the ability of an unmanned combat air vehicle (UCAV) to autonomously and collaboratively defend high-value aircraft such as aerial refueling tankers and E-3 AWACS. Skyborg is absorbing LCAAT and LCASD and will be AFRL's new umbrella program for developing attritable UAS.[136]
- Low Cost Attritable Aircraft Platform Sharing (LCAAPS). An AFRL program focused on developing low-cost UAS avionics, electrical systems, and core airframes that could rapidly be refitted with different wings, tails, and even engines to meet different mission needs.
- Golden Horde. A new AFRL program that seeks to network expendable munitions and other systems to conduct collaborative attacks on targets.[137]
- Gremlins. A DARPA program to demonstrate the ability to use airborne C-130 cargo aircraft or other platforms to launch and recover attritable UAS.
- Air Combat Evolution (ACE). A DARPA program to develop artificial intelligence algorithms to perform aerial combat operations.
- Collaborative Operations in Denied Environments (CODE). A DARPA program to develop artificial intelligence algorithms to enable future UAS to operate in contested environments without GPS and communications—and some UAS to independently or collaboratively find and engage highly mobile ground and maritime targets.[138]

Other DoD programs are developing modular open-systems architectures to rapidly upgrade attritable UAS avionics and sensors or quickly change their capabilities as operational needs change.

135 Harry Lye, "Skyborg: the US Air Force's Future AI fleet," *Air Force Technology*, August 28, 2019.

136 Ibid.

137 Rachel S. Cohen, "AFRL's New Goal: Make Munitions Plan Attacks," *Air Force Magazine*, June 21, 2019.

138 "CODE Demonstrates Autonomy and Collaboration with Minimal Human Commands," DARPA, November 19, 2018, available at https://www.darpa.mil/program/collaborative-operations-in-denied-environment.

Some Potential Operational Advantages of Attritable UAS

Reduced dependence on fixed runways and infrastructure. AFRL's Skyborg umbrella program is developing UAS that would not be dependent on using runways for their launch and recovery, including attritable UCAVs similar to the XQ-58A Valkyrie.[139]

FIGURE 17: XQ-58A VALKYRIE FIRST FLIGHT

Source: https://commons.wikimedia.org/wiki/File:XQ-58A_Valkyrie_demonstrator_first_flight.jpg

In the near future, a crew of three to four people may be able to launch Group 2, 3, or 4 UAS equipped with rocket-assisted take-off (RATO) packages from small clearings. Future air-launched "Gremlins" attritable UAS could support some of the operating concepts illustrated in Figure 19. DARPA's Gremlins program is developing low-cost small UAS that are reusable and could be launched by C-130 cargo planes or other aircraft in large numbers. These UAS could penetrate contested airspace, collaboratively perform various missions, and then return and be recovered by the mothership aircraft without landing (see Figure 18).[140] According to DARPA, Gremlins could "provide U.S. forces with improved operational flexibility at much lower cost than is possible with today's expensive, all-in-one platform."[141] UAS in development will also be able to use different kinds of parachutes, possibly combined with airbags, to help protect UAS sensors, electronics, and other key components for recovery after missions.

139 Richard Scott, "Fighting Chance: 'Loyal Wingman' Drones Seek to Alter the Air Power Equation," *Jane's by IHS Markit*, April 16, 2019.

140 DoD, *Fiscal Year (FY) 2020 Budget Estimates, Defense Advanced Research Projects Agency, Research, Development, Test & Evaluation* (Washington, DC: DoD, March 2018), p. 108, available at https://insidedefense.com/sites/insidedefense.com/files/documents/2019/mar/03182019_darpa.pdf.

141 "The gremlins' expected lifetime of about 20 uses could provide significant cost advantages over expendable systems by reducing payload and airframe costs and by having lower mission and maintenance costs than conventional platforms, which are designed to operate for decades." Scott Wierzbanowski, "Gremlins," DARPA, available at https://www.darpa.mil/program/gremlins.

FIGURE 18: ARTIST'S CONCEPT OF C-130 CARGO AIRCRAFT RECOVERING ATTRITABLE GREMLINS

Graphic courtesy of DARPA, available at https://www.darpa.mil/ddm_gallery/gremlins-news-release.jpg

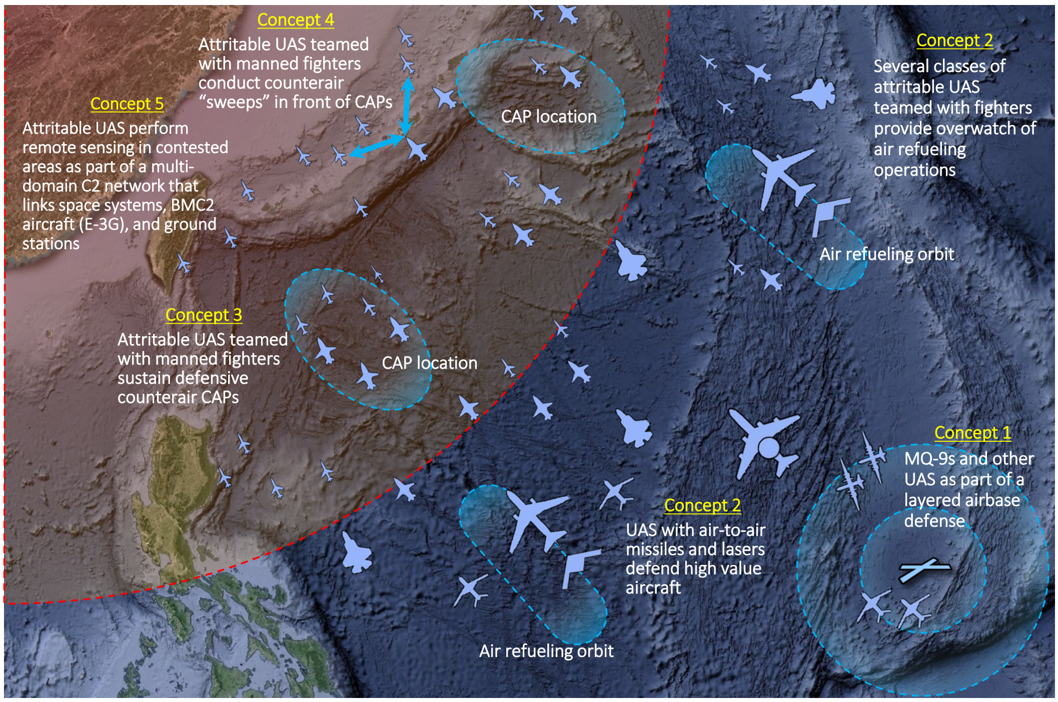
A future CAF with attritable UAS that can be air-launched and recovered or ground-launched using RATO and recovered to austere locations would give the Air Force the ability to generate combat sorties from virtually anywhere along the First Island Chain in the Indo-Pacific and along NATO's eastern frontier. This independence from fixed runways would help increase the Air Force's capacity to maintain a more robust combat presence forward and create a more resilient posture by reducing its reliance on airbases that are vulnerable to air and missile attacks.

Increased persistence in the battlespace. Future UAS, including attritable platforms, could have ranges that are as long or longer than the manned aircraft they team with. Some attritable medium UAS could have ranges that far exceed the unrefueled range of manned fighters (see Table 9). Launching and recovering these UAS from areas located near their intended areas of operation would further increase their dwell times in the battlespace and ability to penetrate deep into enemy airspace. UAS designed to conduct persistent operations in high-threat areas will require stealth and other design features that enhance their survivability. Operating concepts for teaming attritable and non-attritable UAS in contested areas such as those illustrated in Figure 19 should also consider the potential for an enemy to disrupt command, control, and communications links between teamed aircraft. Short-range directional LPI/LPD datalinks on teamed aircraft could help reduce the impact of these countermeasures.

Potential Concepts for Manned-unmanned Teaming

AFRL has funded multiple programs to develop technologies and systems for manned and unmanned aircraft teaming operations.[142] DoD uses the term "loyal wingman" to refer to operating concepts that take advantage of the attributes of manned and unmanned aircraft to collaboratively conduct strikes, counterair operations, electronic warfare, and other missions. DoD's vision is to create a new class of cost-effective, high-performance UAS that could survive and improve the survivability of other air platforms in contested environments. Replacing several manned fighters in a typical formation of counterair aircraft with low-cost attritable Valkyries or other UAS could help reduce risk to the manned fighters. Valkyries or other UAS equipped with sensors and datalinks could further extend a teamed pilot's awareness of the battlespace, improving a pilot's ability to detect and initiate actions to avoid or defeat enemy fighters before they can act.[143] Figure 19 illustrates five concepts for manned-unmanned teaming and other UAS operations in a future notional Indo-Pacific conflict.

