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EVALUATE LIKE WE OPERATE

WHY THE DEPARTMENT OF DEFENSE SHOULD EVALUATE WEAPONS SYSTEMS AS NETWORKED FORCE PACKAGES, NOT INDIVIDUAL PLATFORMS

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Contents

FIGURES

Executive Summary

Each year, the U.S. defense community devotes considerable attention to individual weapons.[1] From 2021 to 2022, for example, congressional proceedings mentioned the F-35 aircraft more than 420 times, including in speeches and reports discussing its flight performance, economic implications, and more. The time spent appraising specific platforms is understandable given the huge investments and cutthroat politics surrounding these projects, not to mention the defense budget boiling everything down to line items.[2] Yet this extensive attention is also misplaced.

Weapons do not conduct military operations in isolation from one another. Since classical antiquity, successful militaries have combined different types of forces, such as Alexander the Great's phalanx infantry and long-lance cavalry, to disorient and destroy the enemy.[3] Evolving from this combined arms tradition, modern weapons systems operate together as networks of sensors, shooters, enablers, and deciders linked through both analog and digital means. These networked force packages (NFPs), as this report calls them, form a middle layer sitting above individual weapons systems but below battle networks and force structure. In basic terms, an NFP is an impermanent grouping of two or more interconnected weapons systems, including sensor and communication elements, formed to perform a military mission.

The Department of Defense (DoD) should devote more analytical attention to evaluating NFPs to unlock new insights into the operational effectiveness and cost-effectiveness of

1 Portions of this report's research first appeared in Travis Sharp, Chris Bassler, and Tyler Hacker, "In a Connected Era, We Talk Too Much About Individual Weapons," *Defense One*, June 8, 2022, https://www.defenseone.com/ideas/2022/06/connected-era-we-talk-too-much-about-individual-weapons/367898/.

2 A weapons platform is a means for delivering military capabilities to perform military tasks. Platform-centric evaluation refers to analyzing a platform without also considering the onboard capabilities that it delivers and the offboard capabilities that it enables (and that enable it). Under this definition, an advanced munition, such as the upgraded GBU-53 analyzed in Chapter 2, functions as a type of platform by delivering both sensing and strike capabilities to destroy enemy ground targets.

3 Barry Strauss, *Masters of Command: Alexander, Hannibal, Caesar, and the Genius of Leadership* (New York: Simon & Schuster, 2012), pp. 31–32.

weapons systems. Adopting the NFP approach will more closely align how the Pentagon evaluates weapons with how the U.S. military fights. The NFP approach will become more important as future force structures include attritable drones, loitering weapons, and unmanned munition carriers that blur the lines between platform and weapon. Thoughtfully combining these new capabilities with other platforms and weapons will require evaluating potential combinations using an NFP-style approach.

The Promise of Collaborative Munitions

Chapter 2 uses the NFP approach to illustrate the operational advantages of next-generation munitions that communicate and collaborate with each other.[4] Current weaponeering practices tend to compare the expected effects of munitions on targets narrowly, leaving mission planners to consider how NFPs influence operational effectiveness. Current planning practices might not account for the ability of collaborative munitions, empowered by their networks, to self-deconflict, track enemies, loiter, and reattack. This ability would pay operational dividends.

Applying the NFP approach illuminates the operational advantages gained with next-generation munitions. In a hypothetical air interdiction targeting an enemy battalion tactical group, F-15Es loaded with 200-pound GBU-53s upgraded with collaborative capability could strike nine times as many vehicles per attack run and remain further away from enemy air defenses relative to F-15Es loaded with an equal number of 500-pound GBU-12 laser-guided bombs. The innovative attack tactics enabled by collaborative munitions would help drive this outcome and should become a key consideration in future mission planning.

Fighter Aircraft and Mission-Level Cost Avoidance

Chapter 3 uses the NFP approach to reassess the perceived cost-effectiveness of advanced fighter aircraft by incorporating mission-level cost avoidance. Platform-centric evaluation's favored metric, cost per weapons system, does not reflect how having one weapon in an NFP can avoid the need to have other activities and weapons in the same NFP. If a weapon reduces an NFP's expected cost per mission by eliminating the need to perform certain supporting activities, then that weapon has demonstrated cost-effectiveness – even if the weapon's cost per unit exceeds that of an alternative system.

Applying the NFP approach reveals the underappreciated cost-effectiveness provided by advanced fighter aircraft. In a hypothetical fighter attack operation targeting enemy ground-based mobile ballistic missiles, four F-35As would cost approximately 50% to 70% less, in terms of hourly operation and support costs, than a strike package composed of F-16s, F-15Es, and support aircraft providing capabilities such as signals collection, electronic

4 The report's two illustrative analyses function as proofs-of-concept. They demonstrate the method's feasibility and encourage future research without performing exhaustive empirical investigations.

warfare, and airborne early warning. Because stealthy F-35As carry onboard advanced versions of these enabling capabilities, they could operate independently in this scenario without help from support aircraft. As a result, the F-35A NFP would be smaller and its cost per mission would be lower than the F-16 NFP, despite the F-16 costing less per aircraft.

Advancing the NFP Approach

Future research could apply the NFP approach to naval warfare and ground warfare, building on the report's air warfare analyses. Fruitful areas for investigation include the potential operational advantages of unmanned surface vessels and the potential cost savings of precision-guided artillery. The NFP approach likely will encounter resistance organizationally and politically, but the Pentagon can overcome it by starting small and focusing on key decision makers. Teams of embedded analysts from federally funded research and development centers represent one option for providing the U.S. military with the analytical capabilities required to implement the NFP approach. Successful pilot programs and analytical tools could then be scaled across commands and codified in training and doctrine. By embracing the NFP approach, DoD will leverage an enduring U.S. advantage–openness to rigorous analysis, even if contrarian–to compete more effectively against China and Russia.

CHAPTER 1

The Networked Force Package Approach to Weapons Systems Evaluation

U.S. policymakers have launched the latest phase in their perennial quest to rationalize defense investments. In this phase, officials have called for concentrating resources on the geopolitical challenges created by China's military expansion and Russia's military aggression.[5] Several new initiatives have pushed the Pentagon to reexamine the operational effectiveness and cost-effectiveness of weapons systems. In September 2021, for example, the Department of Defense (DoD) started yet another review of how weapons programs perform during their life cycles with respect to operational availability, cost, and sustainment.[6] Additionally, the 2022 National Defense Authorization Act directed the Pentagon to review whether weapons programs remain relevant to current and emerging military threats.[7]

Although helpful, initiatives like these assume that scrutinizing individual platforms marks the path to enlightenment. The widespread attention paid to individual weapons is misplaced when one considers that weapons do not fight alone. Instead, they operate within larger systems-of-systems, or what this report calls networked force packages (NFPs). This report argues that DoD should focus more evaluation on NFPs to discover new perspectives about the operational effectiveness and cost-effectiveness of weapons systems.

5 Department of Defense (DoD), "Fact Sheet: 2022 National Defense Strategy," March 28, 2022, https://media.defense.gov/2022/Mar/28/2002964702/-1/-1/1/NDS-FACT-SHEET.PDF.

6 Lee Hudson, "Hicks Orders a Sweeping Review of All Major Programs with an Eye toward China," *Politico Pro*, September 2, 2021.

7 Public Law 117–81, "National Defense Authorization Act for Fiscal Year 2022," 117th Congress, December 27, 2021, Sec. 146, https://www.congress.gov/117/plaws/publ81/PLAW-117publ81.pdf.

This chapter critiques platform-centric evaluation methods, summarizes previous efforts to rise above them, and introduces the NFP approach as an alternative. The chapter focuses on applying the NFP approach to weapons systems evaluation, the systematic and objective assessment of current and future weapons programs to determine their effectiveness.[8] Applying the NFP approach would enable DoD to allocate resources with greater sophistication when planning operations, creating acquisition requirements, budgeting, and performing other tasks.

Critique of Platform-Centric Evaluation

The U.S. defense community has long treated individual weapons systems as the key unit of analysis when evaluating operational effectiveness and cost-effectiveness despite repeated calls to take a broader view. The longevity of platform-centric evaluation stems in part from how the defense budget is organized and how systems analysis has been applied to research questions since World War II.[9] Within the military services, communities form around weapons systems such as submarines in the Navy, bombers in the Air Force, or tanks in the Army. The existence of these communities focuses attention on individual weapons because the weapons symbolize the relevance of the communities themselves.

Platform-centric evaluation possesses the virtue of transforming complex problems into smaller, more tractable trade-offs. However, it neglects how an individual system both contributes to and depends on other systems and activities. This shortcoming has become more problematic as technological advancements have increased the connectivity of U.S. military forces and altered the potential force combinations available to defense planners.

Evaluating an individual weapons system without considering its interdependence with other systems and activities is like evaluating a hitter's runs batted in without considering how often his teammates get on base before he comes up to bat. In both cases, individual performance depends on team performance (and vice versa). The savvy decision maker should evaluate investments, whether in weapons or players, based on how they affect performance, affordability, and sufficiency in the aggregate, not in the individual. Analysts should evaluate the team, not just the individuals.

8 Department of Energy, "Program Evaluation: Glossary," https://www.energy.gov/eere/analysis/program-evaluation-glossary. The phrase "weapons systems evaluation" invokes the group bearing that name which supported the Joint Chiefs of Staff from 1948 to 1976. Although the chapter does not propose recreating that group or its work, the group's focus on broader analyses aligns with the chapter's emphasis. John Ponturo, *Analytical Support for the Joint Chiefs of Staff: The WSEG Experience, 1948-1976* (Arlington, VA: Institute for Defense Analyses, 1979), https://apps.dtic.mil/sti/pdfs/ADA090946.pdf.

