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A Model of Air Force Squadron Vitality

Maj Gen Stephen L. Davis, USAF
Dr. William W. Casey

Articulating the Challenge

During his Senate confirmation hearing in June 2016 to become Air Force Chief of Staff, Gen David L. Goldfein not only assured senators that he would fully support then-Secretary of the Air Force Deborah Lee James's priorities of taking care of people, balancing readiness and modernization, and making every dollar count, he also articulated the overarching effort to link those goals together.

"Foundational to these priorities," he said, "will be to revitalize the most critical organizational level in the Air Force—Squadrons."[1]

Squadron revitalization was long overdue. For a moment in time, the downsizing of the US military following the end of the Cold War was both a rational and politically popular response to what seemed like the end of great-power competition in world affairs. Within a few years, however, the so-called peace dividend collided with the terrorist attacks of 11 September 2001 and then began the longest sustained operations tempo in Air Force history. Forces surged, and missions were accomplished, but the unrelenting grind against nonpeer adversaries took a toll on the basic building blocks of the Air Force: the squadrons and Airmen who are responsible for all they achieve. Just as Russia returned to its bellicose ways, and China rose to the level of determined rival, squadron vitality—the key to readiness and lethality—had become dangerously low.

Shortly after taking command, General Goldfein ordered an exhaustive review of Air Force policies to single out shortfalls and find solutions. "It will be a journey," he said in announcing the effort. But toward what? There would undoubtedly be a few easy wins and simple tweaks along the way, but easy fixes would not be enough to address the underlying problems. That's where we came in. Our team was fortunate to be assigned the task of finding system-level problems and recommend fixes. The first job for our team of experienced Air Force leaders and organizational experts would be to identify the attributes of squadron vitality. With that model clearly defined, we could make specific recommendations to achieve fundamental solutions for squadrons and squadron-like organizations.

We had a lot of help. We began by crunching the numbers in the metadata already gathered by the Air Force from earlier surveys and other sources. These data were used to create a targeted online survey answered by almost 15,000 Airmen from across the force. Then the team made field visits to speak with almost 4,000 Airmen at all 10 major commands and 25 bases around the world, hosting large and small focus groups and sitting for one-on-one interviews. We also launched a crowdsourcing website, gathering 966 ideas, 29,000 votes, and 180,000 views. All stages of the process included officers, enlisted and Air National Guard members, reservists, and civilians. Families, too, were tapped for their input. Along the way, the information we gathered, aided by social science, coalesced into a definition of squadron vitality. After more than a year of research, our team was able to distill squadron vitality down to three essential attributes resting on one foundation.

First, achieving success requires clarity of purpose above all else. Clarity of purpose is foundational to all other aspirations and is clearly reflected in the three other essential attributes of squadron vitality. By listening to Airmen in the field and consulting with organizational experts on team effectiveness,[2] we confirmed the importance of clarity of purpose and the three critical attributes made possible with it: verifiable mission success, purposeful leadership, and esprit de corps. These are the keys to vibrant, effective, and innovative squadrons.

Squadron Vitality Defined

By unpacking clarity of purpose and the three vitality attributes that rest on it, we can address systemic factors to find systemic solutions. Without an overarching construct for squadron vitality, we would have been limited to simply recording and responding to the many ideas and opinions conveyed in interviews, group sessions, and surveys. This four-part vitality model (as depicted in the figure) applies to any Air Force unit or team, not just squadrons. Its aim here, though, is to help sharpen the Air Force's focus on the goal of revitalizing squadrons as the foundation for restoring readiness and increasing the lethality of the Air Force.

- **Clarity of purpose** is the foundation of the other three attributes and underpins their distinct roles in maintaining squadron vitality. This means knowing and conveying the "why" behind, say, a task, a role, or the squadron itself. Clarity of purpose guides all other decisions, large and small.
- **Verifiable mission success** is the first attribute. Determining a squadron's few vital mission outcomes requires squadron leaders to possess a thorough understanding of purpose beyond mere compliance with Air Force Instructions, and sometimes instead of it.
- **Purposeful leadership** is the second attribute. It means not only that the squadron understands its purpose, but that each supervisor achieves several critical purposes as a leader.
- **Esprit de corps** among a squadron's Airmen is the third attribute. Across time and across cultures, it is a common denominator among successful warfighting forces.

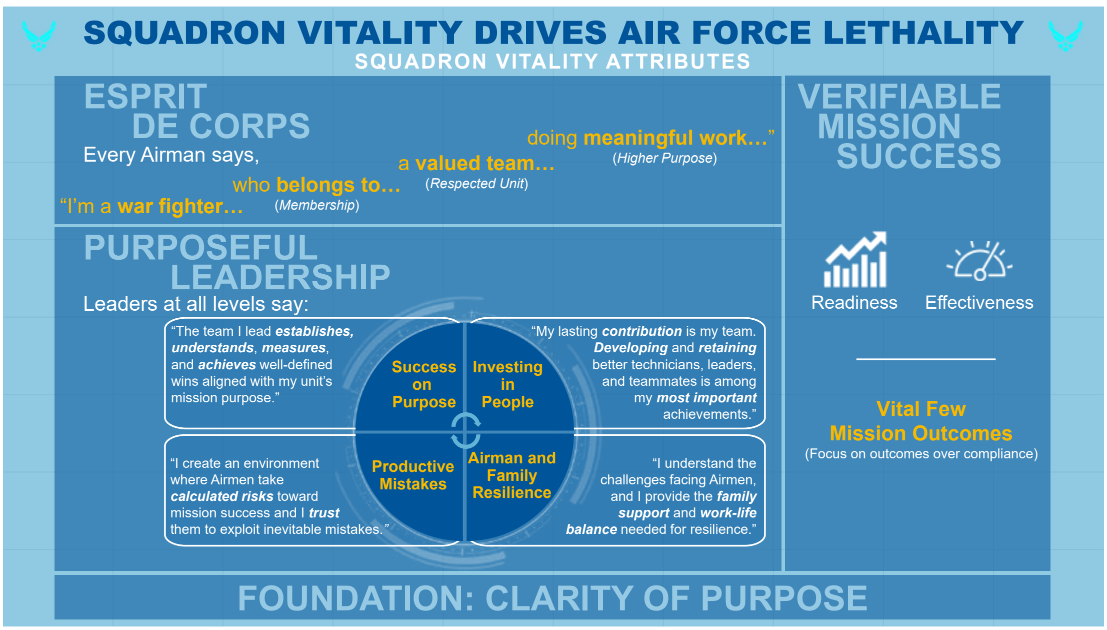

Figure. Squadron vitality attributes

"Squadron Vitality Drives Air Force Lethality"

Clarity of purpose: the foundation. In life, work, or war, people get their meaning from seeing how they fit into a higher purpose. For that to happen, first a higher purpose must exist. Second, it must be known. The Air Force has abundant higher purpose to offer its Airmen. Unfortunately, Airmen don't always know it.