FIGURE 19: ILLUSTRATIVE CONCEPTS FOR MANNED-UNMANNED TEAMING



These five concepts were chosen primarily for illustrative purposes and are not intended to be exhaustive, there are likely other missions and capabilities for manned-unmanned teaming that should be developed by the Air Force.

142 Man-machine teaming concepts are designed to take advantage of what humans do best, such as infer and make decisions in complex environments, and what machines can do best, such as manipulate data and execute repetitive tasks.

143 According to Assistant Secretary of the Air Force for Acquisition, Technology, and Logistics Will Roper, "We can take risk with some systems to keep others safer . . . We can separate the sensor and the shooter. Right now they're collocated on a single platform with a person in it. In the future, we can separate them out, put sensors ahead of shooters, put our manned systems behind the unmanned. There's a whole playbook." Valerie Insinna, "Under Skyborg Program, F-35 and F-15EX jets could control drone sidekicks," *Defense News*, May 22, 2019.

- Concept #1 illustrates how modified MQ-9s and future multi-mission UAS (MM-UAS) carrying air-to-air missiles and directed energy weapons could help defend a forward airbase against air and missile attacks. These UAS could team with manned airborne and ground defensive systems to detect, track, target, and engage enemy cruise missiles, armed UAS, and, potentially, ballistic missile threats.[144]

- Concept #2 teams attritable UAS, other multi-mission UAS, and 5th generation fighters to defend U.S. AWACs, aerial refueling tankers, and other high-value manned aircraft. Teamed aircraft could carry a mix of extended-range interceptors and directed energy weapons capable of defeating enemy counterair aircraft, air-to-air missiles, and other airborne threats.

- Concept #3 depicts how attritable and non-attritable UAS equipped with appropriate sensors and air-to-air missiles could team with 5th generation fighters to sustain CAPs that screen vulnerable U.S. high-value aircraft from enemy fighters.

- Concept #4 teams several kinds of attritable UAS with 5th generation fighters to conduct "sweeps" that locate and defeat airborne threats in contested and highly contested airspace. These multi-axis pulses of airpower could attrite enemy fighter, BMC2, and other aircraft; probe enemy air and ground defenses; and shape enemy air defensive operations in ways that are advantageous to U.S. forces.

- Concept #5 illustrates attritable UAS with various sensors penetrating contested and highly contested areas as part of a future multi-domain command and control network. This concept is described in greater detail in the next chapter.

Maintaining the degree of secure communications in contested areas needed to conduct these teaming operations is not an insurmountable challenge. Equipping manned and unmanned systems with LPI/LPD datalinks such as the Multifunction Advanced Data Link (MADL) is feasible. Equipping future attritable UAS with advanced collaborative autonomy and AI technologies would also reduce operational disruptions created by enemy electronic warfare systems and could increase combat mass.

Potential Cost Efficiencies

Table 9 contains performance and cost information on UAS that range from attritable Gremlins and larger Group 4 UAS to non-attritable MQ-9s and Avenger ERs. Information for an F-16C fighter is included for comparison purposes. The relatively lower cost of procuring and operating some of these UAS for appropriate missions could help free up funding for other critical force modernization priorities.

144 For a more extensive assessment of this layered airbase defense concept, see Rehberg and Gunzinger, *Air and Missile Defense at a Crossroads*.

TABLE 9: FIGHTERS, UAS, AND EMERGING ATTRIABLE UAS COMPARISONS

	UAS Group	Range and Endurance	Payload in pounds	Launch and Recovery Modes	Average Unit Cost	Cost per Flying Hour relative to an A-10
Gremlins Attritable Small-Medium UAS	2/3	About 250+ nm, about 1.3 hours	About 100	Aerial launched and recovered	$700,000 or less estimated	Less than 10%
Attritable Medium UAS	3	1,400 nm, about 3 hours	About 500 internal and external	RATO, parachute recovery; may use 5,000-ft or shorter runways in peacetime	$1 million or less estimated	Less than 10% excluding cost of equipment to launch & recover the UAS
LCAAT Attritable Medium-Large UAS (Valkyrie)	4	3,000 nm, endurance information not available	600+ internally, external payload information not available	RATO, parachute recovery; may use 5,000-ft or shorter runways in peacetime	$2-3 million	Less than 10% excluding cost of equipment to launch & recover the UAS
MQ-9	5	1,150 nm, 34-plus hours	3,000 internal and external	Uses approximately 5,000-ft runways	About $20 million	About 25%
Avenger ER	5	6,000 nm, about 20 hours	6,500 internal and external	Uses approximately 6,000-ft runways	About $25 million	Not available
F-16C fighter	N/A	Air refuellable	16,000 external carriage	Improved runways	About $70 million	About 1.06 times the A-10's flying hour cost

Data for Table 9 was derived from the Air Force Magazine USAF Almanac, June 2019, pp. 100 and 122, available at http://airforcemag.com/MagazineArchive/Magazine%20Documents/2019/June%202019/AFM_June2019%20Full%20Issue.pdf; "Kratos Unmanned Systems Overview Brief"; and a briefing provided to CSBA by Kratos which had surrogate performance specifications for several classes of attritable UAS. Information on the Predator C (Avenger ER) was provided by General Atomics Aeronautical Systems Inc. For data on the unit cost of the MQ-9, see Sara Sirota, "Senate Appropriators Criticize Air Force's FY-20 Procurement Profile for MQ-9s," *Inside Defense*, September 16, 2019.

The operational cost per flying hour (OCPFH) of attritable UAS shown in Table 9 are far less than the least expensive Air Force manned aircraft OCPFH. Only a handful of Air Force aircraft has an OCPFH that is better than the Group 5 MQ-9 Reaper, which is now one of the least costly aircraft to operate in the entire Air Force. While the OCPFH of the Avenger ER is not available, based on the MQ-9 enterprise, it is also likely to be well below all of the Air Force's fighters, including the A-10. It should also be mentioned that the U.S. defense industrial base may be able to quickly surge the production of some attritable UAS models if needed. The ability to surge production would improve the Air Force's ability to ramp-up its capacity to deter or counter emerging threats in a crisis.

Summary

The Air Force should develop new concepts for using MQ-9 Reapers and other UAS now in the force to deter gray zone aggression, defend U.S. airbases, and support multi-domain command and control operations. In the medium term, the Air Force should procure new, attritable UAS that could team with manned aircraft for missions that span the spectrum of conflict. These concepts could help fill capacity shortfalls that now exist in the CAF, increase the Air Force's ability to generate combat sorties from forward locations, and reduce the Service's reliance on fixed runways that could be attacked by China or Russia.

Table 10 complements the recommendations for a future Air Force aircraft inventory published in CSBA's *An Air Force for an Era of Great Power Competition*. Of note, the Air Force may use a different force presentation methodology for its future attritable UAS.[145] Instead of using PMAI and TAI, Table 10, therefore, recommends a ramp for procuring squadrons of attritable UAS that could be forward stationed, dispersed in a time of crisis, and then used to support the generation of multiple sorties. The data in the table accounts for the rapid pace of development of attritable UAS and the growing need for offensive and defensive combat capacity that MQ-9s, upgraded Predators, variants of the MQ-25, and other near-term unmanned systems could provide.

TABLE 10: RECOMMENDATIONS FOR NEW AIR FORCE UAS THROUGH FY30

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
MQ-9 UAS for traditional ISR and light strike missions (illustrative inventory)	252	246	240	234	228	222	222	222	222	222	222
MQ-9 UAS for airbase defense and gray zone operations (illustrative procurement)	0	6	12	18	24	30	30	30	30	30	30
Fighter-sized UAS (illustrative procurement)	0	2	6	12	18	24	30	36	42	48	54
LCAAT/Medium UAS Squadrons (illustrative procurement)	0	0	0	1	1	2	4	6	8	10	12
Future "MQ-X" stealth UAS (illustrative procurement)	0	0	0	0	0	0	0	0	0	1	5

145 This is based on conversations with subject matter experts in the Air Force working on attritable UAS programs and operating concepts.