9 Eric M. Lofgren, *The DoD Budget Process: The Next Frontier of Acquisition Reform*, White Paper Series No. 5 (Fairfax, VA: Center for Government Contracting, George Mason University School of Business, July 29, 2020), https://business.gmu.edu/news/2021-10/no-5-dod-budget-process-next-frontier-acquisition-reform; and Emily Mushen and Jonathan Schroden, *Are We Winning? A Brief History of Military Operations Assessment* (Arlington, VA: CNA, September 2014), https://www.cna.org/archive/CNA_Files/pdf/dop-2014-u-008512-1rev.pdf.

Previous Proposals to Transcend Platform-Centric Evaluation

Defense thinkers have long aspired to transcend platform-centric thinking. The examples offered in this section, although far from comprehensive, illustrate the long-running interest in using a concept broader than individual weapons systems to conduct evaluation and plan future forces. Unfortunately, this drive for broader thinking has not taken hold within the larger public policy debate. Most public commentaries still focus on either the individual weapons platform or the force structure, neglecting the all-important NFP situated in between.[10]

Enterprising experts have proposed broadening evaluation to look beyond individual weapons systems. In the 1960s, Gene Fisher, a renowned RAND cost researcher, recommended supplementing platform-centric evaluation with what he called "total force analysis" that more broadly surveyed support systems and various non-system activities. He recognized the problem that "because the many components of a total force are often interrelated," neglecting these interrelationships could produce results that were "seriously in error."[11] In the 1990s, Admiral William Owens, then Vice Chairman of the Joint Chiefs of Staff, advocated a "system-of-systems" vision of future warfare. Although he emphasized military operations, not evaluation per se, he recognized the problem that "We are more adept at seeing the individual trees than that vast forest of military capability which the individual systems, because of their interactions, are building for our fighting forces."[12] Studies of Gulf War airpower outcomes complemented Owens's ideas, as analysts such as David Deptula, Barry Watts, and Thomas Keaney examined how stealth and precision munitions affected the number of aircraft required to perform strike missions.[13]

The U.S. military services have repeatedly attempted to move past platform-centric thinking. Immediately after World War II, the Navy designated anti-submarine warfare (ASW) as a top priority due to its growing concern that the Soviet Union would deploy new

10 Force structure is the number and types of combat units that DoD can generate and sustain. Congressional Budget Office (CBO), *The U.S. Military's Force Structure: A Primer* (Washington, DC: CBO, July 2016), p. 8, https://www.cbo.gov/sites/default/files/114th-congress-2015-2016/reports/51535-fsprimer.pdf

11 G. H. Fisher, "Resource Analysis," in E. S. Quade and W. I. Boucher, eds., *Systems Analysis and Policy Planning: Applications in Defense* (Santa Monica, CA: RAND Corporation, June 1968), pp. 129–130, https://www.rand.org/pubs/reports/R0439.html.

12 William A. Owens, *The Emerging U.S. System-of-Systems*, Strategic Forum No. 63 (Washington, DC: Institute for National Security Studies, National Defense University, February 1996), p. 2, https://apps.dtic.mil/sti/pdfs/ADA394313.pdf.

13 David A. Deptula, *Effects-Based Operations: Change in the Nature of Warfare* (Arlington, VA: Aerospace Education Foundation, 2001), https://secure.afa.org/Mitchell/reports/0901ebo.pdf; and Barry D. Watts and Thomas A. Keaney, *Part II: Effects and Effectiveness*, in *Gulf War Air Power Survey, Volume II*, directed by Eliot A. Cohen (Washington, DC: Government Printing Office, 1993), PDF pp. 373–798, https://media.defense.gov/2010/Sep/27/2001329806/-1/-1/0/AFD-100927-067.pdf.

quieter submarines copied from German designs.[14] The Navy endeavored to combine the disparate efforts of its aviation, surface, and submarine forces into a more aggregated ASW force, drawing both inspiration and instruction from the Royal Navy's ASW practices.[15]

In the 1970s and 1980s, the Air Force and Army concentrated on the threat posed by a Soviet armored assault in Europe.[16] Drawing on new technologies, including those associated with DARPA's "Assault Breaker" program, the two services adopted new concepts, such as "AirLand Battle" and "Follow-On Forces Attack," calling for tighter integration of land and air forces.[17]

Finally, the Marine Corps has long embraced the Marine Air-Ground Task Force (MAGTF) – a package of ground, air, logistics, and command elements – as its fundamental organizing principle. The MAGTF comes in different sizes and specialties, but, at its heart, it aggregates people and weapons systems, thereby standing as the antithesis of platform-centric thinking.

Recently, DoD has flirted with more holistic approaches to weapons system evaluation and future force development. In September 2021, it announced new reviews that would assess weapons investments as portfolios rather than programs.[18] This portfolio or "family of systems" philosophy has also infused several ongoing force development initiatives, with examples including Future Vertical Lift, Marine Littoral Regiment, mega-constellations for missile warning and tracking, U.S. airpower with uncrewed complements, and future Carrier Strike Groups.

Despite these efforts, most expert attention continues to fall on individual weapons systems. Breaking this pattern will require refining the ideas summarized above while demonstrating the benefits of doing things differently. The NFP approach is one such method to break the pattern.

14 R. F. Cross Associates, *Sea-Based Airborne Antisubmarine Warfare 1940-1977*, Volume I, 1940-1960 (Alexandria, VA: R. F. Cross Associates, February 1978), pp. 61–65, https://www.secnav.navy.mil/foia/readingroom/HotTopics/THRESHER%20RELEASE/USS%20Thresher%20Interim%20Release%205%20pt%201(RS)_Part1.pdf.

15 Corbin Williamson, "'We Have the Equipment but You Have the Know-How': Anglo-American Antisubmarine Training, 1946–1953," *International History Review* 43, no. 3 (2021), pp. 677–696.

16 Phil Haun, "Peacetime Military Innovation through Interservice Cooperation: The Unique Case of the U.S. Air Force and Battlefield Air Interdiction," *Journal of Strategic Studies* 43, no. 5 (2020), pp. 715–724.

17 Robert Tomes, "The Cold War Offset Strategy: Assault Breaker and the Beginning of the RSTA Revolution," *War on the Rocks*, November 20, 2014, https://warontherocks.com/2014/11/the-cold-war-offset-strategy-assault-breaker-and-the-beginning-of-the-rsta-revolution/.

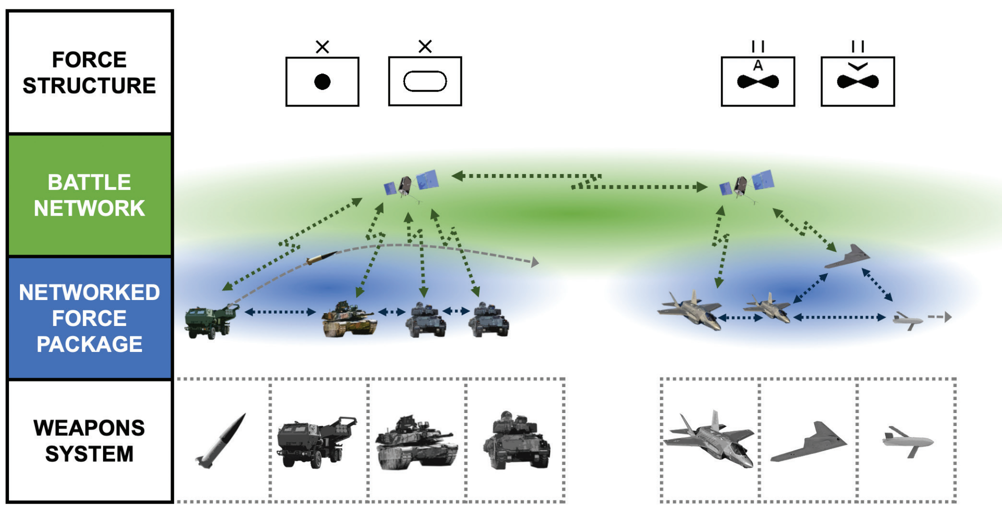
18 Tony Bertuca, "DOD Embarks on New Acquisition Portfolio Reviews," *Inside Defense*, September 28, 2021.

The Networked Force Package Approach

This report defines an NFP as an impermanent grouping of two or more interconnected weapons systems formed to perform a military mission.[19] "Interconnected" implies communication (typically electronic) that is sufficiently continuous and informative that one weapons system can operate effectively based in part on information provided by another weapons system. "Weapons system" indicates any weapon or platform plus the communication devices, personnel, subsystems, and components required to command and operate it, including sensors, command and control elements, and electronics. Finally, "mission" indicates the dispatching of forces to perform a particular task for a defined purpose, such as launching aircraft to destroy enemy tanks and prevent attacks against friendly forces.[20]

One can think of an NFP as a middle layer sitting above individual weapons systems but below battle networks and force structure (Figure 1).[21] Two attributes differentiate an NFP from these other concepts: permanence and geographic scale (Figure 2).

FIGURE 1: NETWORKED FORCE PACKAGE AS THE MIDDLE LAYER



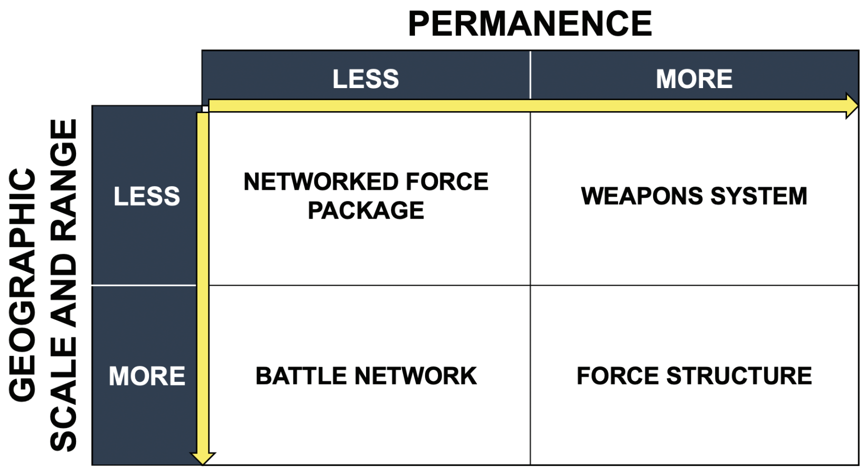
Source: CSBA graphic.