We encountered many mixed signals during our time in the field. While many Airmen said that their mission needs to be much clearer, some countered that their mission was plenty clear: "We have lots of measures," one leader asserted. Therein lies the problem; nobody griped about an insufficient number of metrics; the complaints were about insufficient clarity of purpose. This is the simplest, hardest, and most important question for leaders to ask. It's the existential, strategic question, "Why do we, as an Air Force, exist?" Or, at a lower level, "Why do we, as a squadron, exist?" Put differently, the question is not, "What are we here to do?" The real question is, "What are we here to achieve?" It's about the few, important outcomes, not the many, many tasks along the way.

Carl von Clausewitz famously asserted that the talent of the strategist is to identify the decisive point and to concentrate everything on it, removing forces from secondary fronts and ignoring lesser objectives. Such agile, purpose-focused leadership is known as "mission command," among military theorists.[3] When that decisive point is unclear, it is impossible for Airmen to distinguish lesser objectives from the central one. In these cases, with blurred or fragmented purpose, bureaucratic demands fill the vacuum. Then, mission command—which depends on clear purpose[4]—gives way to *compliance command*, a term we coined for when success is defined as following the rules to stay out of trouble.

Mission command derives from the operational environment. In mission command, the commander's intent "should convey absolute clarity of purpose by focusing on the essentials and leaving out everything else. The task should not be specified in too much detail."[5] Mission command wins wars in-theater, but any organization, operational or otherwise, becomes more innovative, agile, and effective when its purpose drives analysis, decisions, and action.[6]

One Airman nicely summarized the distinction between compliance command and mission command when he suggested, "We have to get away from a compliance-based approach to an effects-based approach."

When Airmen's concerns weren't directly about clarity of purpose, they expressed misgivings about the second-order effects of unclear or absent purpose, such as checking boxes with computer-based training of questionable value in order to stay in compliance. When a squadron's few, major outcomes aren't clear, it lacks the overarching basis to decide what tasks to take on, how to prioritize, and how to tailor all sorts of rules and resources. The centrality of purpose-driven work extends to efforts at all levels—squadron leadership, training classes, morale events, family support, and so forth. The idea, "Begin with the end in mind," is a cliché for a reason: it is a foundational truth.

The Operational Spirit Every Day

Purpose-driven organizations and effort are not uncommon in operational and deployed environments. Military mission planning always begins with a clear understanding of intent and purpose. When intended results are clear and matter, good things tend to happen: Airmen have little problem connecting to purpose and sensing their membership in a valued team doing meaningful work—the prerequisites for esprit de corps. Decisions get smarter as the focus becomes "What will accomplish our mission?" instead of "Am I going to get dinged?"

The irony here is difficult to ignore. It should not be surprising that a global organization like the Air Force may sometimes have difficulty communicating its goals to constituent units far removed from headquarters. It should be very surprising, however, that those faraway units are usually the ones that get it right. In operational environments, objectives are clear, and a high operations tempo is accepted and often embraced. Higher purpose drives Airmen on and feeds esprit de corps. But in nonoperational environments, Airmen resent long hours because the higher cause isn't always evident. In effect, "We are working 12-hour days . . . why?"

An operational team, working toward the same clear, important purpose, has quite a leg up in the morale and cohesion department over their counterparts at home. Why do operational environments bear these advantages? Is it just high stakes and adrenaline? Probably not. Many Airmen reported home-station leaders and squadrons that successfully created vitality, and a clear, shared, important purpose was an essential part of their success.

Consider this: any Airman—not just an operator—who overcomes great obstacles to serve a noble purpose is the courageous Airman the Air Force requires. On the other hand, any person whose sole intent is to follow the rules, even when they serve no clear purpose, becomes just another "bureaucrat." Many of us would like to be up front, in the thick of it all, yet most of us wield keyboards or wrenches, not control sticks or M4 carbines. But if we are connected to our clear and elevating purpose, then we get to make a difference and be part of something vital.

One month into his current tenure, General Goldfein asserted, "Squadrons are the engines of innovation and esprit de corps. Squadrons possess the greatest potential for operational agility."[7] That is true, and clarity of purpose is the enabler. Airmen linked to purpose will capably surf the ever-shifting sea of warfare and geopolitics. Airmen linked solely to procedures and checklists will fare less well; they will be stuck with outdated turn-by-turn directions in a fast-morphing world.

Increasing clarity of purpose will increase innovation, agility, and many other cultural strengths. True empowerment becomes possible when purpose is sharply defined. It enables us to tailor and align authorities with purpose-linked responsibilities. It helps us distinguish time-wasting micromanagement from life-saving checklists. It is how we can know when detailed guidance is central to success or when it wastes time and hinders the mission.

As General Goldfein said, "Secretary Wilson and I told the Inspector General: 'If you go out and inspect an organization, and that commander has made a prudent, reasonable decision to change course, and that decision has actually increased the lethality and the readiness of that unit to accomplish their mission, then we're not going to ding them. We're going to celebrate it.'"[8] When we understand the purpose of our effort, then "agility," "innovation," and "empowerment" are not just buzzwords, they are tools.

Verifiable Mission Success

Squadrons exist to achieve their few, uniquely vital mission outcomes. Either enabled by others or by enabling others, each squadron's vital mission outcomes result in the lethality we bring to the Joint fight. Verifiable mission success reflects clarity of purpose at the unit level.

Vital mission outcomes are the essence of a mission command culture. All units are responsible for *doing* many of the same things, like training requirements, meeting physical fitness standards, and generally staying in compliance with rules and regulations. Each individual unit, however, exists to *achieve* a few very specific mission outcomes. They are what matter, and all squadron *activities* ought to aim toward achieving those few mission outcomes. For example, security force squadrons exist to protect life and property. Airlift squadrons exist to transport people and things, on time, intact, and at optimum capacity. Munitions squadrons exist to ensure that all weapons are accounted for, secured, and ready to use.

Unfortunately, it is often easier to measure mundane tasks like completing computer-based training than it is to measure the success of a relatively complex mission outcome. When mission and goals are not measured, but failure is, then success can only be defined as not failing: a surefire way to engender micromanagement and other risk-avoidant habits that fester in compliance command. Variations on scorekeeping, from unit inspections to leaders' performance reports, often put more weight on compliance with the mundane than on success with the mission. This is exactly backward.

For leaders to lead in the right direction, and for teammates to rally around the right things, they all must be able to articulate the small handful of mission outcomes a squadron is established to produce, and then keep score of those few outcomes. This is essential. Verifiably successful mission outcomes are not only the ultimate indicators of a squadron's vitality, they are the building blocks of Air Force's lethality.

Purposeful Leadership

Good squadron leaders lead their teams to achieve the *team's* purpose, but those leaders also understand their own purpose as leaders more broadly. That purpose includes strengthening the individuals and the teams they lead. This is a longer-term investment that includes creating an environment that rewards calculated risks and reaps benefits even from mistakes, and building the resilience of Airmen, their families, and support networks.

Purposeful leadership is the backbone of institutional culture and unit ethos. That ethos is then passed along with every change of command and spread throughout the force as team members rotate to new units. It is clarity of purpose manifested in unit leadership.