CHAPTER 5

Prioritize the Development of Other Future Force Multipliers

This chapter addresses how the Air Force could prioritize the development of force multipliers that would enhance the combat potential of its future force and reduce U.S. sortie, weapons, and other logistics requirements as it transitions to "The Air Force We Need." The emergence of adversaries with PGMs and effective countermeasures against precision attacks has eroded the U.S. military's dominance in precision strike. Previous CSBA reports have assessed the implications of a salvo competition dynamic wherein militaries seek to gain advantages by continuously improving their capabilities to attack with precision and defend against competitors' precision strikes.[146] A major insight from those reports is that brute force approaches that try to compensate for an adversary's air and missile defenses by simply increasing the number of sorties and weapons used to attack a target set can be prohibitively expensive. A better alternative would be to develop and field a new generation of weapons that have a higher probability of surviving to reach their designated targets. This would have the effect of reducing the number of aircraft sorties and weapons needed to attack a target set. Integrating advanced adaptive cycle engines in some existing and future CAF aircraft would also have a force multiplying effect. Adaptive cycle engines now in development promise to significantly improve the performance and unrefueled combat range of combat platforms, possibly without the need to make extensive changes to their airframes. Chapter 5 concludes with recommendations for pursuing multi-domain command and control capabilities. When mature, these capabilities could accelerate the pace of the joint force's operations and reduce the resources needed to achieve desired effects in the battlespace.

146 For more information, see Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*; and Gunzinger and Clark, *Winning the Salvo Competition*.

Hypersonic Weapons and Other Advanced Munitions

As addressed in Chapter 2, Russian and Chinese multi-layered IADS are designed to intercept or otherwise render ineffective individual weapons as well as the aircraft that launch them. Short- and medium-range systems such as the SA-22 Pantsir frequently deploy with strategic SAMs to increase the overall capability of the resulting system-of-systems to engage PGMs, anti-radiation missiles, UAS, and other threats.[147] These systems are supplemented by non-kinetic active defenses, including jammers that disrupt PGM guidance systems and GPS signals they use for guidance.[148] China and Russia are also aggressively pursuing directed energy weapons that can disrupt or damage the aerodynamic features, external casings, or susceptible sensors of guided weapons. They have likewise normalized the use of passive means to degrade an enemy's ability to find, fix, and track targets with precision.[149] Collectively, these active and passive defenses reduce the probability that an attacker's weapons will arrive at their designated target aimpoints or strike actual targets.[150] Compensating for reduced weapons probability of arrival (P_a) values by simply launching more sorties and weapons at a given set of defended targets could substantially increase an attacker's resource requirements, potentially to prohibitive levels (see Figure 20).

FIGURE 20: WEAPONS AND SORTIES NEEDED TO ATTACK A NOTIONAL LARGE TARGET SET INCREASE AS WEAPONS PROBABILITY OF ARRIVAL DECREASES

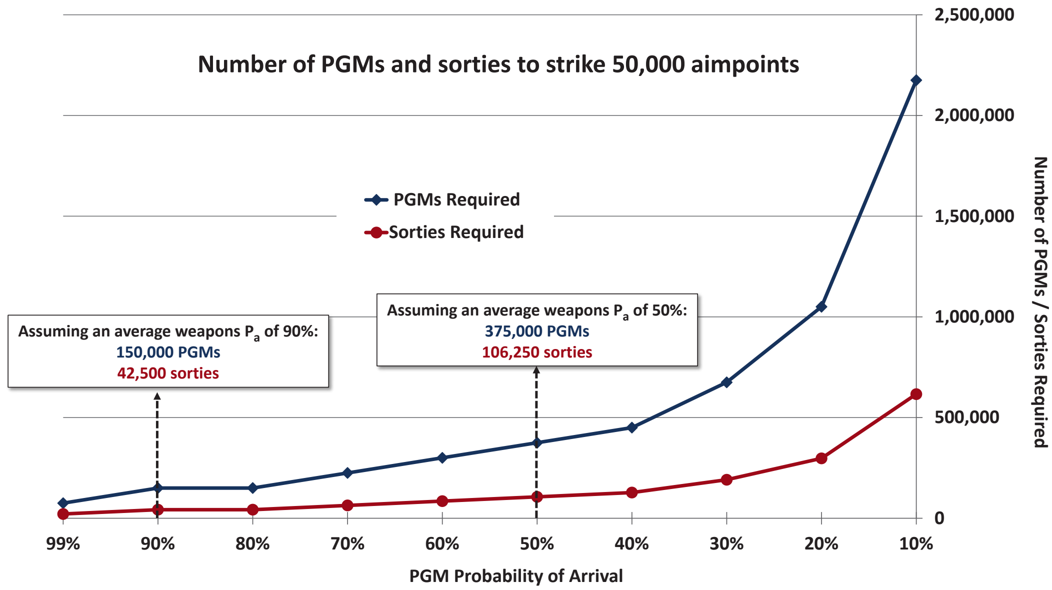


Figure 20 is based on attacks against a notional China target set that was developed from unclassified sources to support the analysis of an Indo-Pacific region conflict scenario. The target set includes 50,000 aimpoints and is limited to potential conventional counter-force targets

147 DIA, *Russia Military Power*, p. 80.

148 Cazalet and Cranny-Evans, "All Quiet on the Eastern Front."

149 Richard D. Fisher Jr., Senior Fellow, International Assessment and Strategy Center, "China's Progress with Directed Energy Weapons," testimony before the U.S.-China Economic and Security Review Commission hearing on "China's Advanced Weapons," February 23, 2017, available at https://www.uscc.gov/sites/default/files/Fisher_Combined.pdf.

150 Gunzinger et al., *An Air Force for An Era of Great Power Competition*, p. 104.

Instead of this "brute force" approach, the U.S. Air Force should develop and field capabilities that increase the survivability and lethality of its strikes, including new weapons that can fly at hypersonic speeds and use maneuvering, signature management, and other means to reduce the probability that enemy defenses will achieve a successful intercept.

Hypersonic Weapons

The U.S. military has expended large numbers of GPS-guided Joint Direct Attack Munitions (JDAMs), non-stealth subsonic cruise missiles, and other PGMs during contingency operations over the last 20 years. Many of these weapons would be ill-suited for initial strike operations against China, Russia, and other adversaries with capable air and missile defenses.[151] Future hypersonic weapons that have higher probabilities of reaching their designated aimpoints in contested areas could have the force multiplying effect of reducing strike sortie and weapon requirements. Hypersonic weapons can achieve and sustain speeds of at least Mach 5 after launch. Broadly speaking, there are two classes of hypersonic weapons: "boost-glide" and "airbreathing" systems. Future boost-glide weapons could use a conventional missile to launch a glide vehicle to high altitudes and accelerate it to hypersonic speeds, after which the vehicle separates from its booster and glides to a target using dynamic non-ballistic flight paths. Future air-breathing hypersonic weapons will include cruise missiles that are powered by ramjet or scramjet engines capable of sustaining flight at hypersonic speeds.[152] Weapons that fly at hypersonic speeds are not new; many types of ballistic missiles fly far faster than Mach 5.[153] What distinguishes them is their ability to fly more unpredictable, dynamic flight paths and operate at much lower altitudes compared to ballistic missiles (see Figure 21). The combination of increased maneuverability, high speeds, and low altitude flight increases the survivability of hypersonic weapons against missile defenses.[154]

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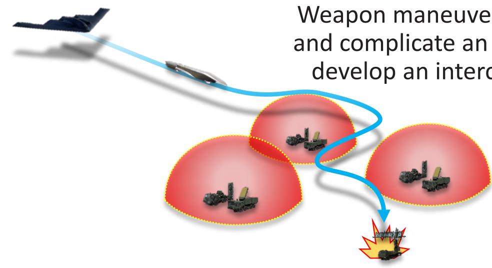
151 For a more in-depth assessment of the shortcomings of U.S. legacy PGMs, see Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*.

152 Kelley M. Sayler, *Hypersonic Weapons: Background and Issues for Congress* (Washington, DC: Congressional Research Service, September 17, 2019), available at https://fas.org/sgp/crs/weapons/R45811.pdf. Ramjet engines compress high-speed air entering their inlets and combine it with fuel-enriched air in a combustion chamber to create thrust needed for hypersonic travel. Supersonic-combustion ramjet (scramjet) engines require the air entering the engine to be traveling at supersonic speeds (about Mach 4.5) to ensure the air is properly condensed to effectively combust with the hydrogen mix. Future ramjet or scramjet powered weapons launched by aircraft or vertical launch systems will need boosters that carry them to approximately 70,000 feet in altitude before their engines can ignite and accelerate them to hypersonic speed.

153 Amy F. Woolf, *Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues for Congress* (Washington, DC: Congressional Research Service, August 14, 2019), available at https://fas.org/sgp/crs/nuke/R41464.pdf.

154 OSD, *Missile Defense Review* (Washington, DC: DoD, January 2019), available at https://media.defense.gov/2019/Jan/17/2002080666/-1/-1/1/2019-missile-defense-review.pdf.

FIGURE 21: ILLUSTRATING A MANEUVERING WEAPON



DoD and the Air Force are currently funding multiple hypersonic weapons technology development programs (see Table 11).