19 This definition and discussion draw on several past Center for Strategic and Budgetary Assessments (CSBA) studies. Among other works, see Barry Watts, *Six Decades of Guided Munitions and Battle Networks: Progress and Prospects* (Washington, DC: CSBA, 2007), https://csbaonline.org/research/publications/six-decades-of-guided-munitions-and-battle-networks-progress-and-prospects; and Andrew F. Krepinevich, Jr., *The Military-Technical Revolution: A Preliminary Assessment* (Washington, DC: CSBA, 2002), https://csbaonline.org/research/publications/the-military-technical-revolution-a-preliminary-assessment/publication/1.

20 Joint Chiefs of Staff (JCS), *Joint Publication 3-0: Joint Operations* (Washington, DC: DoD, October 2018), p. GL-13, https://irp.fas.org/doddir/dod/jp3_0.pdf.

21 A battle network combines target acquisition sensors, target localization sensors, command and control elements, weapons, weapon platforms, and the electronic communications linking them together. John Stillion and Bryan Clark, *What It Takes to Win: Succeeding in 21st Century Battle Network Competitions* (Washington, DC: CSBA, 2015), p. 1, https://csbaonline.org/research/publications/what-it-takes-to-win-succeeding-in-21st-century-battle-network-competitions/publication/1.

FIGURE 2: PERMANENCE, GEOGRAPHIC SCALE, AND NETWORKED FORCE PACKAGES



Source: CSBA graphic.

Unlike a force structure element, such as a brigade, or a weapons system, such as a submarine, an NFP does not exist over the long term in any meaningful sense. Rather, its existence begins when it is assigned to a mission and ends when the mission is complete. The same NFP may perform an identical mission again in the future, but that would technically represent a second NFP rather than a continuation of the first.

An NFP shares this property of impermanence with a battle network and related terms such as a reconnaissance strike complex.[22] An NFP is a subcomponent of a battle network. Both concepts generally place equal emphasis on the network and on the weapons systems connected to it. The difference between the two concepts is scale, particularly geographic scale.

Whereas an NFP can be as small as two interconnected weapons systems searching a stretch of road or as large as a multinational fleet patrolling the open ocean, a battle network typically refers only to large combinations of weapons systems arrayed over large distances.[23] Indeed, an overriding concern with geographic scale has driven the battle network literature's emphasis on performing long-range sensing and long-range precision strike.[24] The

22 Experts have used interchangeably the terms battle network, reconnaissance strike complex, precision strike complex, kill web, and kill chain, among others. Michael C. Horowitz and Joshua A. Schwartz, "To Compete or Retreat? The Global Diffusion of Precision Strike," working paper, February 2021, p. 4, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3752391; and Todd Harrison, *Battle Networks and the Future Force, Part 1: A Framework for Debate* (Washington, DC: Center for Strategic and International Studies, August 2021), p. 1, https://www.csis.org/analysis/battle-networks-and-future-force.

23 Stillion and Clark, *What It Takes to Win*, p. 1.

24 Barry D. Watts, *The Evolution of Precision Strike* (Washington, DC: CSBA, 2013), p. 4, https://csbaonline.org/research/publications/the-evolution-of-precision-strike.

NFP approach does not share this preoccupation with range, although it acknowledges that long-range weapons systems can afford operational advantages.

Conclusion

Some readers may object to introducing a new concept, NFP, given the dense jargon and overlapping concepts already populating this area of defense analysis. However, the NFP concept differs significantly enough from related ideas that, in our view, the benefits of strengthening analysis outweigh the costs of layering on concepts. The next two chapters demonstrate those benefits by using the NFP approach to assess the operational effectiveness of collaborative munitions and the cost-effectiveness of advanced fighter aircraft.

CHAPTER 2

An Application to Operational Effectiveness: The Promise of Collaborative Munitions

In modern military operations, an individual weapons system is only as good as the networked force package (NFP) it relies on for proper employment. A basic weapon embedded in a sophisticated NFP can outperform a sophisticated weapon embedded in a basic NFP.[25] Perhaps no weapon illustrates this principle better than a munition since it relies on a network of systems to identify targets and deliver it within attack range.

Although many analysts recognize that a munition depends on its NFP, current weaponeering practices tend to compare munitions in isolation without considering how their NFPs influence their operational effectiveness.[26] During targeting, weaponeers choose the effect that they want to create against a given target.[27] They consult applications and manuals comparing the effectiveness of different munitions against the target. They then select potential munitions and determine the quantity of weapons required to achieve the highest probability of creating the desired effect. From there, mission planners develop the strike

25 In World War II, for example, U.S. Sherman tanks were regarded as inferior to German heavy tanks. However, the quantity of Shermans fielded allowed them to be packaged with infantry, artillery, and tank destroyers and outduel Germany's Tiger and Panther tanks. Kyle Mizokami, "How Did America's Sherman Tank Win against Superior German Tanks in World War II?" *National Interest*, May 21, 2021, https://nationalinterest.org/blog/reboot/how-did-americas-sherman-tank-win-against-superior-german-tanks-world-war-ii-185625.

26 JCS, *Joint Publication 3-60: Joint Targeting* (Washington, DC: DoD, January 2013), p. II-15; and Air Force, *Air Force Doctrine Publication 3-60: Targeting* (Washington, DC: DoD, November 2021), p. 50. On the history of weaponeering, see Morris R. Driels, *Weaponeering for the Warfighter* (Reston, VA: American Institute of Aeronautics and Astronautics, 2021), pp. xv–xviii.

27 Throughout this monograph, we use the definition of weaponeer found in *Joint Publication 3-60: Joint Targeting*, which defines a weaponeer as "An individual who has completed requisite training to determine the quantity and type of lethal or nonlethal means required to create a desired effect on a given target." See JCS, *Joint Publication 3-60: Joint Targeting*, p. GL-11.

package using a plethora of tactical and operational factors. These practices have worked reasonably well with previous generations of munitions. However, next-generation munitions will feature advancements in collaborative capability, standoff range, and onboard sensors. Current weaponeering and mission planning practices do not incorporate factors such as these consistently. Practices and training will therefore need to evolve to keep pace with technology and ensure that planners fully account for the advanced capabilities of tomorrow's weapons.

NFP evaluation provides a starting point for thinking about the operational effectiveness of next-generation munitions. This chapter conducts an illustrative analysis of the effectiveness of two munitions in executing a hypothetical air interdiction against an armored vehicle column. The analysis compares a future precision-guided munition (PGM), the 200-pound GBU-53 upgraded with collaborative capability, against a current PGM, the 500-pound GBU-12 laser-guided bomb. The two munitions deliver similar explosive effects against armored vehicles when compared in isolation using current planning practices.

Yet, embracing a broader NFP perspective uncovers several advantages provided by the upgraded GBU-53. Because of its superior ability to self-deconflict, track enemies, loiter, and reattack, the upgraded GBU-53 allows aircraft to attack nine times as many targets in a single attack run, reduces the effects of enemy countermeasures, and keeps friendly aircraft further away from enemy air defenses. These findings depend on a stylized scenario and simplifying assumptions to analyze a tactical engagement. Still, they suggest that judging the operational effectiveness of next-generation munitions will require weaponeers and mission planners to embrace an NFP perspective. Comparing munitions in isolation or failing to account for the innovative features of modern weapons will not suffice.

Collaborative Munitions Technology

Today, the Department of Defense (DoD) is developing a future generation of smaller, smarter bombs that can communicate and collaborate with each other. Known as Networked Collaborative and Autonomous (NCA) munitions, these weapons feature prominently in the U.S. Air Force's "Golden Horde" research and development program.[28] The Air Force explains NCA munitions with a football analogy. The weapons can establish, communicate, and modify a "play" or "game plan" to accomplish a mission under predefined conditions and rules of engagement.[29] The Air Force Research Laboratory has successfully tested these capabilities using the GBU-53's predecessor, the GBU-39B Small Diameter Bomb.[30]

28 Air Force Research Laboratory (AFRL), "Golden Horde Colosseum," accessed February 21, 2023, https://afresearchlab.com/technology/vanguards/successstories/golden-horde.

29 Ibid.

30 Valerie Insinna, "U.S. Air Force Completes Tests of Swarming Munitions, but Will They Ever See Battle?" *Defense News*, June 7, 2021, https://www.defensenews.com/air/2021/06/07/us-air-force-successfully-completes-tests-of-swarming-munitions-but-their-future-is-unclear/.

The most likely candidates for NCA upgrading are miniature PGMs such as the GBU-53 StormBreaker glide bomb, known previously as the Small Diameter Bomb II. The GBU-53's onboard datalink, extended glide range, and tri-mode seeker make it ideal for NCA improvements.[31] Compared to other munitions, the GBU-53 is lighter and smaller with more onboard sensors. These attributes should reduce its need for certain supporting systems, thereby streamlining its NFP. Over time, NCA capabilities likely will further improve the GBU-53's effectiveness.

Scenario: Air Interdiction

During a regional conflict in the late 2020s, an American air component command is tasked to conduct air interdiction to destroy enemy maneuver forces headed to assembly areas behind the forward line of troops. Previous U.S. operations have degraded the enemy's integrated air defense system and long-range surface-to-air missiles (SAMs) enough to enable air attacks against enemy ground forces.[32] However, U.S. aircraft still face threats from point air defense systems, whether organic or attached to maneuver forces. Signals intelligence has identified a suspected battalion tactical group (BTG) traveling in a column along a major motorway.[33] The primary targets for destruction are the BTG's short-range air defense (SHORAD) systems and main battle tanks. The secondary targets are infantry fighting vehicles (IFVs). This scenario could transpire in numerous future contingencies – including those involving Russia, North Korea, or Iran – making it a relevant hypothetical for analyzing operational effectiveness.