Purposeful leadership is an ongoing responsibility and requires regular attention to four focus areas.

Success on Purpose. Purposeful leaders can say with confidence: "*The team I lead defines, understands, measures, and achieves well-defined wins.*" These savvy leaders ask: "Why does my team exist? What purpose are we meant to achieve? How will we recognize success?" Then they make sure that their Airmen know the answers.

This process provides focus, but also the meaning all Airmen want as context for their work. Leaders should always be able to articulate how day-to-day tasks—even the mundane ones—lead to the achievement of the unit's unique vital mission outcomes.

Likewise, good leaders establish goals for improving how the unit delivers verifiable mission success. They launch timebound unit initiatives, each with their own clear purpose that clearly contributes to delivery on the unit's purpose. Success on these efforts are wins for the squadron, ratcheting up its capabilities and capacity.

The knowability—and measurability—of achieving such "success on purpose" is essential. Otherwise, achieving success too easily defaults to compliance and error avoidance. As one recent study on squadron effectiveness found, "Airmen who understood the unit's mission and their specific contribution to the overall wing mission were more motivated to accomplish goals."[9] In fact, both experience and research have shown that opportunities for meaningful work is a key factor in work satisfaction. But leaders must continually communicate to team members how they fit into that purpose. It does not happen automatically.[10]

Time Invested in People. "*My lasting contribution is my team. Developing and retaining better technicians, leaders, and teammates are among my most important achievements.*" Purposeful leaders' time invested in their people is time invested in the future—a future that those leaders will not directly share. It's the pay-it-forward philosophy of leaders who aim to enable tomorrow's results while achieving today's.

It's a balancing game: achieving today's success while enabling future success. That latter success requires mentoring and coaching; it requires asking and listening; and it requires genuine demonstration of interest in Airmen as professionals and as individuals.

Productive Mistakes. "*I create an environment where Airmen take calculated risks toward mission success, and I trust them to exploit inevitable mistakes.*" History is filled with declarations of the importance of allowing for and learning from errors. The trick is creating an environment that induces people to do it—not just telling them to. Purposeful leaders create that environment. Leaders place confidence in their subordinates, and subordinates in turn understand that the boss will protect them when they make decisions in good faith—especially hard ones.[11]

Good leaders know that everybody makes mistakes and they don't shy away from taking appropriate and calculated risks. Perhaps the strongest statement a leader can make to his or her Airmen is to own up to mistakes and turn them into teachable moments so that a mistake by one person—even the boss—can lead to learning by all. Leaders make an impression on their people when they protect subordinates who make honest mistakes. No leader should have to choose between protecting their people and protecting their career.

Airmen and Family Resilience. "*I understand the challenges facing Airmen, and I provide the family support and work-life balance needed for resilience.*" Good leaders care about their team members' families[12] and support networks, and they do so for more than simple reasons of humanity. The unique challenges of military life also mean leaders must support Airmen's families for two practical reasons.

The first reason is about resilience: Airmen who deploy or are otherwise gone for a long time have to wonder, "Is my family really okay?" As General Goldfein recently said, families "exhibit a very special kind of courage when they endure the long hours, separations, and hardships that have become a part of an Air Force at war."[13] If their families are okay, then those Airmen can focus on their tasks at hand. The burden of being away from home, especially in dangerous environments, is made lighter by knowing that the Air Force has their backs.

The second reason is about retention. The Air Force recruits individuals but retains families. As one observer commented years ago, "If there is a tug-of-war between the military and the family, it is the family who usually wins."[14] However, a family connected to the importance of the mission is more likely to want to retain that connection. For leaders in the Air Force, a commitment to those things that enhance Airman and family resilience is not just an act of compassion, it is a leadership responsibility.

Esprit de Corps

Esprit de corps is *a feeling of pride, fellowship, and loyalty shared by the members of a group*. It's an attractive concept, and verifiable mission outcomes and purposeful leadership certainly create fertile ground for it. Unbundling *esprit de corps* into its component parts, however, helps to create an actionable framework. Consider these three elements: membership, respected unit, and higher purpose. At a summary level, we believe that each Airman should be able to say, "*I'm a warfighter who belongs to a valued team doing meaningful work!*"

Membership. "*I'm a war fighter who* ***belongs*** *to a valued team doing meaningful work.*" The need for belonging and camaraderie is considered a fundamental human motivation,[15] as recognized by the Air Force's drive for inclusiveness. It is a truism that warriors fight as much for their brothers and sisters in arms as they do for a cause.[16] If that is so, then a sense of belonging, of having fellow Airmen one would fight for, is important to esprit de corps.

A sense of membership is profoundly affected by how well leaders can make team members' similarities—such as shared mission and values—more salient than their natural differences.

Respected Group. "*I'm a war fighter who belongs to a* ***valued team*** *doing meaningful work.*" Squadrons and their flights are teams. Part of one's personal pride comes from pride in the team to which one belongs. In fact, two things happen when one's team is highly respected:[17] team members' identification with the team goes up and so does their own self-esteem.

If a squadron has an impressive history, then its members should understand that they have a reputation to uphold. If a squadron doesn't have much heritage, then they have a reputation to create. Either way, it will be the team's continuous high performance that invites respect and helps Airmen feel part of a valued team.

Higher Purpose. "*I'm a war fighter who belongs to a valued team doing* ***meaningful work***." Experience and research tell us that high-performing teams have much in common, including team goals that are both clear and elevating.[18] Such goals also have a unifying effect, reinforcing membership in an important unit. When members do not share a goal(s), they are members of a team only in the sense that Sam's Club members or private health club members are teams. They may go to the same place, but there is no common connection to purpose.

Opportunities for meaningful work—work linked to a higher purpose—is a key factor in work satisfaction. However, leaders must continually communicate to team members how they fit into that purpose.[19]

Esprit de corps is another way of saying, "It's not the size of the dog in the fight, it's the size of the fight in the dog." Good leaders of any kind or size of squadron know their team members want to make a difference, to be part of something greater than themselves. The more Airmen understand "the wins" for their team and how their role achieves them, the more meaningful their work becomes. This virtuous cycle is mutually reinforcing and exactly the kind of squadron attribute that leaders should work hard to foster. Whether it's the security forces defender securing a base, the maintenance technician ensuring equipment is ready and safe, or the fighter pilot who joins the fight, every Airman has a specific role in contributing to the joint fight. Every Airman is a war fighter, and the combined esprit de corps of the thousands of war fighters who make up the Air Force is nothing if not a strategic asset.

Conclusion

Squadron vitality drives Air Force lethality. That is why the Air Force must focus on revitalizing squadrons. With clarity of purpose as the foundation, the key attributes of squadron vitality—verifiable mission outcomes, purposeful leadership, and esprit de corps has shown that two things happen when one's team is highly esteemed: it provides the framework to start doing things differently, and it enables our squadron culture to overcome internal obstacles to its own success.

The issues facing the Air Force are nothing new. Risk aversion, undermanning, and compliance command are common to militaries around the world.[20] Most proposed solutions to these problems and others like them are strictly tactical, aiming to solve one problem at a time without addressing the larger problems inherent in the culture. But changing culture is hard.