TABLE 11: MAJOR AIR FORCE HYPERSONIC PROGRAMS

Program	Description
Hypersonic Conventional Strike Weapon (HCSW)	Weapon will pair a glide vehicle with a solid-rocket-powered, GPS-guided system that can be launched from a B-52
Air-launched Rapid Response Weapon (ARRW)	Program will develop an air-launched hypersonic glide vehicle capable of Mach 20 speed at a range of about 575 miles
Tactical Boost Glide	DARPA-Air Force cooperative effort to test a hypersonic glide vehicle capable of Mach 7-plus speeds
Hypersonic Air-breathing Weapons Concept (HAWC)	Partnership with DARPA to develop an effective and affordable air-launched hypersonic cruise missile

Michael Bruno, "Identifying Potential Hypersonics Winners and Losers," *Aviation Week & Space Technology,* August 13, 2019. The Navy, Army, and DARPA are also funding multiple hypersonic weapon development programs.

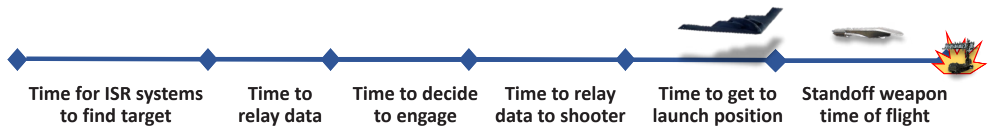
Within a few years, hypersonic weapon programs could give the Air Force the means to strike high-value targets located in contested threat environments without the need to resort to brute force approaches that rely on using mass to overcome advanced air and missile defenses.

Suppressing IADS. Hypersonic weapons could be used for initial strikes against the most heavily defended critical nodes of adversary's IADS, such as space downlink systems, C2 centers, and long-range surveillance systems. Suppressing these threats would also reduce risk to U.S. ISR and strike aircraft, and enable follow-on, higher-volume strikes of less expensive PGMs that otherwise would have difficulty surviving to reach their targets. The unpredictable flight path and high speed of hypersonic weapons significantly reduce the reaction time of a defender, complicates missile tracking and targeting, and otherwise degrades a defender's ability to successfully complete a kill chain to achieve an intercept.[155] Furthermore, the speed of a hypersonic weapon decreases opportunities for a defender to re-engage a threat should an initial intercept attempt prove unsuccessful.

155 Richard H. Speier, George Nacouzi, Carrie A. Lee, and Richard M. Moore, *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons* (Santa Monica, CA: RAND Corporation, 2017), pp. 10–15.

Attacks on time-sensitive targets. U.S. air forces could use hypersonic weapons to prosecute high-value time-critical threats when other forces are denied access or are not preferred. This would give commanders greater operational flexibility. A strike kill chain has a number of steps that collectively add significant time delays between the initial identification of a target and its eventual engagement (see Figure 22).[156] Russia and China both seek to exploit this latency by mobilizing their weapon systems and other key assets that would be targeted by U.S. air forces, creating target location challenges. The high speeds of hypersonic weapons reduce the time they need to reach a target, which has the effect of reducing target location errors. This will improve the Air Force's ability to prosecute highly mobile high-value targets such as missile TELs and other elements of an IADS.

FIGURE 22: ILLUSTRATING KILL CHAIN TIMING



Deep strikes from standoff ranges. Given their speed, ability to circumvent enemy defenses, and long range, some hypersonic weapons could be effective against very high-value targets such as anti-satellite (ASAT) weapon sites that are located deep in the interiors of China and Russia. Long-range hypersonic weapons could be launched by non-penetrating aircraft from outside the effective range of an adversary's IADS to supplement penetrating strikes. The ability to launch from standoff ranges would enable legacy aircraft that will comprise a significant proportion of the CAF well into the future to engage in a fight on day one. Additionally, striking from standoff ranges could possibly lessen the CAF's overall demand for aerial refueling tankers, electronic warfare aircraft, and other supporting assets.[157]

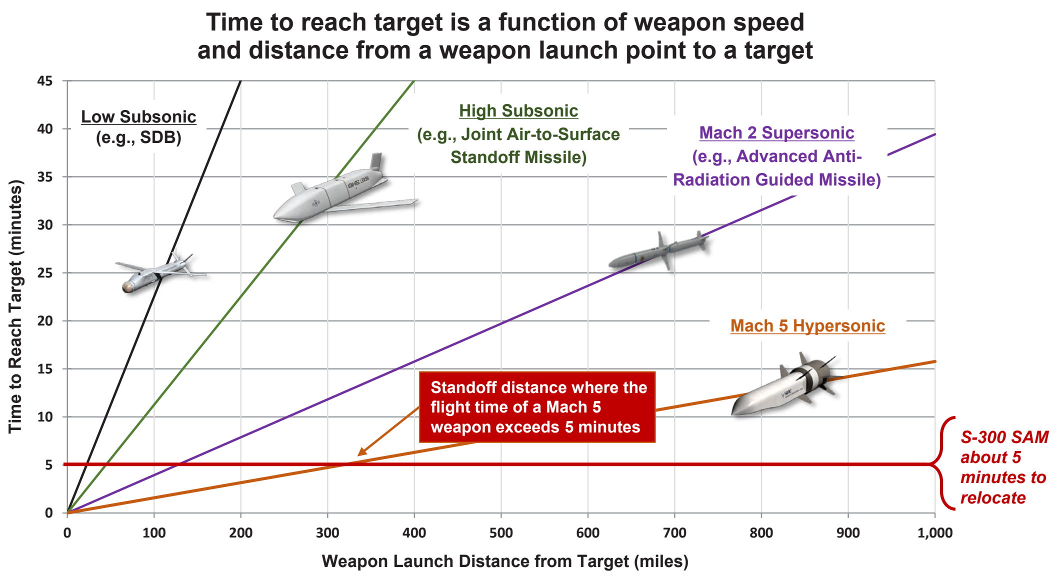
Need to consider weapons cost, range/size, and other factors. Similar to other weapon systems, future force planners should not consider hypersonic weapons as a panacea. Some hypersonic weapons could have high unit costs that limit the number the Air Force can afford to procure. Future weapons that use intermediate-range ballistic missiles to launch a hypersonic glide vehicle could have an all-up-round (AUR) unit cost of tens of millions of dollars. Very long-range—greater than 1,000 nm—air-breathing hypersonic weapons will also be larger than most short-range air-launched weapons that do not need engines or fuel to extend their range. Increasing the size of weapons reduces the number of weapons that an aircraft can carry per sortie, and fewer weapons per sortie can increase the number of sorties needed to attack a given target set. Long-range glide and air-breathing hypersonic weapons will also have limitations in the size and weight of warheads they can carry that reduce their

156 John A. Tirpak, "Find, Fix, Track, Target, Engage, Assess," *Air Force Magazine*, July 2000.

157 Richard P. Hallion, Curtis M. Bedke, and Marc V. Schanz, *Hypersonic Weapons and US National Security: A 21st Century Breakthrough* (Arlington, VA: Mitchell Institute for Aerospace Studies, 2016), pp. 4–12.

effectiveness against hardened or deeply buried targets.[158] Finally, speed alone may not suffice to overcome target location errors created by targets that have the capability to quickly relocate. As Figure 23 illustrates, weapons that are launched from longer ranges to strike a highly mobile S-300 launcher would need to fly at faster speeds in order to arrive at the S-300's known position before it can relocate. A very long-range standoff cruise missile launched from 800 nm standoff distance from the example target would need to fly in excess of Mach 14, and do so without making many time-consuming maneuvers in order to reach the target before it could relocate.

FIGURE 23: PROXIMITY MATTERS FOR HIGHLY MOBILE/RAPIDLY RELOCATABLE TARGETS



Location errors caused by a target's movement after a weapon is initially cued and launched can be compensated for by providing the weapon with inflight target updates and by equipping the weapon with a seeker capable of locating and identifying targets. Weapon datalinks and seekers, however, would further add to the cost and complexity of long-range hypersonic weapons. Another alternative would be to use a larger number of shorter-range hypersonic weapons that are sized to be carried in the internal weapons bays of penetrating aircraft. Launching these shorter-range weapons from penetrating manned and unmanned aircraft would reduce the time needed to strike highly dynamic targets, and the weapons might also be cheaper because they would not require terminal seekers or mid-flight datalinks. However, they would also require a larger inventory of penetrating stealth aircraft capable of employing them than is currently in the force.

158 Hypersonic weapons that will rely on kinetic energy generated by their speeds to create effects on targets rather than explosive blast/fragmentation warheads could further reduce their effectiveness against hardened or deeply buried sites. James M. Acton, *Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike* (Washington, DC: Carnegie Endowment for International Peace, 2013), p. 85.