Two NFP Options: Collaborative GBU-53 versus GBU-12

The American air component commander assigns two F-15E Strike Eagles to execute the interdiction. The commander tasks air planners to match the aircraft's munitions loadouts to the targets.[34] A traveling column of armored vehicles requires munitions capable of attacking moving targets, a requirement that disqualifies many GPS-guided bombs and standoff munitions. Figure 3 depicts two candidate NFPs that might conduct the attack.[35]

31 Thomas Newdick, "StormBreaker Mini Glide Bombs Take Longer to Load Onto Strike Eagles Due to Their Data Links," *The Drive*, December 15, 2021, https://www.thedrive.com/the-war-zone/43529/stormbreaker-mini-glide-bombs-take-longer-to-load-onto-strike-eagles-due-to-their-data-links.

32 Air superiority is typically identified as a prerequisite for successful air interdiction. Phillip S. Meilinger, "Air Interdiction," *Air Force Magazine*, February 1, 2014, https://www.airforcemag.com/article/0214air/.

33 The scenario assumes that a battalion tactical group contains 10 main battle tanks, around 40 infantry fighting vehicles, and two batteries of SA-19 or SA-22 SHORAD systems. Nicholas J. Fiore, "Defeating the Russian Battalion Tactical Group," *Armor* 128, no. 2 (Spring 2017), pp. 9–17.

34 JCS, *Joint Publication 3-03: Joint Interdiction* (Washington, DC: DoD, September 2016), p. xi.

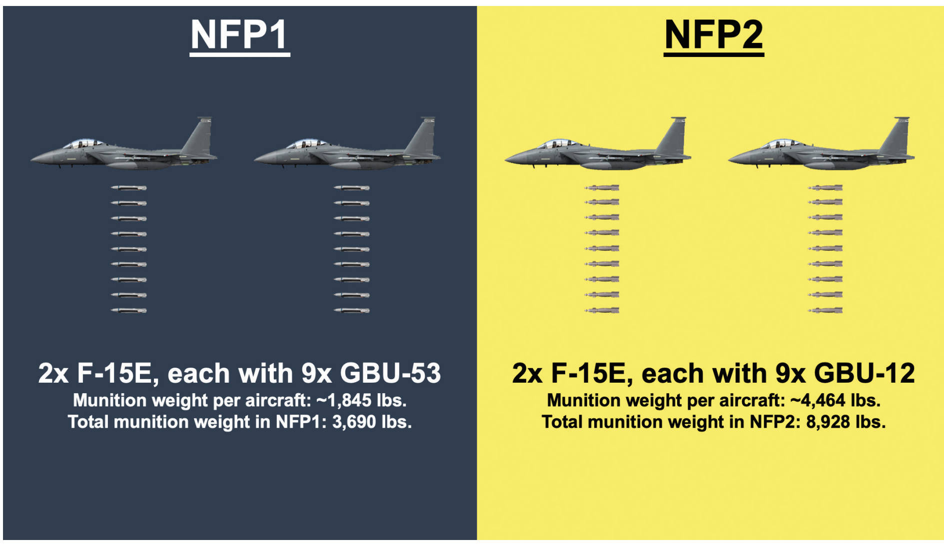
35 Cluster munitions represent another potential attack option. However, friendly ground forces might travel along the motorway or through the target area during follow-on operations. Any dud submunitions left behind could endanger them and limit their freedom of maneuver. Ibid., p. II-3.

NFP1 would load the F-15Es with GBU-53 StormBreaker glide bombs upgraded with NCA capabilities. Each F-15E can carry up to 28 GBU-53s. To create a fair comparison, however, each F-15E in NFP1 will carry only nine StormBreakers, giving NFP1 18 total munitions. The StormBreaker features a maximum glide range of around 83 kilometers (km) when released at high altitude and carries a tri-mode seeker for terminal guidance.[36]

NFP2 would load the F-15Es with GBU-12 Paveway II laser-guided bombs (LGBs). Each F-15E can carry nine GBU-12s, meaning that, as with NFP1, NFP2 would have 18 total munitions. The GBU-12 features a maximum range of around 10 km and uses a semi-active laser guidance system to track an aircraft's laser designator beam to a target.[37]

Current weaponeering practices would likely stop here, judging the two options roughly equal in terms of effectiveness because the GBU-53's armor-defeating warhead and advanced explosive filler produce similar effects against armored vehicles to those of the GBU-12.[38] Having assessed how the munitions will affect the targets, current weaponeering practices would leave it to mission planners to consider the pros and cons of the munitions' NFPs. These planners, however, might not evenly compare the munitions' effectiveness and could overlook the advantages provided by the upgraded GBU-53 due to its collaborative capability. The next section details those advantages by illustrating potential attack tactics.

FIGURE 3: MUNITIONS LOADOUTS IN NFP1 VS. NFP2



Sources: Janes, "StormBreaker Bomb (GBU-53/B SDB II)," *Weapons: Air Launched*, August 6, 2021; and Janes, "GBU-10/12/16/58 Paveway II," *Weapons: Air Launched*, August 5, 2021.

36 Janes, "StormBreaker Bomb (GBU-53/B SDB II)," *Weapons: Air Launched*, August 6, 2021.

37 Janes, "GBU-10/12/16/58 Paveway II," *Weapons: Air Launched*, August 5, 2021.

38 Kevin P. Sweeney, *Miniature Munitions: Is the U.S. Military Prepared to Support Major Combat Operations?* (Maxwell, AL: Air Force Air Command and Staff College, April 2016), p. 3.

Comparative Effectiveness Analysis

With the scenario and NFP configurations specified, the analysis now sketches brief attack vignettes to illustrate each NFP's potential operational effectiveness.

NFP1

The F-15Es approach the target area and, at a range of around 90 km, use their radar to locate and identify enemy BTG elements moving along a motorway in staggered company column formations.[39] At a range of approximately 60 km, just under the GBU-53's maximum range for moving targets of 72 km, the aircraft assume an attack heading and begin releasing GBU-53s in timed intervals.[40] At 20 km from the armored column, the F-15Es turn around to avoid entering the engagement range of the BTG's SA-22 air defenses.

The upgraded GBU-53s glide together and establish network connections with each other and with the egressing aircraft. As the first bombs approach the target area, they use their tri-mode seekers to identify moving SHORAD vehicles and tanks within the formation. The munitions collaborate to share targeting data and formulate a game plan that self-assigns each munition to a different vehicle. The first GBU-53s strike the BTG and, with their armor-defeating warheads, destroy several main battle tanks. The GBU-53 can identify and track targets in suboptimal weather conditions and would not trigger laser designator countermeasures on armored vehicles.[41]

The remaining GBU-53s use their seekers while loitering to locate any moving vehicles that survived the initial salvo. The munitions do not target destroyed vehicles for reattack because those vehicles appear both immobile and obscured by smoke, dust, and debris. Each loitering munition uses its onboard datalink to relay battle damage assessment from the preceding weapon back to the aircraft. If the F-15Es do not release all their GBU-53s in the first engagement, they can reattack in subsequent engagements.

With these techniques, NFP1 can destroy up to 18 armored vehicles using a single attack run, assuming all GBU-53s hit their intended targets and deliver the desired effects. Given the attack ranges specified above, the F-15Es would remain outside the maximum range of the BTG's organic air defense systems, namely the SA-19 and SA-22.

In sum, NFP1's best-case outcome involves destroying up to 18 SHORAD systems, tanks, or IFVs in one attack run, with both aircraft remaining undetected by BTG air defenses. If the

39 Janes, "AN/APG-82(V)1," *C4ISR & Mission Systems: Air*, August 26, 2021.

40 Raytheon, "StormBreaker Smart Weapon," accessed February 21, 2023, https://www.raytheonmissilesanddefense.com/capabilities/products/stormbreaker-smart-weapon.

41 Sensors such as the Russian Shtora-1 system found on main battle tanks can detect laser designator beams and automatically deploy countermeasures such as thermal smoke screens. Tom J. Meyer, "Active Protection Systems: Impregnable Armor or Simply Enhanced Survivability?" *Armor* 107, no. 3 (May-June 1998), pp. 7–11.

attack proved less successful, it might destroy fewer than 18 vehicles but would still likely keep the pilots at a safe distance from enemy air defenses.

NFP2

NFP2's vignette begins in the same manner as NFP1. The F-15Es fly toward the target and use radar to locate the armored columns. In this case, the F-15Es must approach much closer–to around 8 km–to employ the GBU-12 at just under its maximum range of 10 km.[42] The aircraft use their targeting pods to identify and track high-priority vehicles within the column, and each aircraft releases one GBU-12. Before impact, the F-15Es turn on their laser designators, and the LGBs guide themselves toward the laser's energy. The maximum effective employment of the GBU-12s would require optimal weather conditions and an obscurant-free path between the aircraft's targeting pods and the target.

NFP2 requires the F-15Es to laser designate each target and remain on station for the engagement's duration. The need to laser designate limits each attack run to two GBU-12s and forces the F-15Es to make nine attack runs to expend their 18 munitions.

After the first two GBU-12s hit their targets, the aircraft conduct battle damage assessment and evaluate whether to reattack. If a tank survived the strike, the pilots reattack with another GBU-12. Reattacking with laser-guided munitions would require the pilots to wait for dust and smoke to clear the target area so the munition could follow the laser spot.[43] If the attack destroyed the targets, the pilots would identify the highest priority vehicles remaining and initiate another attack run.

NFP2 can destroy a maximum of 18 armored vehicles after nine attack runs, assuming all GBU-12s hit their intended targets and achieve the desired effects.[44] The aircraft must maintain an altitude high enough to employ the GBU-12 but low enough for their targeting pods to designate the enemy vehicles through clouds or obscurants with sufficient laser energy. As a result, the F-15s must fly well within the range of SA-19s and SA-22s accompanying the BTG, likely degrading the mission's overall effectiveness.[45]

In sum, NFP2's best-case outcome is destroying 18 SHORAD systems, tanks, or IFVs with both aircraft surviving nine attack runs. A less successful engagement could result in fewer vehicles destroyed and one or both aircraft downed by air defenses.