That's why the solutions we offered at the conclusion of our study were systemic in nature. We asked questions like: Why is unit purpose so unclear despite thousands of pages of mission-related instructions? Why is noncandid feedback on officer performance reports and enlisted performance reports the norm among otherwise honest and candid people? Why is there so much reliance on ineffective computer-based training? Understanding the patterns that *create* these problems is more helpful than developing one-time, one-off solutions.

Some of our recommendations are already being implemented. General Goldfein, Secretary of the Air Force Heather Wilson, and Chief Master Sergeant of the Air Force Kaleth O. Wright recently authorized the Squadron Revitalization Implementation Plan to put many of our study's findings into practice. That's right, our efforts have already outgrown this essay and are starting to bear fruit.

Air Education and Training Command is building the tools and curriculum to support wing commanders in the creation of wing-led flight commander courses. Those courses will help squadron leaders engage with civic leaders, school boards, chambers of commerce, and other institutions that are part of the communities where they live and work. Meanwhile, Air University is developing a new squadron leadership course that stresses the virtues of purposeful leadership. And Secretary Wilson last year announced a two-year project to reduce Air Force instructions and review directive publications that include more than 130,000 compliance items at the wing level. These are all steps in the right direction.

Our recommendations recognize that it is our own bureaucracy and culture that we must employ to achieve long-term cultural change. For example, our performance reports must truly reflect the performance we value, such as achieving mission outcomes and building strong, competent teams and Airmen. All of our institutional influencers must point in the same, correct direction. This direction must be determined by fundamental principles like those we derived from our research and thousands of interviews.

Everyone can help. Senior leaders: insist upon clarity of purpose at the strategic level and then architect a reimagined Air Force that naturally encourages the attributes of squadron vitality. Unit leaders, both officers and enlisted: employ the squadron vitality model, and take the opportunity to remake your units, empower your people, and focus on your few, vital mission outcomes like never before. Young Airmen, officers and enlisted: seize the opportunity to use the concepts put forth here to send your ideas up the chain, demand purposeful leadership, question the box-checking of compliance command, and use your technical expertise to help senior leaders drill down to what really matters. The same goes for Air Force civilians: if you don't see the value in the mountains of paperwork that cross your desk, then ask, "Why?"

Air Force family members, it's you we fight for, and it's you we worry about when we're gone. Engage with your loved one's unit. Try to understand their mission and what it means to maintain the lethality that keeps the Air Force ahead of its adversaries. The vital Key Spouse Program and Community Action Board / Integrated Delivery System, along with its many programs to deal with issues like domestic violence and sexual assault prevention, have been targeted for their own revitalization as part of the Squadron Revitalization Implementation Plan. Take advantage of them.

Our comprehensive review of the challenges faced by Airmen and their families provides a basis for squadron revitalization. This is the first step in a long-term effort that will require constant reevaluation to determine what's working and what's not. We're not kidding ourselves—changing culture doesn't happen overnight. But with clarity of purpose lighting the way and the attributes of squadron vitality providing a framework for change, we know we can hone our edge and make our Air Force more lethal than ever. ✪

Notes

1. United States Senate Committee on Armed Services, *Advance Questions for General David L. Goldfein, USAF Nominee for the Position of Chief of Staff of the U.S. Air Force*, 114th Cong., 2nd sess., 2016, 7, https://www.armed-services.senate.gov/download/goldfein_apqs_06-16-16.

2. A detailed description of our project methodology (pages 3–5 and Appendix pages A1–A10), as well as our Findings (pages 15–41 and Appendix pages A11–A54), can be found in Stephen L. Davis, et al., *Improving Air Force Squadrons—Recommendations for Vitality*: *Report to the Chief of Staff of the United States Air Force* (Washington, DC: Department of the Air Force, 2018), https://www.milsuite.mil/revitalize or https://www.facebook.com/200999403407041/posts/1031450507028589/.

3. Eitan Shamir, *Transforming Command: The Pursuit of Mission Command in The U.S., British, and Israeli Armies* (Stanford, CA: Stanford University Press, 2011).

4. Stephen Bungay, "The Road to Mission Command: The Genesis of a Command Philosophy," *British Army Review* 137 (Summer 2005): 22–29.

5. Ibid.

6. *Whole Goals* is one term for this approach to strategic direction. See William Casey et al., "Are We Driving Strategic Results or Metric Mania? Evaluating Performance in the Public Sector," *International Public Management Review* 9, no. 2 (2008): 90–105, http://journals.sfu.ca/ipmr/index.php/ipmr/article/view/57.

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8. "2017 Air & Space Conference: Gen David Goldfein—Air Force Update," 19 September 2017, video, 1:10:23, from a speech by Gen David L. Goldfein at the Air Force Association's Air and Space Conference in National Harbor, Maryland, posted by "AirForceTV," https://www.youtube.com/watch?v=p1LZNZYGwtw.

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10. Society for Human Resource Management (SHRM), *Employee Job Satisfaction and Engagement: Revitalizing a Changing Workforce* (Alexandria, VA: SHRM, 2016), https://www.shrm.org/hr-today/trends-and-forecasting/research-and-surveys/Documents/2016-Employee-Job-Satisfaction-and-Engagement-Report.pdf.

11. Milan Vego, "Mission Command and Zero Area Tolerance Cannot Coexist," *Proceedings Magazine* 144, no. 7 (July 2018), https://www.usni.org/magazines/proceedings/2018-07/mission-command-and-zero-error-tolerance-cannot-coexist.

12. For simplicity, we'll say "families" here but we are including that meaningful and close support network that most people have in one form or another.

13. Gen David L. Goldfein, *CSAF Airman to Airman—Revitalizing the Squadron*, Air Force Television Pentagon, 5 August 2016, video, 2:16, https://www.dvidshub.net/video/478527/csaf-airman-airman-revitalizing-squadron.

14. Edna J. Hunter, ed., *Families Under the Flag: A Review of Military Family Literature* (Westport, CT: ABC Clio/Praeger, 1982), 3.

15. For example, as in David C. McClelland's well-known "Three Needs Theory," McClelland, *Human Motivation* (Cambridge, MA: Cambridge University Press, 1988).

16. Army War College's Leonard Wong and associates show that American war fighters do fight for higher causes and for each other. Leonard Wong, et al., *Why They Fight: Combat Motivation in the Iraq War*, *Strategic Studies Institute* report (Carlisle, PA: Strategic Studies Institute, 2003), https://ssi.armywarcollege.edu/pubs/display.cfm?pubID=179.

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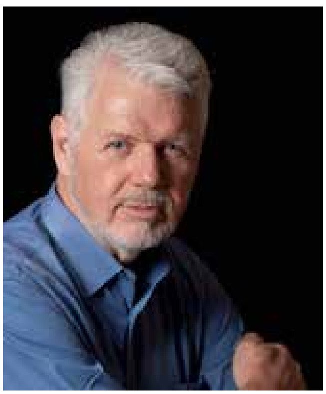
19. SHRM, "Employee Job Satisfaction and Engagement."