Attacking Multiple Aimpoints Per Weapon

The Air Force should also invest in force-multiplying munitions that are *each* capable of striking more than a single aimpoint. Weapons that carry submunitions or are armed with high-power microwave (HPM) payloads capable of engaging multiple targets could be a cost-effective means to increase the Air Force's strike capacity and help offset weapons that will be attrited by enemy air and missile defenses.

Countering large numbers of Russian mechanized forces in contested EMS environments may be the most pressing reason why DoD should develop new submunitions-dispensing precision-guided weapons.[159] These weapons could help blunt a Russian invasion of a NATO ally that occurs with little prior warning, particularly early in the conflict when Russia would seek to exploit its time-distance advantage and localized force overmatch to rapidly seize territory.[160] The saturation effect created by weapons with multiple submunitions that can attack armored vehicles and other appropriate targets could help compensate for the force capacity shortfalls that would exist before U.S. forces can deploy to the fight. Submunitions deployed by standoff attack weapons could also help saturate defenses or cause an enemy to temporarily exhaust their defensive capacity, improving the potential for other weapons to successfully penetrate to their targets.

The Air Force is moving toward increasing its inventory of submunitions-dispensing weapons by procuring BLU-136/B 2,000 pound-class warheads as part of its Next Generation Area Attack Weapon (NGAAW) program.[161] These cast ductile iron bombs have special height-of-burst sensor-enabled fuzes that will enable operators to finely tune how high and wide an area their shrapnel covers. These weapons also use standard bomb shapes, which will allow the Air Force to give them GPS guidance kits or Paveway series weapons laser guidance kits to improve their precision and integrate them with low-observable aircraft.[162] They are not, however, designed to be effective against heavy armor, nor do they have the capability to locate, characterize, and strike individual targets similar to BLU-108/B submunitions that are delivered by the Air Force's CBU-97/B Sensor Fuzed Weapon.[163] The Air Force will maintain the Sensor Fuzed Weapons that it has procured in its inventory due to DoD's decision to indefinitely delay its plans to stop using certain cluster munitions. Despite the BLU-136/B's operational limitations, the Next Generation Area Attack Weapon program is a start toward

159 Michael Jacobson, "Why Cluster Munitions Must Be Replaced," *War on the Rocks*, September 2, 2014.

160 For more information, see Billy Fabian et al., *Strengthening the Defense of NATO's Eastern Frontier* (Washington, DC: Center for Strategic and Budgetary Assessments, 2019), pp. 3–6.

161 Gareth Jennings, "USAF Awards Next-Gen Area-Attack Weapon Contracts," *Jane's Missiles & Rockets*, October 2, 2019.

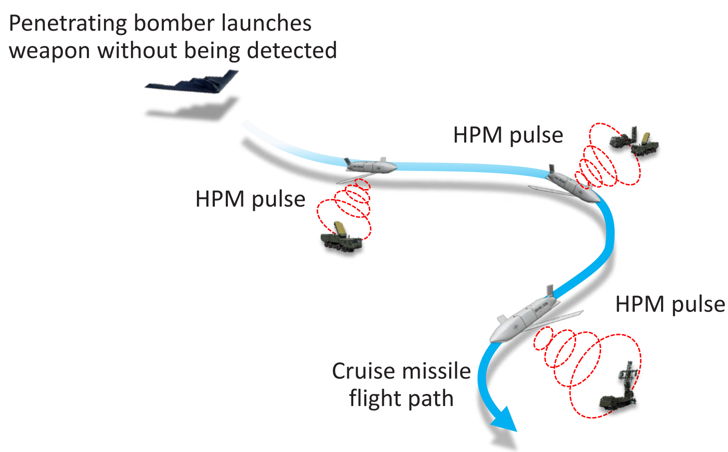
162 Joseph Trevithick, "USAF Getting 'Cast Ductile Iron Bomb' Cluster Munition Replacement Despite Policy Change," *The War Zone*, February 26, 2018, available at https://www.thedrive.com/the-war-zone/18829/usaf-getting-cast-iron-ductile-bomb-cluster-munition-replacement-despite-policy-change.

163 See Deputy Secretary of Defense, "DoD Policy on Cluster Munitions," memorandum, November 30, 2017, available at https://dod.defense.gov/Portals/1/Documents/pubs/DOD-POLICY-ON-CLUSTER-MUNITIONS-OSD071415-17.pdf.

developing the kind of next-generation area effects weapons the Air Force should develop to increase its lethality in the battlespace.

The Air Force should also exploit mature and rapidly maturing directed energy technologies to increase its strike capacity. Cruise missiles armed with HPM payloads are a particularly promising capability. These weapons will be able to generate pulses of microwave radiation that could disrupt or burn out unshielded electronic components in weapons systems such as computers, target acquisition radars, and guidance systems.[164] Similar to kinetic weapons carrying submunitions, cruise missiles equipped with HPM payloads could each strike multiple aimpoints per weapon. Unlike kinetic weapons, an HPM cruise missile could continue to create effects on targets as long as the parent cruise missile has fuel to sustain flight and battery power to generate HPM pulses. HPM warheads could provide effective alternatives to neutralize some access-denial threats by attacking their vulnerable electronic components. They could also be launched as part of a mix of jammers, decoys, and kinetic weapons to increase the overall survivability of a U.S. precision strike.[165] Because they create effects non-kinetically, HPM weapons would minimize the potential for inflicting unwanted collateral damage of the kind that is associated with some area effects weapons.

FIGURE 24: ILLUSTRATING AN HPM CRUISE MISSILE SORTIE



Technologies are sufficiently mature to support the near-term acquisition of HPM weapons. The Air Force completed its first successful trial of an HPM cruise missile called the Counter-Electronics High Power Microwave Advanced Missile Project (CHAMP) in 2012.[166] The Air

164 John Keller, "Air Force Deploys B-52 Missiles That Could Disable Enemy Military Electronics with High-Power Microwaves," *Military & Aerospace Electronics*, May 17, 2019, available at https://www.militaryaerospace.com/rf-analog/article/14033453/air-force-deploys-b52-missiles-that-could-disable-enemy-military-electronics-with-highpower-microwaves.

165 For more information, see Gunzinger and Clark, *Sustaining America's Precision Strike Advantage*, pp. 48–52.

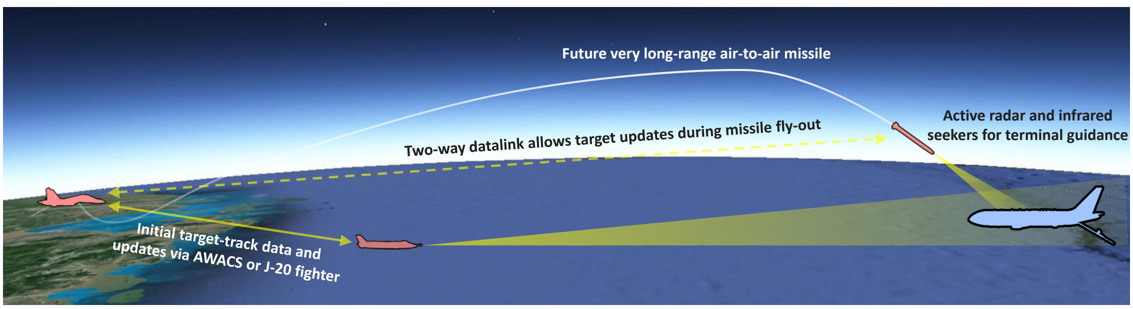
166 Gareth Jennings, "Boeing CHAMP Completes First Operational Trial," *Jane's Missiles & Rockets*, November 5, 2012.

Force and Navy's High Power Joint Electromagnetic Non-Kinetic Strike (HiJENKS) program is developing a multi-mission HPM payload that can be integrated with an advanced airborne platform.[167] Given that HPM weapons will need to be close to their targets to be effective, it will be important to integrate HPM warheads on platforms that are suitable for operating in contested environments.

Advanced Engines to Increase Aircraft Combat Ranges/Mission Persistence

The Air Force's current CAF predominantly consists of short-range platforms that depend on aerial refueling to extend their range and mission endurance. In 2019, about 79 percent of the CAF's daily capacity to deliver weapons by weight was provided by combat aircraft that have less than a 1,000 nm unrefueled combat radius.[168] This range-limited U.S. force encourages Chinese and Russian preemptive strategies that seek to disable nearby U.S. theater airbases with massive missile salvos. Simultaneously, Chinese and Russian long-range surface-to-air and air-to-air threats could force U.S. tankers, BMC2, and non-stealth bomber platforms to standoff from the borders of a great power aggressor (see Figure 25). Moving the tankers out to 500 to 800 nm from the edge of a contested area would have a significant deleterious effect on the depth of CAF penetration and time on station.