42 Air Force Magazine, "GBU-10/12/49 Paveway II," accessed February 21, 2023, https://www.airforcemag.com/weapons-platforms/gbu-10-12-49-paveway-ii/.

43 David Cenciotti, "This Is the Effect of an F-15E Strike Eagle Live Weapons Drop," *The Aviationist*, February 28, 2014, https://theaviationist.com/2014/02/28/48th-fw-live-bombs/.

44 The analysis assumes that enemy vehicles travel in doctrinally recommended intervals sufficient to limit each 500-pound bomb to destroying one vehicle.

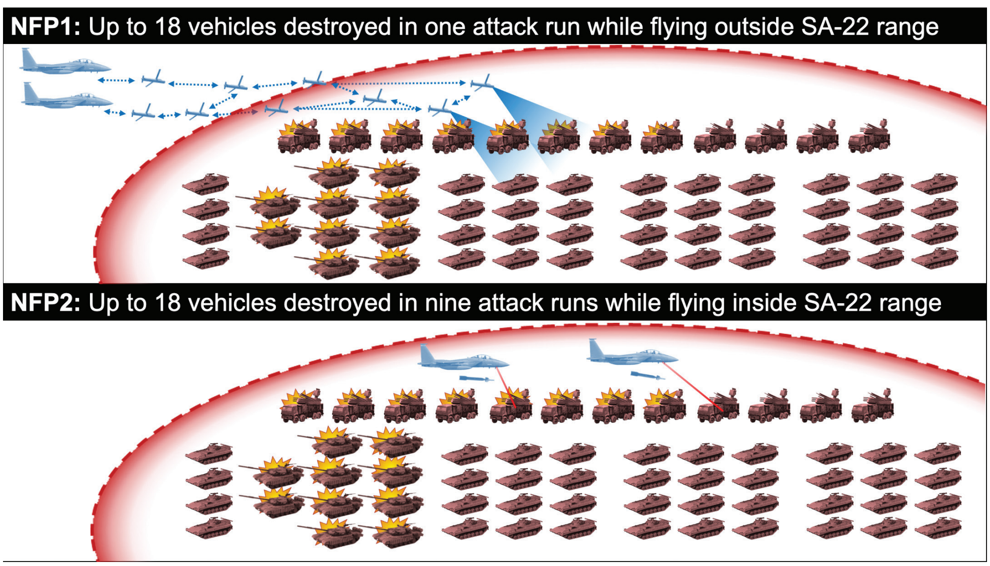
45 JCS, *Joint Publication 3-03*, p. IV-11.

Summary of Findings

Although the GBU-53 and GBU-12 produce similar effects against armored targets, the collaborative GBU-53's onboard systems and light weight give NFP1 three operational advantages. First, NFP1 can attack nine times as many targets per attack run (18 targets per run versus two targets per run).[46] As depicted in Figure 4, this advantage reduces the time required for the aircraft to execute the mission, freeing them to be re-tasked to other missions. Second, NFP1 increases the odds of success by reducing the effects of suboptimal weather, pilot skill, target area obscurants, and laser designator countermeasures. Third, NFP1 avoids the potential cost of losing pilots and their aircraft because the GBU-53 allows the aircraft to remain outside the maximum engagement ranges of BTG air defenses.

This vignette compared two NFP options featuring an equal number of munitions to show the targets-per-attack run advantage offered by NCA munitions. Of course, the upgraded GBU-53's smaller size would also allow the F-15Es to carry more GBU-53s per mission, further increasing the advantages illustrated above. Equipping the F-15E with a full load of GBU-53s would allow a single aircraft to attack up to 1.5 times the number of targets as a pair of aircraft carrying GBU-12s. Although the GBU-53 has a higher per unit cost than the GBU-12, this payload advantage could make it more cost advantageous than heavier weapons which require NFPs to include additional aircraft.

FIGURE 4: OPERATIONAL EFFECTIVENESS OF NFP1 VS. NFP2



Source: CSBA graphic.

46 The analysis uses the rate at which vehicles are engaged to measure operational effectiveness but recognizes that "kill counts" do not always translate into strategic success. Ibid., pp. I-1–I-11.

Assumptions and Limitations

The preceding analysis rested on various assumptions. Most notably, it compared a future capability, the GBU-53 with NCA upgrades, to a current capability, the GBU-12. Although the U.S. military has not yet fielded NCA munitions, it will likely do so soon.[47] The older GBU-39B Small Diameter Bomb has used networking and collaboration to prioritize targets within predefined rules of engagement, synchronize simultaneous impacts, and reassign targets mid-flight.[48] Even without NCA upgrades, currently fielded GBU-53s released in sufficient intervals could use their target recognition sensors to avoid destroyed vehicles. Combined with their reduced size and standoff range, currently fielded GBU-53s already possess many of the operational features described in the analysis. In sum, a GBU-53 with NCA upgrades has progressed far enough in development to justify preliminary comparisons to fielded capabilities such as the GBU-12.

Besides this technological maturity issue, the analysis also did not address a range of other tactical and technical considerations.[49] For example, it did not consider how pilot manning and training should evolve to employ collaborative munitions effectively.[50] The analysis omitted many of these factors because they require classified information and specifications. As collaborative munitions enter the operational force, additional data will emerge, allowing further research on their effectiveness.

Conclusion

The need for NFP-style evaluation will only increase as PGMs become more capable. Current weaponeering and mission planning practices should evolve, specifically by incorporating more diverse operational variables, to wield the advantages offered by next-generation munitions such as the GBU-53 with NCA upgrades. Introducing advanced weapons will require training mission planners to account for these features in their decision-making and equipping them with the tools to perform such analyses in wartime environments. As this chapter demonstrated, munitions that produce similar explosive effects may produce different operational effects due to the relative strengths of their NFPs. As a method for judging operational effectiveness, the days of comparing munitions in isolation are coming to an end.

47 AFRL, "Golden Horde Colosseum."

48 AFRL, "AFRL Demonstrates First Collaborative Weapon Technologies," January 7, 2021, https://www.af.mil/News/Article-Display/Article/2465160/afrl-demonstrates-first-collaborative-weapon-technologies/; and John A. Tirpak, "Small Diameter Bombs Collaborate in Golden Horde Test," *Air Force Magazine*, May 26, 2021, https://www.airforcemag.com/small-diameter-bombs-golden-horde-test/.

49 Issues not considered by the analysis include the exact location and formation of targets; terrain in target area; weather conditions; munitions costs; fuel capacity and range of aircraft with different munitions payloads; planning and preparation measures required by the two munitions; alternative strike options (something other than manned U.S. Air Force fighter aircraft); rules of engagement and collateral damage caused by either munition missing the intended aimpoint or impacting the wrong target; future collaborative munition effectiveness rates; and inventory numbers and production capacity.

50 For an excellent example of a tactical expert analyzing how new capabilities should affect pilot manning and training, see Ivan Kanapathy, "Professional Notes: Crew Solo in the F/A-18D," *Proceedings* 132, no. 11 (November 2006), https://www.usni.org/magazines/proceedings/2006/november/professional-notes.

CHAPTER 3

An Application to Cost-Effectiveness: Fighter Aircraft and Mission-Level Cost Avoidance

Assessments of cost-effectiveness can change markedly when a weapons system is evaluated not in isolation but rather as part of a networked force package (NFP). A system that seems exorbitant when priced *à la carte* can instead appear economical when priced *table d'hôte*.[51] One important reason why is the treatment of cost avoidance.[52] Platform-centric evaluation's favored metric, cost per weapons system, does not reflect how spending on one system can eliminate the need for spending on other activities and systems.[53] Force planners are more likely to appreciate this cost avoidance.[54] Yet it registers infrequently with Congress, oversight organizations, and the public.[55]

51 The opposite can also hold true. A weapon that seems inexpensive in isolation can instead appear high-priced after factoring in support activities and systems. A classic example of this type of analysis is Desmond Ball, "The Costs of Cruise Missiles," *Survival* 20, no. 6 (1978), pp. 242–247.

52 Cost avoidance is "an action taken in the immediate time frame that will decrease costs in the future." Defense Acquisition University, "Cost Avoidance," accessed February 21, 2023, https://www.dau.edu/glossary/Pages/GlossaryContent.aspx?itemid=27170.

53 A representative example of this type of analysis is John Green and Richard Zeckhauser, "Thunder Versus Lightning: A Performance and Cost Analysis of the A-10 'Warthog' Versus the F-35 Joint Strike Fighter," *Journal of Benefit-Cost Analysis* 10, no. 3 (Fall 2019), pp. 434–468.

54 The modeling and simulation community has emphasized cost avoidance when evaluating virtual training's return on investment. For research techniques in that context resembling this chapter's approach, see Tim Cooley and Steve Gordon, "Cost Avoidance for M&S Training Systems: A Subset of Return on Investment," *M&S Journal* (Fall 2012), pp. 35–40.

55 David A. Deptula and Douglas A. Birkey, *Resolving America's Defense Strategy-Resource Mismatch: The Case for Cost-Per-Effect Analysis*, Mitchell Institute Policy Paper Vol. 20 (Arlington, VA: Mitchell Institute for Aerospace Studies, July 2020), p. 3, https://mitchellaerospacepower.org/wp-content/uploads/2021/01/a2dd91_9eb547d3420d47bc932c95f7e949d024-1.pdf.

NFP evaluation puts cost avoidance front and center. It asks not "What does the weapons system cost?" but rather "What does the mission cost?" If a system reduces a mission's expected cost by eliminating the need to perform some supporting activities, then that system has demonstrated a form of cost-effectiveness – even if the system's cost per unit exceeds that of an alternative system.

To support these arguments, this chapter performs an illustrative analysis of a hypothetical attack operation by fighter aircraft, a weapons system that has inspired ferocious debates about cost-effectiveness for decades. The analysis compares the costs of having two different NFPs available to perform the mission: a) F-35As or b) F-16s/F-15Es plus support aircraft. Because the F-35A has low observability and better onboard enabling capabilities, the analysis assumes that it can operate independently in this scenario without help from support aircraft. The analysis finds that the F-35A package would cost approximately 50 percent to 70 percent less than the alternative package in terms of hourly operating and support (O&S) costs. This finding holds up against different configurations of the alternative package.