20. Shamir, *Transforming Command.*

Maj Gen Stephen L. Davis, USAF

General Davis (MA, School of Advanced Airpower Studies; MA, Marine Corps University; MBA, Embry–Riddle Aeronautical University; BA, Wright State University) is the Director of Global Operations, US Strategic Command (USSTRATCOM), Offutt AFB, Nebraska. He serves as the principal advisor to the USSTRATCOM commander on operational matters and is responsible for effectively synchronizing component, joint, and coalition operations and directing assigned forces to achieve USSTRATCOM commander's and national objectives to defend the nation and its allies. Since he was commissioned in 1989, General Davis has served in a variety of operational and staff assignments, including commanding a Minuteman intercontinental ballistic missile (ICBM) wing and the nation's only ICBM flight test squadron. His headquarters staff assignments include duty at Air Force Space Command, the Air Staff, USSTRATCOM, the Joint Staff, and the National Nuclear Security Administration. Before his current position, the general was the special assistant to the Air Force Chief of Staff for Squadron Revitalization, Washington, DC.



Dr. William W. Casey

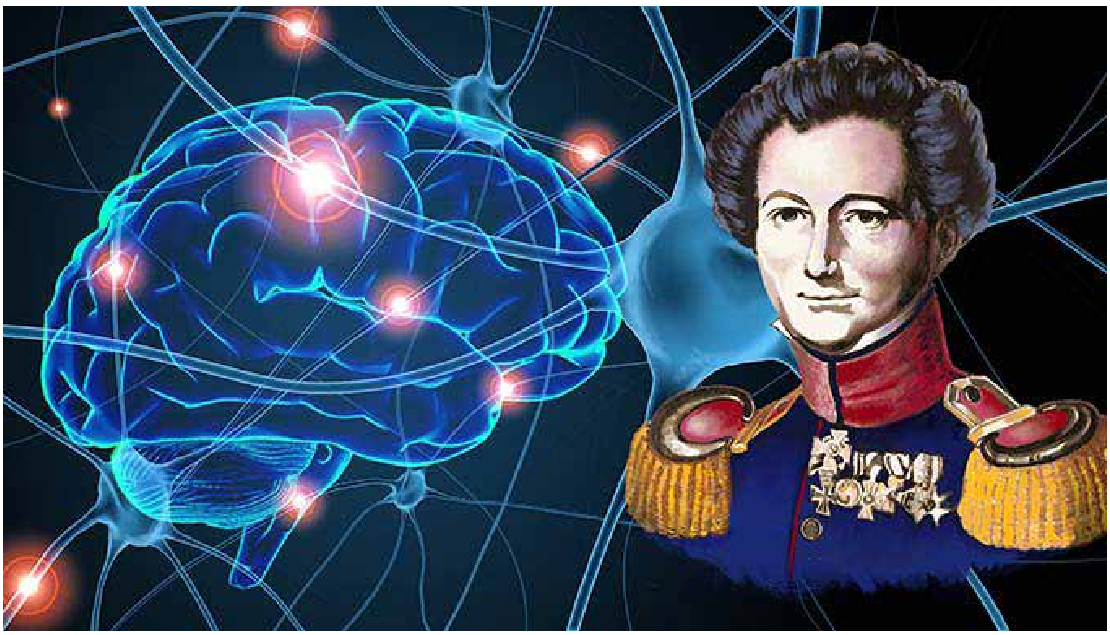
Dr. Casey (MA, University of Denver; PhD, University of Kansas) is president of Executive Leadership Group, an organizational strategy and culture consultancy. He and his team have worked with senior leaders across a wide variety of industries and all US military services, the National Security Agency, and US Coast Guard. Casey has more than 40 years of experience in teaching, coaching, and consulting on the topics of strategic planning and execution, leadership development, organizational behavior management, organizational structure design, and strategic communication. For 10 years, Casey served as curriculum advisor and instructor at the Center for Executive Education at the Naval Postgraduate School in Monterey, California. He codesigned and was the lead faculty member for the award-winning University of Denver/US West master's level certificate program in project management. He also taught for the University of California Haas School of Business, the University of Denver Daniels School of Business and University College, Marylhurst College (Oregon), the Joint Special Operations University, and others. Casey writes on topics of interest to leaders. Most recently, he coauthored *Executive Smarts: 25 Quick Reads on Managing for Results* with Wendi Peck.

Wars of Cognition

How Clausewitz and Neuroscience Influence Future War-Fighter Readiness

Maj Michael J. Cheatham, USAF

> *It is immensely important that no soldier, whatever his rank, should wait for war to expose him to those aspects of active service that amaze and confuse him when he first comes across them. If he has met them even once before, they will begin to be familiar to him.*
>
> —Carl von Clausewitz
> *On War*



What was once thought old has become new again. After almost 200 years since the publishing of Prussian military theorist Carl von Clausewitz's treatise *On War*, emerging neuroscience research brings a fresh perspective to his enduring work. This article proposes a modern analysis of three fundamental Clausewitzian theories: fog, fear, and friction. Viewed through a neuroscience lens, Clausewitz's theories offer thought-provoking insights for military leaders to consider when preparing war fighters for predicted future war.[1] This analysis examines five primary questions to help military leaders understand and guard against factors that diminish human performance in chaotic environments:

1. Why are Clausewitz's theories relevant to modern warfare?
2. How do battlefield conditions influence mental processing (fog)?
3. Why does neuroprocessing impact war-fighter performance (fear)?
4. Why are even simple things so difficult in a complex environment (friction)?
5. What recommended actions should leaders consider?

A core theme of this analysis is that a mismatch exists between what the neuroscience community knows and what military leaders and trainers *should* know about the brain and how it operates. The gap is wide between strategic-level ideals and tactical-level actions. Moving from today's current state to the desired future end state is a daunting, but necessary, challenge. Leaders at all levels are responsible for nesting local actions with strategic intent to achieve future desired effects. Those who fail to grasp the nexus between foundational brain concepts, training methodologies, and war-fighter performance inherently limit their ability to support future desired end states to their fullest potential.

The intent of this article is not to advocate that the joint community convert war fighters into pseudo-neuroscientists. The goal *is* to stop admiring emergent neuroscience research and start integrating it. The growing body of neuroscience knowledge opens new opportunities to re-examine how we address Clausewitz's enduring theories. The analysis is persuasive that even modest enhancements to training applications could make significant differences when applied to a large force over time.

Relevance in Modern Warfare

Since *On War's* publication in 1832, the world experienced three major military revolutions and numerous revolutions in military affairs. These fundamental changes to war fighting stemmed primarily from the cause-and-effect relationships of the growing embrace of the Western way of war, progressive materiel solutions, and prescriptive styles of warfare derived from Swiss military theorist and Clausewitz contemporary Antonie-Henri Jomini. Jomini's technological and formulaic approaches predominate the US war-fighting strategy through the Vietnam War and persist today. While Jomini's theories remain influential to military culture, leadership, and strategy making, his theories are no longer sufficient alone for the complexities of modern war.