FIGURE 25: NOTIONAL LONG-RANGE PLAAF AIR-TO-AIR ENGAGEMENT OF AN AIR FORCE AERIAL REFUELING TANKER AIRCRAFT



Participants in CSBA's 2018 NDAA mandated study on the Air Force's future aircraft inventory developed these tanker standoff assumptions for illustrative future conflict scenarios in the Indo-Pacific and Europe. For more information, see Gunzinger et al., *An Air Force for An Era of Great Power Competition*, p. 63.

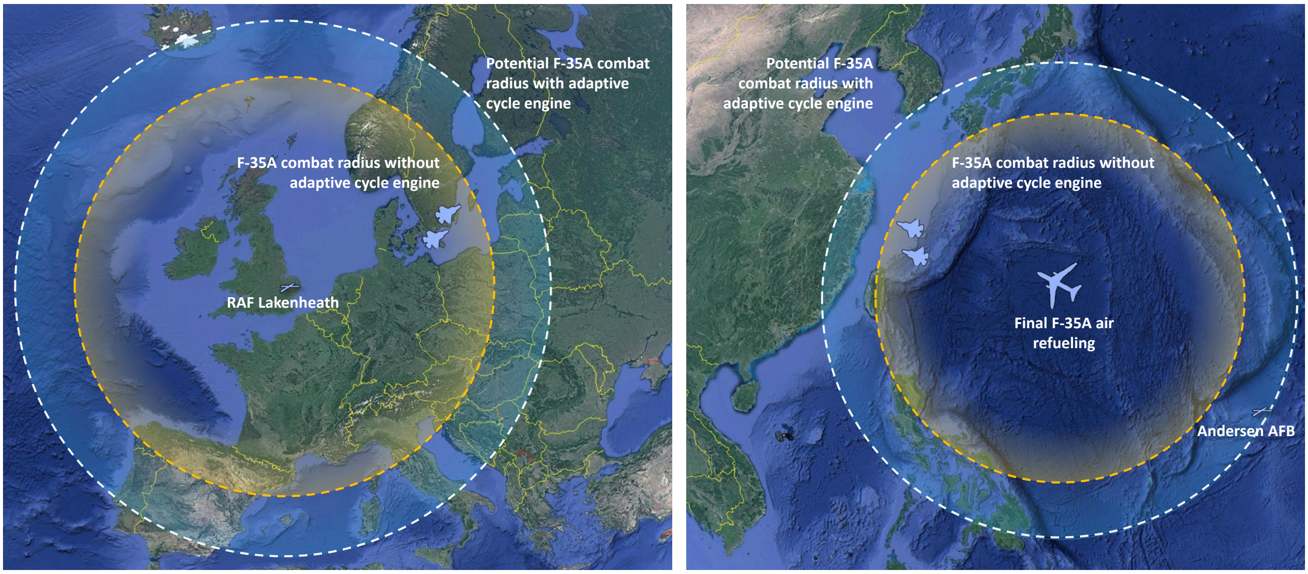
Increasing the range and persistence of the CAF in general and the fighter force, in particular, would help reduce its reliance on vulnerable, quantity-limited aerial refueling tanker assets. Ideally, more fuel-efficient fighter aircraft launching from theater airbases could remain airborne longer within the combat zone. If a retrograde force movement to more distant bases at the outset of a conflict with China or Russia were required, aircraft equipped with

167 James Drew, "USAF Providing Payload for Joint 'HiJENKS' Experiment," *Aerospace Day & Defense Report*, March 20, 2018.

168 Gunzinger et al., *An Air Force for An Era of Great Power Competition*, pp. 15–16.

fuel-efficient engines could help enable them to operate over a more widely dispersed posture without exceeding aerial refueling force capacity limitations. In either instance, new, more fuel-efficient engines would serve as a powerful force multiplier, reducing the CAF's dependence on aerial refueling tankers.

FIGURE 26: ILLUSTRATING THE IMPACT OF ADAPTIVE CYCLE ENGINE TECHNOLOGIES ON THE UNREFUELED COMBAT RADIUS OF AN F-35A



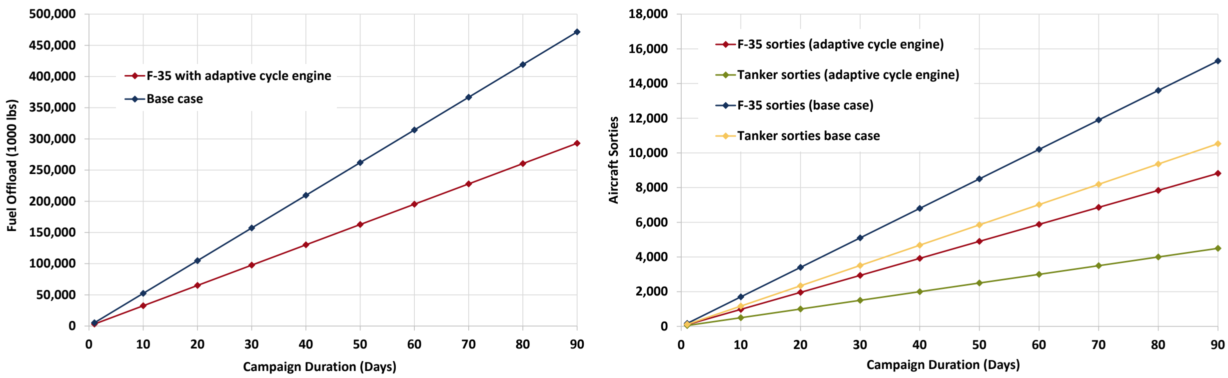
Adaptive cycle engine technology. Current fixed-cycle engines are designed to optimize either fuel efficiency, for increased range, or thrust, for greater speed and power during combat conditions. Adaptive cycle engines can be reconfigured in flight, offering increased range and persistence without sacrificing thrust when required. The Air Force's current Adaptive Engine Transition Program (AETP) is developing a turbofan engine that can change its internal geometry to dynamically adjust its bypass ratio and fan pressure ratio.[169] This could increase an adaptive engine's thrust by 10 percent and improve its fuel efficiency by 25 percent, which would roughly translate into a 30 percent improvement in range for aircraft equipped with the engines (see Figure 26).[170] When paired with new materials such as ceramic matrix composites and the addition of a third stream of cooling air that acts as a heat sink inside the engine,

169 The engine's fan pressure ratio is changed using an adaptive, multistage fan. To alter the bypass ratio, the engine relies on a stream of air that can be dynamically modulated between the engine's core and the bypass stream, providing increased thrust during combat conditions and increasing fuel efficiency during cruise conditions. The high thrust mode directs additional airflow through the engine's core for higher thrust and cooling air, whereas the high-efficiency mode directs air through the engine's third stream to improve propulsion efficiency and lower fuel burn. See Guy Norris, "GE Details Sixth-Generation Adaptive Fighter Engine Plan," *Aviation Week & Space Technology*, January 29, 2015.

170 Aaron Mehta, "US Air Force Funds Next Advanced Engine Stage," *Defense News*, July 1, 2016, available at https://www.defensenews.com/training-sim/2016/07/01/us-air-force-funds-next-advanced-engine-stage/.

improving thermal management and reducing the infrared signature of an aircraft, these new engines can also enhance aircraft survivability.[171] Figure 27 illustrates the projected improvements of retrofitting these types of engines in an F-35.

FIGURE 27: ILLUSTRATING THE IMPACT OF IMPROVING AIRCRAFT FUEL CONSUMPTION BY 25 PERCENT ON NOTIONAL CAP REQUIREMENTS



Technology to support the development of these next-generation engines is relatively mature, having undergone several development cycles. AETP is applying technologies developed by the Adaptive Versatile Engine Technology (ADVENT) and Adaptive Engine Technology Development (AETD) programs to design, develop, and test full-scale adaptive engines in the 45,000-pound thrust class.[172] Although initially envisioned for the Air Force's next-generation combat aircraft and the Navy's F/A-XX program, the engines being designed and produced under AETP are also baselined to fit into the F-35A's engine bay.[173] The Air Force could apply technologies being matured by AETP more broadly to some of its legacy platforms.[174]

A related development is the Air Dominance Adaptive Propulsion Technology (ADAPT) program, which is part of AFRL's effort to gain maximum performance from all available avenues of adaptive engine technology. Unlike AETP, which focuses on the low-pressure spool of the engine, ADAPT is developing adaptive features in the high-pressure spool of an engine as well as integrating the core within the engine's overall variable cycle operation.[175] The basic

171 Jim Matthews, "Engines of Innovation," *Air Force Magazine*, August 2017.

172 ADVENT sought to solve basic engineering and physics problems related to improved propulsion engines, whereas the AETD program focused on component development and rig testing to lower the risk associated with eventually maturing adaptive engine technologies. See Nick Zazulia, "Detailed Design Complete for GE's Revolutionary Adaptive Fighter Engine," *Avionics International*, March 1, 2019, available at https://www.aviationtoday.com/2019/03/01/detailed-design-complete-for-ges-revolutionary-adaptive-cycle-fighter-engine/.