By considering mission-level cost avoidance, the F-35A appears more cost-effective than it often seems in platform-centric evaluations. The chapter uses one simplified scenario, makes multiple assumptions, and excludes various considerations. Nevertheless, it demonstrates how evaluating weapons systems as NFPs can unlock counterintuitive insights about cost-effectiveness.

Scenario: Attack Operations by Fighter Aircraft

During a contingency operation in the early 2030s, an American air component command is tasked to conduct an hour-long attack operation to seek out and destroy time-sensitive targets in a designated area located within the unrefueled combat radius of the command's fighter aircraft. As an offensive mission emphasizing flexibility, the attack operation must be able to engage enemy ground targets and, potentially, enemy air targets located anywhere in the area.[56] The primary target is enemy ground-based mobile ballistic missiles, which U.S. intelligence has found but not fixed in the area. The secondary target is enemy aircraft operating in the area. Previous U.S. operations have reduced but not eliminated the enemy surface-to-air threat, including SA-10 SAMs, meaning the mission will not kick down the door but rather keep it open in a contested environment.[57] U.S. fighter aircraft could fly a

56 The mission could be considered a self-escort attack operation/interdiction or a blended attack operation/fighter sweep because it features enemy ground targets and potential air targets. JCS, *Joint Publication 3-01: Countering Air and Missile Threats* (Washington, DC: DoD, May 2018), pp. IV-9–IV-18; and Air Force, *Air Force Doctrine Publication 3-01: Counterair Operations* (Washington, DC: DoD, September 2019), pp. 8–9.

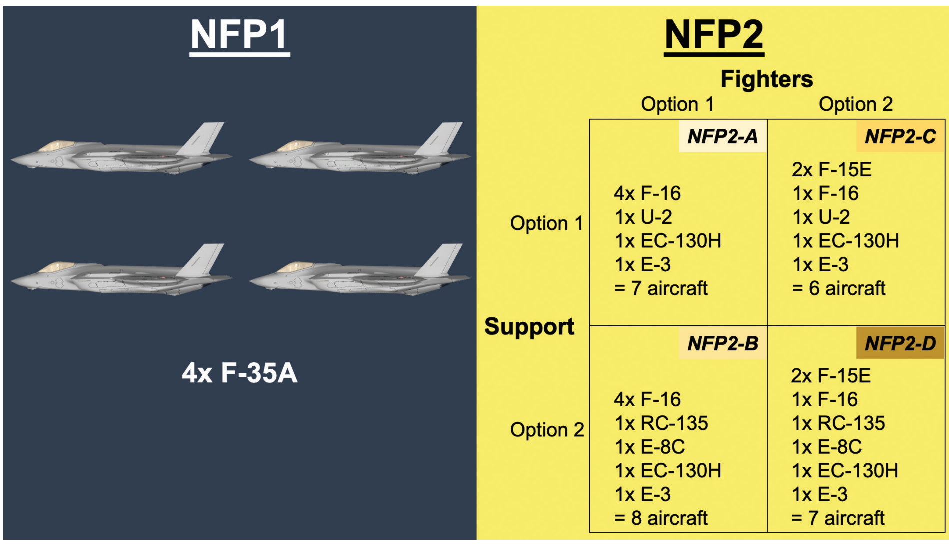
57 Previous CSBA research defined a contested (vice highly contested) environment as follows: "In contested air environments, threats pose episodic to near continuous challenges from a single axis to U.S. operations in the air. Communications, sensing, and other operations through the electromagnetic spectrum are also degraded in contested environments." Mark Gunzinger et al., *An Air Force for an Era of Great Power Competition* (Washington, DC: CSBA, 2019), p. i, https://csbaonline.org/uploads/documents/CSBA_AFAIS_Report_v9.pdf.

moderate-risk mission like this during various campaigns against different adversaries, making it an instructive hypothetical.

Two NFP Options: F-35A versus F-16/F-15E Plus Support Aircraft

Two different NFPs might perform the attack operation. The first option, labeled NFP1, would be four F-35As operating independently. The second option, NFP2, would consist of either four F-16s plus support aircraft or one F-16 and two F-15Es plus support aircraft. Either NFP2 variation would provide an aggregate weapons payload roughly equivalent to NFP1.[58] An air command likely would view the second NFP2 variation skeptically because the single F-16 would fly without a wingman, but the analysis includes it for illustrative purposes. Altogether, NFP2 would include four to eight aircraft depending on the commander's mission guidance and risk tolerance. (The sensitivity analysis below considers a smaller NFP2). Figure 5 displays four base configurations for NFP2 that the analysis will compare against NFP1.

FIGURE 5: AIRCRAFT MIXES IN NFP1 VS. NFP2



Source: CSBA graphic.

NFP1 and NFP2 represent stylized examples of, respectively, a smaller NFP comprised only of attack aircraft and a larger NFP combining attack and support aircraft. The F-35A makes up the "attack only" NFP1 because it features low observability and carries onboard

58 The F-35A carries an externally configured weapons payload of 18,000 lbs, so four F-35As would carry 72,000 lbs. If they only carried weapons internally to maintain low observability, the aggregate weapons payload would be smaller. The F-16 and F-15E carry 20,000 lbs and 24,500 lbs, respectively, so four F-16s would carry 80,000 lbs whereas one F-16 and two F-15Es would carry 69,000 lbs. Janes, "Equipment Profiles," *All the World's Aircraft: Development & Production*, various dates.

advanced versions of enabling capabilities such as signals collection,[59] electronic warfare,[60] and airborne early warning.[61] The analysis assumes that this combination of stealth and enabling capabilities would permit the F-35A to operate independently in this scenario without help from support aircraft. To be clear, the analysis does not suggest that the F-35A never requires support aircraft, operates as effectively without support aircraft as with them, or possesses better enabling capabilities than support aircraft. Additionally, the F-16 and F-15E also carry onboard enabling capabilities, albeit less advanced than the F-35A's, so they could also operate without support aircraft in some scenarios.[62]

To illustrate potential support aircraft mixes, NFP2 features a U-2, RC-135, and/or E-8C to collect signals; an EC-130H to handle electronic threats; and an E-3 to provide airborne early warning.[63] The term "support" applies loosely here, as these aircraft typically fly general missions and do not operate in direct support of fighter aircraft. Other support aircraft might also prove useful, such as the EA-18G performing electronic warfare, but the analysis does not include every possibility. The support aircraft might require their own fighter escorts for protection, but NFP2 excludes such escorts to preserve comparability between NFP1 and NFP2.

Overall, the comparison between NFP1 and NFP2 seeks to draw the reader's attention to the costs of enabling capabilities and support aircraft, a factor often ignored in platform-centric evaluation. The comparison does not intend to render technical judgments about aircraft performance or mission planning. Experts often disagree about those specifics, and important details remain classified. Nevertheless, we believe that the analysis's basic intuition — that an NFP's size and cost will vary based on the enabling capabilities included — remains sound and merits greater attention from policymakers.

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59 Tyler Rogoway, "Could the F-35 Become the Biggest Electronic Intelligence Collection System Ever Devised?" *The War Zone*, July 2, 2020, https://www.thedrive.com/the-war-zone/4291/could-the-f-35-become-the-biggest-electronic-intelligence-collection-system-ever-devised; and Charles R. Davis, "F-35 Lightning II Program Brief," September 26, 2006, pp. 24, 27, https://secure.afa.org/media/scripts/ppt_pdf/F-35_Brief.pdf.

60 Ron Sherman, "F-35 Electronic Warfare Suite: More Than Self-Protection," *Avionics International*, April 1, 2006, https://www.aviationtoday.com/2006/04/01/f-35-electronic-warfare-suite-more-than-self-protection/; and Emma Helfrich, "New Electronic Warfare Suite Top Feature of F-35 Block 4, Air Combat Boss Says," *The War Zone*, March 9, 2023, https://www.thedrive.com/the-war-zone/new-electronic-warfare-suite-top-feature-of-f-35-block-4-air-combat-boss-says.

61 Kyle Mizokami, "An F-35 Just Became the Eyes and Ears of a Destroyer," *Popular Mechanics*, September 13, 2016, https://www.popularmechanics.com/military/weapons/a22840/f-35-network-test/; Tamir Eshel, "Missile Launch Detected by F-35 Provide Early Warning for Ballistic Missile Intercept Test," *Defense Update*, September 16, 2019, https://defense-update.com/20190916_project_riot.html; and Dario Leone, "F-35 Used as Elevated Sensor to Enable Live Fire of PAC-3 Patriot for Cruise Missile Kill in U.S. Army Flight Test," *Aviation Geek Club*, July 16, 2021, https://theaviationgeekclub.com/f-35-used-as-elevated-sensor-to-enable-live-fire-of-pac-3-patriot-for-cruise-missile-kill-in-us-army-flight-test/.