Jomini's theories overemphasize the *prescriptive* "science" of war-fighting strategy on paper and undervalue the *descriptive* "art" of warfare and the nature of conflict from the human perspective. Modern multidomain battle is largely unpredictable and cannot be easily reduced to a set of algorithmic formulae. Indeed, part of what makes real war so difficult is that unexpected adversity requires improvisation because the aspects of an encounter are completely unique. The map is not the territory, and adversaries have a vote. In contrast, Clausewitz recognized that nested within war's organic nature lay an ever-present element of the human cognitive domain.

Human cognition has been studied over the past few thousand years, but little empirical data was produced until recently. Modern advances in brain-imaging technologies are revolutionizing how cognitive function is understood. The introduction of functional magnetic resonance imaging is transforming what the scientific community held as fact as late as two decades ago. Despite the terrible losses of blood and treasure, the wars in Iraq and Afghanistan also served as valuable backdrops to sow combat-related neuroscience understanding during this transformational period. Recent military and nonmilitary derived neuroscience findings should influence how leaders prepare and war fighters perform in possible future war.

Driven by contested domains, complex terrain, technology proliferation, and information as a weapon, future operating environments will present a new warfare thesis born from the dialectic of past wars and political motives. Future adversaries will seek to place commercial technological systems and military space platforms at risk through electronic, kinetic, and cyber attacks to neutralize advantages we rely on to achieve decisive points along strategic and operational lines of operation.[2] As a result, future war success will increasingly rest on human factors more than on the technological superiority enjoyed in the recent past.

Clausewitz's theories universally affect all combatants. In parity conflict, the side with forces more prepared to handle fog, fear, and friction holds the cognitive high ground over its adversary. Neuroscience elements, coupled with the right mix of tactical, organizational, doctrinal, and technological innovations, have the potential to shape the foundation of a new conceptual approach to warfare. Through skillful *applications*, the fusion of neuroscience with the human cognitive domain and widespread military applications could spur a new revolution in military affairs. In this context, Clausewitz's theories remain as relevant as ever.

Battlefield Conditions and Reason: Fog

Clausewitz described war as complex and escaping of man's control.[3] Indeed, the foundations for war's uncontrollable nature stems from human clashes of wills and *fog*—the mental state of confusion or uncertainty developed from available information. Clausewitz's theory of fog was born out of the consistent unreliability of intelligence obtained by untrustworthy scouts with fallible human perception and interpretation. The undefined precision of intelligence often deepened a commander's confusion rather than assuaged it. Despite revolutionary leaps in the quality and training of personnel, technology, and proliferation of collection architecture in land, sea, air, and space domains today, human fallibility in data interpretation remains a persistent system vulnerability.[4]

Modern militaries continue to operate from estimates and laws of probability similar to those used by Clausewitz. Military intelligence, both then and now, is an inexact art. Reliance on intelligence analysts' subjective and sometimes unconsciously biased perceptions to interpret raw data into meaningful information inherently limits its usefulness. The inability to know, for sure, the intentions behind perceived adversary behavior amplifies a commander's fog when determining how to gain and maintain positions of relative advantage.

While imprecise intelligence data can contribute to fog in the minds of commanders, Clausewitz also observed how war's nonlinear nature creates fog in the minds of soldiers. Despite leaders' preparing war fighters through plans generation and rehearsals, modern areas of operation create mental stressors and disorientation that training struggles to replicate. As the war fighter's "cognitive load"—the capacity to absorb, process, and hold information—exceeds the threshold to store, process, and interpret external and internal sensory inputs, fog pervades. Indeed, cognitive *overload* causes distractions to be more disorienting and situational understanding to become or remain shallow. Critical thinking slows, and the brain defaults to the faster, but primitive, limbic system to expedite the cognitive processing cycle. Fog makes it harder for the brain to distinguish between the relevant and irrelevant; signal from noise.[5]

In general, complex operating environments, exposure to new information, sensory overload, fatigue, and the risk of harm or death slows and shifts mental processing. More acutely, the brain integration limitations of young adults (those approximate age 26 and under),[6] familiarity with the situation, and unique "internal (mental) models" of each war fighter further complicate already complex conditions. Internal models operate with a basic input-interpretation-output brain loop. If the brain loop determines the presence of a threat (whether actual or perceived), protective outputs of pain, psychological changes, or motor responses could materialize (figure 1). To alter the output, either the input or interpretation must change. In a combat environment, the input is most often uncontrollable. Interpretation is the controllable variable; cognitive load management is the skill.

Clausewitz asserted individuals could modulate the intensity of fog experienced in war through the development of process-enhancing aspects such as confidence, judgment, expertise, and experience derived from training.[7] Current neuroscience research is confirming Clausewitz's intuitive deduction: individuals *can* deliberately mitigate fog by improving cognitive load capability. Contemporary understanding of cognitive functioning, primarily through functional magnetic resonance imaging, demonstrates cognitive load management to be a trainable, yet highly individualistic, skill.[8] Cognitive load management skill-building takes time and considerable effort to shape and, yet, is perishable; akin to filling a leaky bathtub one thimbleful at a time.[9]

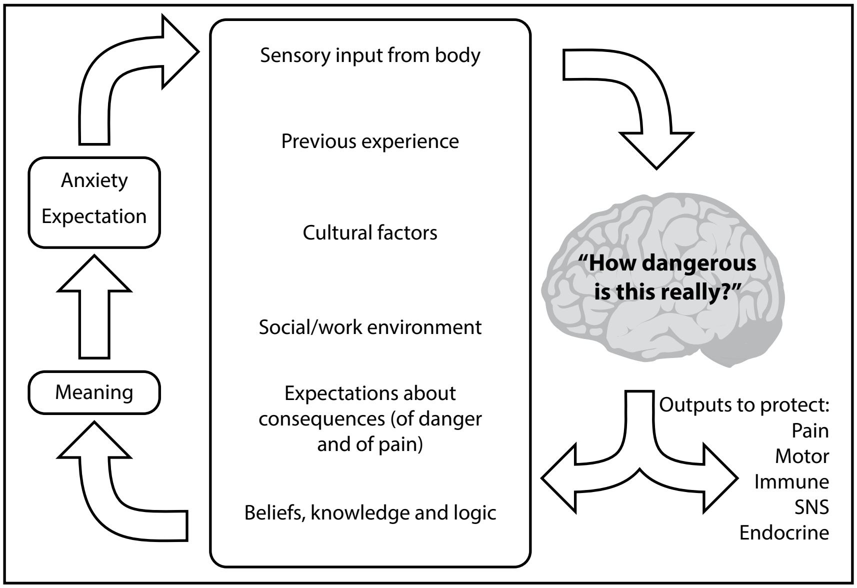


Figure 1. Internal model loop. (G. Lorimer Moseley, "Reconceptualising Pain According to Modern Pain Science," *Physical Therapy Reviews* 12, no. 3 [September 2007]: 171.)