173 Steve Trimble, "U.S. Air Force Faces Next-Generation Engine Funding Crisis," *Aviation Week & Space Technology*, September 24, 2019.

174 Courtney Albon, "Air Force Identifies Candidates for First Wave of AETP Technology Integration," *Inside Defense*, June 24, 2019; and "More Funding for GE's Adaptive-Cycle Engine," *Aviation Week*, July 16, 2018.

175 Guy Norris, "USAF Details Sixth-gen Combat Engine Research Plan," *Aviation Week & Space Technology*, June 22, 2016.

concept is to decouple the flow and pressure ratio going through the core of an engine using a variable area nozzle that would work in conjunction with a variable fan. ADAPT seeks to increase the potential unrefueled range of an aircraft by another 10 percent beyond the range of an adaptive engine now in development without compromising engine performance and achieve fuel burn reductions on the order of another 5 percent.[176]

Battle Management Command and Control in Contested Environments

Advanced Battle Management (ABM) Family of Systems

The Air Force's AWACS and JSTARS aircraft were phenomenal success stories in their day. Neither were designed, however, to operate in the kind of contested environments summarized in Chapter 2. The Air Force is planning to modify seven of its E-3B/C AWACS to an E-3G AWACS configuration that has the ability to fuse multiple land, sea, and air tracks into a single display.[177] Modifications to the AWACS, planned and potential, will not improve their ability to survive in future contested environments. Their large footprint while on the ground also makes them inviting targets for Chinese or Russian missile attacks, and the Air Force currently lacks hardened aircraft shelters for aircraft larger than fighters.[178] As recommended by CSBA's report on the Air Force's future aircraft inventory, creating a future system-of-systems that is able to conduct distributed BMC2 operations in all threat environments will be a better long-term solution.[179] The Air Force calls this the Advanced Battle Management System. An Analysis of Alternatives (AoA) is ongoing to inform future ABM Family of Systems requirements.[180] The AoA will likely recommend developing a package of sensors, communications, C2, and platforms to account for projected threats. When fully mature, the ABM Family of Systems should provide a more resilient multi-domain ISR and BMC2 architecture of air, space, and cyber capabilities that reduce the vulnerabilities in the Air Force's current nodal BMC2 system.[181]

176 For short Air Force descriptions of these technology initiatives, see "Future Initiatives," U.S. Air Force, available at https://www.safie.hq.af.mil/OpEnergy/Future-Initiatives/.

177 The Air Force still intends to retire JSTARS, although its retirement target has slipped from the 2020s until the early 2030s. Michael Sullivan, Government Accountability Office (GAO), "Defense acquisitions: Observations on the F-35 and Air Force's Advanced Battle Management System," testimony before the subcommittee on Tactical Air and Land Forces, Committee on Armed Services, House of Representatives, May 2, 2019, pp. 14–17, available at https://insidedefense.com/sites/insidedefense.com/files/documents/2019/may/05022019_GAO_F35.pdf.

178 Note: To date there have not been cost-effective shelters for larger than fighter aircraft budgeted for the Air Force or any other service. If there are no shelters for these aircraft at forward bases, then additional active defenses (kinetic and non-kinetic) and other passive defenses would likely be required.

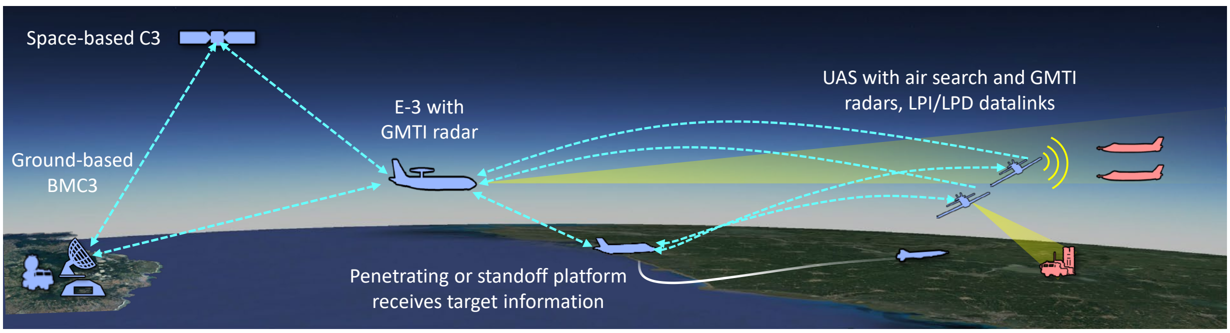
179 Gunzinger et al., *An Air Force for an Era of Great Power Competition*, pp. 118–119.

180 Mandy Mayfield, "Just In: Air Force Advanced Battle Management System Study to Be Delayed," *National Defense Magazine*, August 20, 2019, available at https://www.nationaldefensemagazine.org/articles/2019/8/20/air-force-advanced-battle-management-system-study-to-be-delayed.

181 Gunzinger et al., *An Air Force for an Era of Great Power Competition*, pp. 118–119.

In the near to medium term, attritable and current-generation non-attritable UAS combined with manned systems could provide a bridge to a more advanced BMC2 system-of-systems. As shown in Figure 28, E-3G aircraft could remain in permissive environments and receive information relayed over space-based communications or through LPI/LPD datalinks from attritable UAS operating in contested environments. Although Figure 28 shows the E-3G sensor as active, it would likely limit its emissions by conducting passive sensing in higher threat areas and rely on attritable UAS for active sensing. Larger attritable UAS envisioned by the Air Force could have a variety of different sensors. UAS could network with ground stations and sensors, 5th generation fighters, space-based sensors, and E-3Gs to accomplish missions in contested environments.[182] MQ-9s, RQ-4s, and other UAS could conduct manned-unmanned teaming operations with the E-3G as well as operate in conjunction with ground- and sea-based sensor systems.

FIGURE 28: ILLUSTRATIVE NEAR TO MEDIUM TERM EVOLUTION OF AN ABM FAMILY OF SYSTEMS



Summary

Relying solely on a force development approach that attempts to buy more CAF force structure to address the challenges the Air Force would face in future great power conflict would be prohibitively expensive. Although the Air Force *must* grow its combat capacity, it should also prioritize the development of force multipliers that would enhance the potential of its current and future forces to support the 2018 National Defense Strategy at a moderate level of risk. These force multipliers include hypersonic weapons that increase the survivability and lethality of the Air Force's precision strikes and other non-kinetic and kinetic munitions that can each attack multiple aimpoints. Advanced adaptive cycle engines are another example of a force multiplier. If integrated on next-generation aircraft and used to re-engine current fighters, adaptive cycle engines would simultaneously increase combat performance and possibly reduce some force structure requirements. Finally, replacing legacy Air Force BMC2 aircraft such as the E-3 AWACS and E-8 JSTARS with a multi-domain command and control

182 Sara Sirota, "Air Force to Compete Programs to Demo ABMS Effects, Taps Skyborg," *Inside Defense*, September 17, 2019. See also Theresa Hitchens, "Air Force to Upgrade ABMS Every 4 Months: Roper," *Breaking Defense*, September 18, 2019.

architecture would greatly increase the effectiveness and resiliency of the entire joint force in future operations. Sensors, BMC2 capabilities, shooters, weapons, and other capabilities that are elements of kill chains all have one thing in common: they must be connected in ways that will allow them to rapidly share data and information to be effective. The joint force's ability to close thousands of kill chains in hundreds of hours in a future great power conflict will require the Air Force and other Services to aggressively pursue the development of machine-to-machine interfaces and other capabilities that are not operational today. Taking full advantage of the potential operational value of an integrated system of manned and unmanned capabilities will also hinge on the Air Force's ability to develop operating concepts and capabilities to achieve the degree of command and control needed to operate them in areas where they will likely be subject to enemy counter-C2 actions. In summary, the advantages of a force capable of conducting networked multi-domain joint warfare promise to outweigh the cost of the investments needed to make it a reality.

Conclusion

This report expands on analyses performed in support of CSBA's 2019 study on a future Air Force aircraft inventory. It proposes initiatives that would increase the capacity and capabilities of the Air Force's CAF to deter or defeat major acts of aggression by China and Russia as required by the 2018 National Defense Strategy. Growing the size of the Air Force's CAF alone would not create a more balanced future force that is increasingly capable of multi-domain operations against a great power aggressor. The following recommendations would also accelerate the development of a force mix that would be more lethal, have longer range, improve resiliency, and be better able to penetrate and persist in contested threat environments.