62 Brett Tingley, "608 U.S. Air Force F-16s Are Getting the Type's Largest Combined Upgrade Package Ever," *The War Zone*, March 2, 2022, https://www.thedrive.com/the-war-zone/44525/608-u-s-air-force-f-16s-are-getting-the-types-largest-combined-upgrade-package-ever; and Thomas Newdick, "F-15E Strike Eagle's New Electronic Warfare Suite Put to the Test in Major Exercise," *The War Zone*, November 21, 2020, https://www.thedrive.com/the-war-zone/37766/the-f-15e-strike-eagles-new-electronic-warfare-suite-put-to-the-test-in-big-exercise

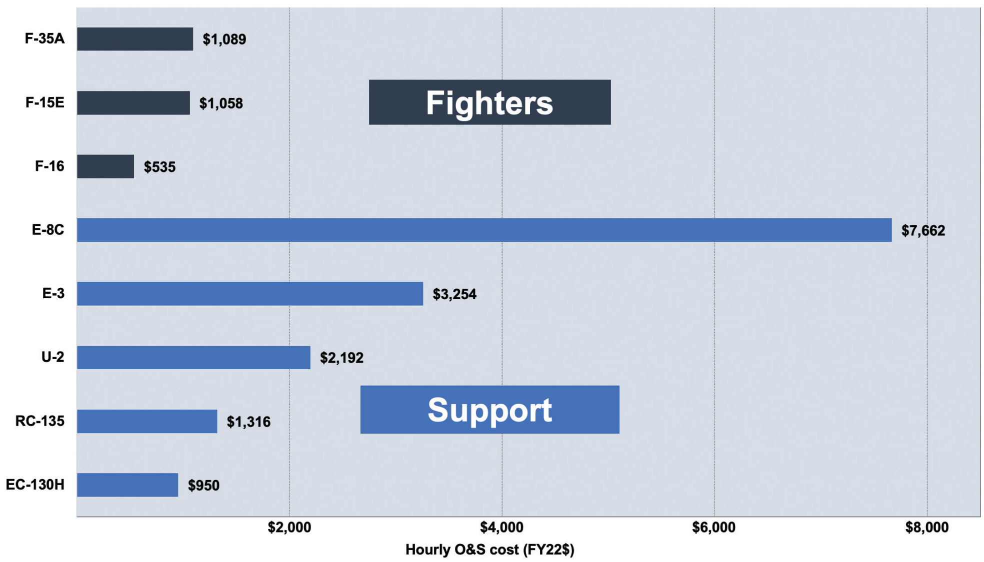
63 Air Force, "Fact Sheets," various dates, https://www.af.mil/About-Us/Fact-Sheets/Category/724/.

Comparative Cost Analysis

The scenario involves a commander choosing between force packages during a contingency operation in the next decade. The cost in question thus consists of having the aircraft available to fly the mission. As a result, O&S cost represents the appropriate cost category to investigate. It covers operating, maintaining, and supporting fielded aircraft as opposed to acquiring new platforms or disposing of old ones.[64]

Additionally, for this question about contingency readiness, O&S cost per aircraft offers advantages over cost per flying hour, a more commonly-used metric, because the former "more intuitively expresses the cost of available aircraft," according to RAND research.[65] O&S cost per aircraft equals the total annual O&S cost for an aircraft fleet divided by the number of aircraft in the fleet that year.

FIGURE 6: HOURLY O&S COST PER AIRCRAFT



Sources: Government Accountability Office (GAO), *Aircraft Mission Capable Rates Generally Did Not Meet Goals and Cost of Sustaining Selected Weapon Systems Varied Widely* (November 2020), pp. 35, 78, 99, 107, 126, 128, 148, 152, https://www.gao.gov/assets/gao-21-101sp.pdf; James Drew, "Lockheed, Northrop Boast Merits of U-2, Global Hawk as BCA Cuts Loom," *Inside the Air Force*, March 13, 2015; and Air Force Magazine, *2015 USAF Almanac* (May 2015), p. 43, https://www.airforcemag.com/app/uploads/2015/05/2015_May_Almanac.pdf.

Notes: The analysis converted annual O&S cost per aircraft to hourly cost by dividing by 8,760. Due to data limitations, the analysis used GAO's KC-135 and C-130H figures as proxies for the RC-135 and EC-130H, respectively. Since the latter pair likely cost more as specialized aircraft, the data proxying works against the chapter's argument. The analysis estimated the U-2 figure based on data cited in *Inside the Air Force* (fleet O&S cost) and Air Force Magazine (fleet size). All figures adjusted for inflation using Department of Defense, *National Defense Budget Estimates for FY 2022* (August 2021), Table 5-8, pp. 70–71.

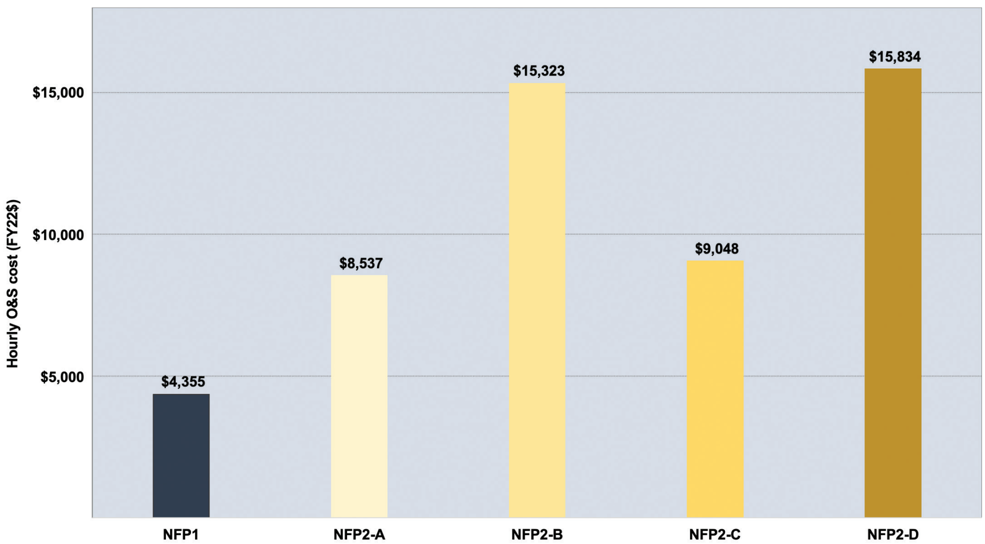
64 Cost Assessment and Program Evaluation, *Operating and Support Cost-Estimating Guide* (Washington, DC: DoD, September 2020), pp. 3–6.

65 Cost per flying hour has the counterintuitive property of varying inversely with flying hours. Michael Boito et al., *Metrics to Compare Aircraft Operating and Support Costs in the Department of Defense* (Santa Monica, CA: RAND Corporation, 2015), p. xiv.

Figure 6 displays *hourly* O&S costs per aircraft, the annual O&S cost per aircraft divided by the number of hours in a year (8,760). The costs were adjusted to hourly to match the mission's 60-minute duration. The O&S costs are based on unclassified data released by the Government Accountability Office. To reiterate, hourly O&S cost per aircraft does not equal cost per flying hour.

Multiplying the aircraft mixes by the hourly O&S costs per aircraft yields total costs for NFP1 and NFP2 (Figure 7). NFP1 would cost 49 percent less than the cheapest alternative (NFP2-A) and 72 percent less than the costliest alternative (NFP2-D). At first glance, this result may appear surprising because the F-35A's hourly O&S cost per aircraft is more than double the F-16's; however, using F-35s costs less per mission than using cheaper F-16s because the F-35A requires fewer support aircraft in the scenario.

FIGURE 7: TOTAL COSTS FOR NFP1 VS. NFP2 (A-D)



Source: CSBA graphic.

This situation is not new. During the Gulf War, stealthy F-117s operated more efficiently than cheaper non-stealthy aircraft in terms of strategic targets destroyed per sortie and support aircraft required per sortie.[66] Based on missions flown in the war, the Air Staff estimated that a small NFP composed of stealthy B-2 bombers operating independently could destroy 16 aimpoints on an airfield at less cost, calculated as procurement plus 20-year O&S

66 James A. Winnefeld, Preston Niblack, and Dana J. Johnson, *A League of Airmen: U.S. Air Power in the Gulf War* (Santa Monica, CA: RAND Corporation, 1994), pp. 163–164, https://www.rand.org/pubs/monograph_reports/MR343.html; and Thomas G. Mahnken, "Weapons: The Growth & Spread of the Precision-Strike Regime," *Daedalus* 140, no. 3 (Summer 2011), p. 48.

expenses, than equally effective alternative NFPs composed of larger numbers of attack and support aircraft.[67]

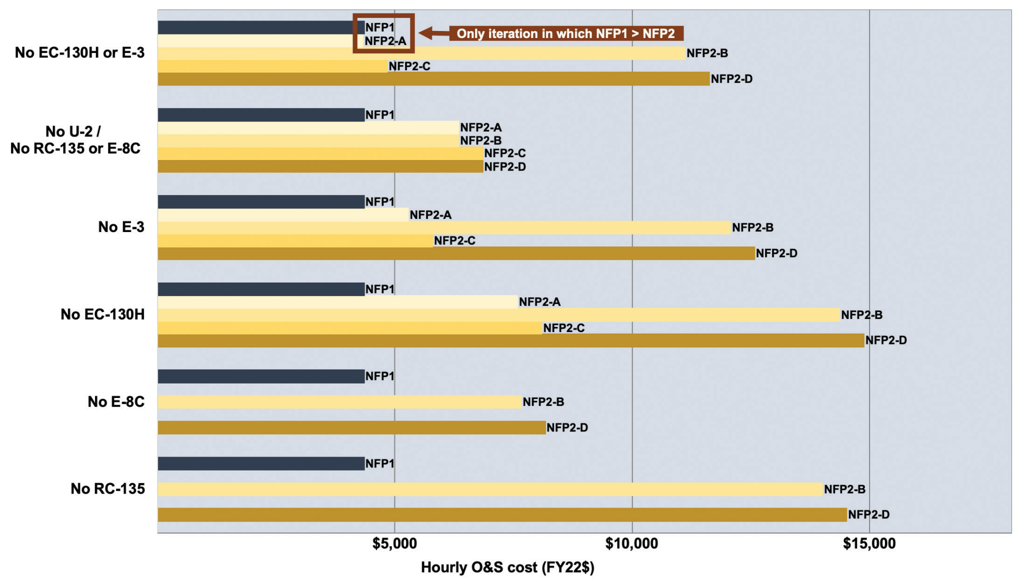
The F-35A, F-117, and B-2 examples illustrate why force development planners should think about cost-effectiveness in terms of cost per mission, not just cost per platform. As General Charles Horner, overall air commander during the Gulf War, once remarked, "The bottom line is not dollars per aircraft but overall capability per dollar."[68]

The F-35 is not the only weapons system conducive to leaner networked force packages. Its advantages there still must be weighed against its disadvantages elsewhere. Still, when viewed as part of an NFP, it appears more cost-effective than conventional wisdom might expect.