A war fighter who encounters a complicated situation searches short- and long-term memory networks reflexively to overlay the present situation with one similar from the past. Under stress, our brains revert to past training and experiences. The closer a retrieved memory is to the current state the better the war fighter's brain can make sense of the situation. Recallable experiences expedite one's decision-making cycle. While whole-life experiences vary widely, especially those before entering service, *training* experiences are within a leader's control.

The more frequent and recent a desired skill is trained, the deeper neurosignature pathways (colloquially called *muscle memory*) become.[10] Stronger neurosignatures increase the speed of desired outputs after input-interpretation-output loops.[11] However, repetitions alone are not enough; the brain also craves novelty. *Training* improves how grouped neurons "fire" and "wire" together. *Novelty* creates neuroplastic change through stronger synapses and faster communication speeds.[12] Together, training and novel experiences build better response patterns through cognitive load resilience. Indeed, the cognitive *ease* developed over time creates the necessary time and space to improve decision making, not only in the trained situation, but also in stressful situations of this type.[13] Under this premise, fog can also be proactively mitigated using currently available tools and training models. The difficulties of this type of training lay in understanding its personalized nature and nonstandardized approach.

Traditional military training protocols prescribe generalized training to all skill levels, ages, and ranks without consideration for individual attributes. An underlying problem with standard training approaches is that every individual has a different neurological story. What most trainers fail to realize is that blindly training without regard for an individual's cognitive load threshold can create more harm than good. The dose makes the poison. Instead, trainers should tailor instruction around constant individual or tiered threat assessment-improvement-reassessment iterations to produce progressively greater cognitive load-bearing abilities.[14]

Leaders must reexamine traditional training norms to improve cognitive loading alongside their specific threat response continuum. An important aspect of a leader's job is to facilitate specific training protocols to reduce the amount of threat perceived by each individual's brain and enable higher-level thinking. Adapting training to target an individual's nervous system is time-consuming and intimidating to some leaders. There is comfort in today's tried and true training protocols, but they may not produce the desired individual abilities needed for tomorrow's predicted future war. Leaders must determine whether today's methodologies will meet tomorrow's needs well before war fighters need them. As a special operations axiom states, competent (war fighters) cannot be created after an emergency occurs.

Neuroprocessing and War-fighter Performance: Fear

Similar to fog, fear is a natural, internally-derived human condition and a by-product of actual or perceived threat. In many ways, modern-era warfare continues to resemble Prussian military leader Frederick the Great's battle culture of forbearance and persistence.[15] Battling forces continue to seek decisive engagement to inflict and withstand casualties, both physically and cognitively, to break the adversary's center of gravity and will to fight.

Unlike the recent exponential growth in technology, the human brain remains physiologically similar as it was more than 10,000 years ago.[16] Today's war fighters are reflections of the soldiers Clausewitz observed: *biological beings who accumulate physical and emotional tolls*. The legitimate possibility of death or severe injury in war, compounded by each war fighter's perception of danger, activates the sympathetic or parasympathetic nervous systems. These autonomic neurological threat responses can overstimulate an individual's central nervous system and produce sympathetic fight-or-flight or parasympathetic freeze-or-faint reactions.[17] Both threat response types employ different ways to achieve the same end: *survival*.

The human brain is experience-expectant, prioritizing survival over performance.[18] The survival mechanism is based on predictive mental models and pattern recognition "wetware" to appraise threat in the current situation. The unconscious brain continually evaluates millions of bits of sensory inputs per second. As important new information is received, the conscious brain is alerted, predictions are made, and behaviors are modified. If the brain lacks either adequate data inputs or previous experience, its predictive abilities decline, and performance is hijacked. Uncertainty about a situation, the incapacity to control what happens, and an inability to predict future outcomes create fear and threat responses. Alternatively, competence and experience deactivate "emotional load" to enable more desirable rational responses. The need for survival becomes the need for safety.

Clausewitz asserted courage was the compensation to fear and presented itself in two forms: as a permanent condition and as an impermanent emotional state.[19] The cultivation of both forms of courage is best. Since the days of Napoleon, militaries sought to develop both forms within their soldiers. Modern armies are no different. Supported by society-at-large, courage is woven into the fabric of the military system and impressed upon the minds of all war fighters through heritage, discipline, peer pressure, realistic training, recognition, societal status, and psychological rewards. Concurrently, today's military leaders seek to reinforce or instill values for honorable and effective action through deliberate emotional and cognitive training approaches.

Emerging neuroscience and psychology-based performance programs, such as the USAF's *Defender's Edge* and the US Army's (USA) *Human Dimension Strategy*, seek to instill self-regulation techniques designed to improve resilience, decrease threat perception, and increase both the confidence and courage to respond to highly stimulating events.[20] These are significant endeavors because, as Clausewitz noted, "ordinary men. . . tend to lose self-confidence when they reach the scene of action: things are not what they expected."[21] While external factors are uncontrollable, the internal factors—our ability to interpret, predict, and respond—are the most important. Emerging performance programs are a step in the right direction. However, most current programs operate independently of, and not integrated with, traditional combat readiness programs. Leaders should seek to weave current performance programs with training efforts seamlessly to synergize understanding and application.

Understanding feeds prediction; the ability to accurately predict what will happen next is a proactive tool to combat fear. *The fusion of neuroscience education with training using real-world equipment, in realistic scenarios, with progressive complexities and consistent feedback loops develops confidence and prediction.* Well-designed training allows one to practice metacognition (thinking about thoughts) while under stress and answer "danger-reasoning" questions in a controlled environment. In future events, when facing real-life high-threat situations, the brain can draw on previous experiences and reduce the bandwidth demand on our limited mental resources. The more frequently and steadily leaders expose war fighters to dynamic situations and objects of fear, the greater the opportunity to develop threat habituation.[22]

Cognitive distance, or the gap between the training form and its applied context, strongly influences deliberate training effectiveness. The closer the simulated training environment is to expected reality the more prepared war fighters will be cognitively. A cognitively-readied war fighter is more confident and more likely to anticipate what comes next. For instance, the cognitive distance of active shooter response training is much less during an actual rehearsal walkthrough than when using a PowerPoint presentation; real firearms with blank ammunition are closer than a rubberized blue gun; actual expected response locations are better than conceptual "glass houses."

Time and money are limited assets and prohibit frequent rehearsals of every conceivable situation. Fortunately, the menu of options available now is safe, repeatable, and highly effective. Modern technologies such as dye-marking and laser-based munitions, four-dimension virtual reality simulators, and highly-realistic training scenarios supplement experience gaps while practicing doctrinally-based concepts and learning to manage judgment in the fog of simulated war. Additionally, emerging tools, such as augmented reality and brain activity monitors (e.g., the smartphone-sized BrainScope monitor), promise even greater future training and evaluation capabilities.[23] Habituation takes time but increases the likelihood that sound decision making will occur while under stress. Leaders should incorporate as many simulation tools as possible to exploit their full cognitive and survival enhancement benefits over time.