Recommendations

Size the CAF for great power conflict. The 2019 Air Force aircraft inventory studies completed by the Air Force, the MITRE Corporation, and CSBA all recommended the Air Force increase the size of its CAF. The studies concluded that, as it does so, the Service should place a higher priority on growing the capacity of its future bomber force. This would shift the force toward a mix of capabilities that would be better able to operate over the vast distances of the Indo-Pacific region and rapidly project lethal airpower over long ranges to quickly halt, then defeat great power aggression. CAF force structure growth should be matched by increases in penetrating ISR capabilities, electronic warfare systems, multi-domain C2 networks, and a future weapons mix needed to sustain high tempo combat operations in contested areas.

Increase the survivability of the future CAF. In addition to increased capacity, the Air Force should continue to develop a next-generation CAF family-of-systems to conduct counterair, precision strike, and other missions. China, Russia, and other potential adversaries continue to take advantage of information technologies to increase the lethality of their defenses against U.S. legacy aircraft. This family-of-systems should include a PCA/PEA aircraft, penetrating unmanned ISR systems, and a force of stealth bombers capable of operating in contested environments. In the near to medium term, increasing the Air Force's procurement of 5th generation F-35As would help accelerate its transition to a future force that is better capable of countering advanced IADS and other emerging surface-to-air and air-to-air threats.

Maintain the CAF's ability to generate combat sorties from forward bases and operating locations. A future CAF capable of deterring or denying a great power aggressor from achieving a *fait accompli* should be able to operate from a dispersed network of airbases and other operating locations in Europe and along the First and Second Island Chains in the Indo-Pacific. The ability to generate combat power forward would help reduce Chinese and Russian time and distance advantages in areas on their periphery where their governments aspire to increase their influence and control. Shifting the preponderance of the Air Force's CAF sortie generation operations to more distant airbases early in a conflict with China or Russia would erode DoD's ability to assure America's regional allies. Maintaining the CAF's ability to generate combat power forward would require DoD to field higher capacity airbase defenses and pursue other measures to improve airbase resiliency. Creating more resilient forward postures in the Indo-Pacific and Europe does not mean the Air Force should neglect opportunities to increase its capacity to operate from airbases that are located in more distant, lower-threat areas. The future CAF should have increased capacity to operate aircraft with long ranges and large payloads from more distant bases *and* generate significant combat power from forward bases in Japan, elsewhere along the First Island Chain, and in Europe. Furthermore, airbases located in areas that are now considered to be at less risk of large-scale air and missile attacks will also need resiliency improvements, given the continued improvement in the ranges, accuracy, and size of China's and Russia's precision strike weapons inventories.

Develop and employ UAS for a wider set of missions and threat environments. The Air Force's CAF now lacks sufficient capacity to support high-end combat operations, sustain homeland defense, and meet other requirements of the 2018 National Defense Strategy simultaneously. To reduce risk caused by this capacity shortfall, the Air Force should develop new concepts for employing contemporary and future UAS. In the near term, these systems should include MQ-9s, lower-cost attritable UAS, and other unmanned systems. In the long-term, more advanced UAS designs capable of penetrating contested environments could team with manned aircraft to conduct counterair missions, precision strikes, and EW operations in addition to traditional ISR and light strike missions.

Accelerate the development of next-generation force multipliers. Future force multipliers should include next-generation hypersonic weapons, cruise missiles with counter-electronics HPM payloads capable of attacking multiple targets per weapon, advanced engines that will increase the range and mission endurance of CAF aircraft, and datalinks needed to support multi-domain operations in contested environments. Replacing legacy Air Force BMC2 aircraft such as the E-3 Airborne Warning and Control System (AWACS) and E-8 Joint Surveillance Target Attack Radar System (JSTARS) with multi-domain BMC2 architectures would also increase the effectiveness and resiliency of the entire joint force in future operations.

Conclusion

Since CSBA released the results of its 2019 Air Force aircraft inventory study, the Air Force has developed an FY 2021 budget proposal that is designed to further align its force structure and capabilities mix with 2018 National Defense Strategy priorities. The FY 2021 President's Budget will be the Service's first real opportunity to shift its planning and resources toward programs that are needed to develop "The Air Force We Need." Although the Air Force's overall "blue-only" TOA is now close to a historic high, its blue-only procurement budget is well below historical levels, and the Air Force is buying less than 70 new combat aircraft per year. Should this budget trend continue, it is unlikely that the Air Force will have sufficient resources to address the force structure shortfalls created by 30 years of a next-generation aircraft procurement holiday. Faced with this fiscal reality, the Air Force may be considering some additional cuts to its CAF and other force structure in its FY 2021 budget proposal to free resources that could help recapitalize and modernize the CAF. This could increase risk in the near and medium term and would likely not result in savings that approach the level needed to support the development of its 2030 "The Air Force We Need."

In conclusion, the return of great power competition has closed the window in time where the Air Force could accept increased risk by forgoing major investments to rebuild and modernize its aircraft inventory. Creating a more range-balanced, survivable, and lethal force will require a commitment by DoD and the Congress to significantly increase the Air Force's annual budgets. Addressing the force structure and capability shortfalls created by decades of a modernization holiday may require decades of increased budgets. Further delays to recapitalizing and modernizing the Air Force's CAF would risk increasing the Service's existing strategy-resource gaps.

LIST OF ACRONYMS

ACE	Air Combat Evolution
ADAPT	Air Dominance Adaptive Propulsion Technology
ADVENT	Adaptive Versatile Engine Technology
AESA	Active electronically scanned array
AETD	Adaptive Engine Technology Development
AFB	Air Force Base
AFRL	Air Force Research Lab
AI	Artificial intelligence
AMRAAM	Advanced Medium-Range Air-to-Air Missile
AoA	**Analysis of Alternatives**
ASAT	Anti-satellite
ATLC	Automatic Takeoff and Landing Capability
AWACS	Airborne Warning and Control System
BCA	Budget Control Act
BMC2	Battle management and command and control
BVRAAM	Beyond-visual-range air-to-air missiles
CAF	Combat air forces
CAPs	Combat air patrols
CHAMP	Counter-Electronics High Power Microwave Advanced Missile Project
CODE	Collaborative Operations in Denied Environments
CONUS	Continental United States
DARPA	Defense Advanced Research Projects Agency
DMS	Defensive Management System
DMS-M	Defensive Management System Modernization
DoD	Depatment of Defense
EABO	Expeditionary Advanced Base Operations
EMD	Engineering and manufacturing development
EMS	Electromagnetic Spectrum
ESM	Electronic support measures
EW	electronic warfare
FY	Fiscal Year
GPS	Global Positioning System
HELs	High energy lasers
HiJENKS	Joint Electromagnetic Non-Kinetic Strike
HPM	High power microwave
HVAAs	High-value aircraft assets
IADS	Integrated air defense system
ICBMs	Intercontinental ballistic missiles
IRST	Infrared search and track

JASSM-ER	Joint Air-to-Surface Standoff Missile - Extended Range
JDAM	Joint Direct Attack Munition
JSTARS	Joint Surveillance Target Attack Radar System
LCAAPS	Low Cost Attritable Aircraft Platform Sharing
LCAAT	Low Cost Attritable Aircraft Technology
LCASD	Low Cost Attritable Strike Demonstrator
LOSSM	Low Observable Signature and Supportability Modifications
LPI/LPD	Low probability of intercept/low probability of detection
LRASM	Long Range Anti-Ship Missile
LRE	Launch and recovery element
MADL	Multifunction Advanced Data Link
MALD	Miniature Air-Launched Decoy
MALD-J	Miniature Air-Launched Decoy - Jammer
MDC2	Multi-domain command and control
MM-UAS	Multi-mission UAS
NATO	North Atlantic Treaty Organization
NDAA	National Defense Authorization Act
NDS	National Defense Strategy
NGAAW	Next Generation Area Attack Weapon
NGAD	Next Generation Air Dominance
O&S	Operating and support
OCPFH	Operational cost per flying hour
OML	Outer mold line
Pa	Probability of arrival
PCA/PEA	Penetrating Counterair/Penetrating Electronic Attack
PGMs	Precision-guided munitions
PLA	People's Liberation Army
PLAAF	PLA Air Force
PLARF	PLA Rocket Force
PMAI	Primary Mission Craft Inventory
RADR	Rapid airfield damage repair
SACM	Small Advanced Capabilities Missile
SAM	Surface-to-air missile
SEAD/DEAD	Suppression of enemy air defenses/destruction of enemy air defenses
SLEPs	Service life extension programs
TAI	Total Aircraft Inventory
TELs	Transporter erector launchers
TOA	Total Obligation Authority
UAS	Unmanned aircraft systems

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