Sensitivity Analysis

Good analysis should try to prove itself wrong to persuade the reader that it is right. Would NFP1 still cost less if NFP2 featured fewer aircraft? A commander might select a leaner NFP2 for various reasons, including competing requirements, risk tolerance, weather conditions, or aircraft availability.

FIGURE 8: TOTAL COSTS FOR NFP1 VS. NFP2 ITERATIONS



Source: CSBA graphic.

67 Authors' correspondence with Chris Bowie, March 26, 2023; Air Force, "Stealth Week Brief Book," June 10-14, 1991, PDF p. 10, https://documents.theblackvault.com/documents/stealth/AFD-080128-004.pdf; and David A. Perin, *A Comparison of Long-Range Bombers and Naval Forces* (Alexandria, VA: CNA, December 1991), p. 2, https://apps.dtic.mil/sti/pdfs/ADA533405.pdf.

68 Air Force, "The Bottom Line," accessed March 31, 2023, https://www.af.mil/News/Photos/igphoto/2000441580/.

Figure 8 compares NFP1 against 20 leaner iterations of NFP2. Each NFP2 iteration subtracts one or two support aircraft from the base configurations, leaving four to seven aircraft in NFP2 to compare against the four F-35As in NFP1. NFP1 costs less than every NFP2 iteration except for one: four F-16s plus a U-2 (i.e., NFP2-A minus the EC-130H and E-3). Leaving aside risk considerations, that single exception costs only about ~$20 less than NFP1, a negligible difference. Overall, NFP1's assessed mission-level cost-effectiveness holds up well to sensitivity analysis.

Assumptions and Limitations

The preceding analysis probed a simplified scenario and excluded various considerations.[69] For example, it treated aircraft acquisition expenditures as sunk costs that would not affect choices about force employment once aircraft had entered the active inventory. Future research could relax this assumption by calculating aircraft acquisition cost per hour, the R&D plus procurement cost per aircraft divided by its expected total service life in hours, to highlight the depreciation effects of how much investment was burned up with each hour of flying.[70] Regardless of how that research might proceed, the analysis provided a starting point for thinking about NFPs and mission-level cost avoidance.

Conclusion

NFP evaluation can provide a different look at cost-effectiveness, highlighting factors that traditional platform-centric analysis might miss. Readers might take issue with aspects of this chapter's illustrative analysis. Such is the nature of evaluating complex weapons systems within the uncertain context of defense planning. Yet any disagreements about analytical specifics should not distract from the chapter's broader argument; namely, that the U.S. defense community ought to pay greater attention to mission-level cost avoidance when assessing weapons system cost-effectiveness.

69 Issues not considered by the analysis include aircraft acquisition costs, service life, and age; fighter aircraft munitions, survivability, range, and multi-mission versatility; pilot requirements; and alternative strike options (i.e., platforms other than manned U.S. Air Force fighter aircraft).

70 The authors thank Chris Bowie for this suggestion.

CHAPTER 4

Conclusion: Advancing the NFP Approach

This report's two illustrative assessments used air warfare missions to demonstrate the networked force package (NFP) approach, but analysts could apply it to other warfighting domains, too. The NFP approach proves especially eye-opening under two conditions. The first condition, showcased in the collaborative munitions chapter, involves two weapons systems that appear equally effective according to traditional evaluation criteria but perform differently when their NFPs are considered. The second condition, showcased in the fighter aircraft chapter, involves a pricier weapons system embedded in a smaller NFP that costs less overall than a cheaper weapons system embedded in a larger NFP.

Extending the NFP approach to naval warfare, ground warfare, and multi-domain operations could reframe important choices about force design. With naval warfare, for example, an NFP composed of a large surface combatant and unmanned surface vessels could potentially generate greater (or at least equal) strike capacity at less cost than a comparable NFP of multiple manned surface ships.[71] With ground warfare, an NFP built around precision-guided artillery potentially could cost less overall in the long run, despite higher up-front costs for certain individual systems, than an NFP built around traditional non-precision artillery. Traditional artillery would require more salvos and additional ammunition resupplies to achieve comparable effects, lengthening vulnerable logistics trains and driving up costs.[72] Finally, examining multi-domain operations from an NFP standpoint could help illustrate how joint forces complement each other. For instance, an NFP combining

71 Bryan Clark and Timothy A. Walton, *Taking Back the Seas: Transforming the U.S. Surface Fleet for Decision-Centric Warfare* (Washington, DC: CSBA, 2019), https://csbaonline.org/research/publications/taking-back-the-seas-transforming-the-u.s-surface-fleet-for-decision-centric-warfare.

72 Linwood R. Nelson, "Optimizing U.S. Army Field Artillery: A Future for the King of Battle," M.A. thesis, School of Advanced Military Studies, U.S. Army Command and General Staff College, 2019, p. 49, https://apps.dtic.mil/sti/pdfs/AD1071213.pdf.

ground-based fires to suppress enemy defenses and airborne strike platforms to conduct attack operations could prove more effective and/or less expensive than either force operating by itself.[73]

These examples by no means exhaust the analytical possibilities of the NFP approach. Rather, they illustrate the contexts in which the approach can produce counterintuitive findings and offer distinctive insights to decision makers. The NFP approach will only grow in importance as future force structures include attritable drones, loitering weapons, and unmanned munition carriers that blur the lines between platform and weapon. Every enabler or intermediary added between platform and weapon creates a new opportunity for NFP analysis to reassess operational- and cost-effectiveness.

Anticipating Organizational and Political Resistance

At least two obstacles may hinder DoD from embracing the NFP approach to weapons systems evaluation. The first is organizational. Over the last decade, DoD has gravitated away from aggregated styles of analysis, including campaign models and force structure trade-off studies. Some leaders consider them excessively cumbersome and labor-intensive.[74] However, DoD need not overhaul its existing analytical enterprise to advance NFP evaluation. Initiating a few pilot projects run by small teams would suffice, especially if they leveraged ideas from outside the Pentagon's traditional analytical approaches.[75] The congressionally mandated Planning, Programming, Budgeting, and Execution (PPBE) Commission should endorse such a pilot program to help build momentum.

The existing "deployed analyst" and field programs of federally funded research and development centers (FFRDCs) represent one option for integrating the NFP approach into operational planning and decision-making.[76] FFRDC analysts have previously served with warfighting commands to help them tackle difficult challenges, such as the threat posed by improvised explosive devices in Iraq and Afghanistan.[77] Small teams of researchers embedded with combatant commands, component commands, or air operations centers could help warfighters access the kinds of analyses presented in this monograph. Deployed

73 Theresa Hitchens, "Long-Range All-Domain Prompts Roles & Missions Debate," *Breaking Defense*, July 9, 2020, https://breakingdefense.com/2020/07/long-range-all-domain-prompts-roles-missions-debate/.

74 Government Accountability Office (GAO), *Revised Analytic Approach Needed to Support Force Structure Decision-Making* (Washington, DC: GAO, March 2019), pp. 13–16, https://www.gao.gov/assets/gao-19-385.pdf; and Paul K. Davis, *Capabilities for Joint Analysis in the Department of Defense: Rethinking Support for Strategic Analysis* (Santa Monica, CA: RAND Corporation, 2016), p. 3, https://www.rand.org/pubs/research_reports/RR1469.html.

75 Rachel Tecott and Andrew Halterman, "The Case for Campaign Analysis: A Method for Studying Military Operations," *International Security* 45, no. 4 (Spring 2021), pp. 44–83.

76 See CNA, "Field Program,", https://www.cna.org/centers-and-divisions/cna/special-programs/operations-evaluation/field-program.

77 Tom Allen and Michael Fischerkeller, "Supporting Warfighting Commands" (Arlington, VA: Institute for Defense Analyses), https://apps.dtic.mil/sti/trecms/pdf/AD1124172.pdf.

analysts could provide planning support and conduct baseline assessments before shifting their focus to training the command staff to perform the research themselves using methodologies or tools developed by the FFRDCs. Successful pilot programs could then be scaled and integrated into U.S. military training, practices, and doctrine.

The second obstacle is political. Even if NFP evaluation gained traction, it would not necessarily persuade all military and political leaders to foreswear their preferences and subscribe to the "right" answer—particularly if the right answer contradicts existing community or organizational commitments. Besides, right answers rarely exist in the uncertain business of defense planning. What NFP evaluation could do, however, is reframe problems for key decision makers, helping them ask the right questions. A spark of insight delivered to the right leader at the right time has shifted weapons investments before.[78] It can happen again.

Analysis Is an Enduring American Advantage

The United States currently enjoys several advantages in its strategic competitions against China and Russia. One is the ability and willingness to use analysis to challenge assumptions, expose flaws, and consider alternatives to its own official thinking. Defense bureaucracies in authoritarian states brook such activity far less abidingly. Intellectual ferment remains a relative strength of American strategic culture. DoD should exploit this advantage by using the NFP approach to spur critical thinking about defense investments in the 2020s and beyond.

78 William J. Perry, *My Journey at the Nuclear Brink* (Stanford: Stanford University Press, 2015), pp. 33–44.

LIST OF ACRONYMS

AFRL	Air Force Research Laboratory
ASW	anti-submarine warfare
BTG	battalion tactical group
CBO	Congressional Budget Office
CSBA	Center for Strategic and Budgetary Assessments
DoD	Department of Defense
FFRDC	federally funded research and development center
FY	fiscal year
GAO	Government Accountability Office
GBU	guided bomb unit
IFV	infantry fighting vehicle
JCS	Joint Chiefs of Staff
KM	kilometer
LGB	laser-guided bomb
MAGTF	Marine Air-Ground Task Force
NCA	Networked Collaborative and Autonomous
NFP	networked force package
O&S	operating and support
PGM	precision-guided munition
RAND	Research and Development Corporation
SAM	surface-to-air missile
SDB	small diameter bomb
SHORAD	short-range air defense

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