Although training capabilities vary from place to place, leaders must take advantage of existing opportunities and innovate the best they can with what is available. In some cases, leaders may need to assume more risk in training to more closely mirror real-world conditions. Leaders must seize the initiative to shape war fighters' battlefield responses by building the *character* of competence. "Training is the most important thing we do" is the philosophy organizational leaders should embrace to support the *skills* of competence.

Fear is an important part of the human condition; it exists to increase the likelihood of survival. Fear is an alarm programmed to alert the brain that a threat is present. A leader's goal is not to prevent fear from presenting itself. Rather, a leader's goal is to dilute the corrosive effects uncontrolled fear can have on an individual's performance to improve the odds of survival and mission success.

Complexity: Friction

Fog and fear are individual factors of war's internal struggle. Together, fog and fear contribute to create an invisible force Clausewitz termed *friction*. Clausewitz notes how everything in war is very simple; yet what is simple is also difficult.[24] On paper, theoretical war and real war are the same. In real war, they are quite different. Friction is the difference between the best-laid conceptual plans and what actually happens—it is the original Murphy's Law. Friction manifests through external and internal means.

Externally, friction is the unforeseeable, unplanned, and uncontrollable difficulties of war. The accumulation of often small irritants produces mental and physical complications that are inconceivable to those who have not experienced it firsthand. In action, both sides in the US Civil War experienced the friction of small-scale raids against railroad infrastructure, suicide bombers vex conventional militaries today, and the loss of cyber and communication capabilities will frustrate tomorrow's forces. Beyond the adversary, weather, resource shifts, obstacles, and countless other factors contribute to "unknown-unknowns" that are impossible to know in planning phases.

Internally, friction manifests from the presence of unclear information (fog), the danger of war (fear), and—most notably—by war's demanding physical and mental efforts (fatigue). The immense energy required to move humans and hardware is exhausting. Physically, the body fatigues from constant tension and stress under the load of restrictive combat load and countless other factors. Neurologically, brain function wanes from lack of sleep, loss of energy, and decision-making fatigue. The brain and body have finite resources unique to each individual. Once stores are exhausted, the combined effects of friction and war as a human endeavor inevitably lead to mistakes and missteps.[25]

Friction is an ever-present peripheral opponent to all militaries in the modern era. US joint forces recognize friction as a core warfare limitation, and, thus, have embedded mitigation strategies into their cultures and doctrines. Current joint operations doctrine embrace *simplicity* as a core principle to combat the self-imposed friction in planning. Commanders are educated to recognize that every degree of increased complexity or rigidity directed by mission orders exponentially increases the difficulty of completion at the execution level. Clausewitz promoted the idea that plans must leave a margin for uncertainty, in the greatest things as much as in the smallest.[26]

Commanders should know they cannot instill certainty into an order, no matter how perfectly the plan is conceived. Instead, commanders must allow for improvisation when inevitable human factors emerge at unknown places and times for even the simplest tasks. Friction is a human problem because it creates both real and perceived threats. As friction creeps onto the operating environment, tactical flexibility is essential. War fighters executing a plan must be empowered to compensate for unanticipated friction and uncertainty through their own originality and creativity.

The USA approaches tactical flexibility through the philosophical fusion of the art of command and science of control, otherwise known as *mission command*. According to Army Doctrine Reference Publication (ADRP) 6-0:

> Mission command is the exercise of authority and direction by the commander using mission orders to enable disciplined initiative within the commander's intent to empower agile and adaptive leaders in the conduct of unified land operations. Mission command is one of the foundations of unified land operations [ADRP 6-0]. This philosophy of command helps commanders capitalize on the human ability to take action to develop the situation and integrate military operations to achieve the commander's intent and desired end state. Mission command emphasizes centralized intent and dispersed execution through disciplined initiative. This precept guides leaders toward mission accomplishment.[27]

Disciplined initiative enables tactical leaders to overcome friction at the lowest levels by allowing freedom of action. Disciplined initiative supports the chairman of the Joint Chiefs of Staff's future operations intent to create a force that is adaptable, thinks critically, and can make rapid, independent decisions at the point of friction.[28]

Since friction is organic to war, mental agility and adaptation are premium skills to train while preparing for the unexpected. While friction persists in the mission command construct, empowering soldiers engaged in a decisive point the flexibility to adjust their actions based on the conditions presented dissipates its effects. Leaders who understand war's innate complexities amplify efforts to combat friction. Those who understand basic brain functionality and apply core concepts into training will optimize each individual's performance in chaos.

Beyond training design and operation, leaders have a direct role in helping forces overcome friction. Leaders can assume personal responsibility to fight the effects of friction in two key ways: *cultivating military genius and skillful use of leader-imposed stress*.

Military Genius

Clausewitz's concept of coup d'oeil describes a leader who possesses an advanced ability to draw upon experience and intuition to see clarity amidst chaos almost immediately and *act*. Napoleon and Patton had coup d'oeil. This developed mastery—what Clausewitz characterized as *military genius*—offers a firm understanding of the situation at hand and the ability to skillfully mitigate and infuse human limitations into a simple, coherent plan repelling the effects of chance and probability. Military genius is at the heart of the USA's mission command philosophy and what Clausewitz deemed as the solution for both external and internal friction.

From a neuroscience perspective, coup d'oeil refers to a leader's ability to consciously and deliberately consider and understand a situation at the "stroke of an eye"—to *thin-slice* a moment in time. Thin-slicing refers to the trained ability to recognize patterns and, in turn, create accurate expectations of what will happen next.[29] This unconscious quick cognition ability stems from the development of sophisticated wetware. On average, the cognitive brain's ability to hold information is limited to about seven items (plus or minus two); it processes about 40 bits of information per second. The more primitive unconscious brain holds troves of information; it processes more than 11 million bits of sensory information per second.[30] The unconscious brain expedites information interpretation to produce focused, complex judgments quickly—often in ways not immediately articulable. The abilities to produce accurate quick-glance decisions and immediately distinguish nuance separate those who have military genius from those who do not.

Military genius is neither ingrained at birth nor accidentally developed. *Military genius can only develop from deliberate practice, focused professional and personal study, and experience over time*.[31] Today's US military is the most educated of any in any nation's history. However, it is stretched thin and lacks the developmental time, expertise, and cultural support necessary to facilitate the neural network development required to produce more widespread military genius for future war. Brains have not changed much over the millennia, but access to dopamine-producing activities has. When we overindulge in digital immersion, it has a threefold effect: it addicts us to engage in more digital activity over time, it affects how we absorb information, and it removes what already limited time exists to focus on the work that really matters.[32]

Strategic-level leaders must strive more than ever to provide the cultural scaffolding necessary to encourage service- and self-directed efforts required to produce military genius in a modern society driven by distraction. Trainers cannot teach military genius through formal training alone. Leaders must set conditions that encourage thought-shaping. However, individuals must take personal responsibility from there by studying and shaping their neural connectomes on their own. It is the sincere *pursuit* of military genius that matters most.

Leader-imposed stress

Clausewitz notes, "Iron will-power can overcome friction. . . but of course, it wears down the machine as well."[33] Known today as the Yerkes–Dodson Law (figure 2), Clausewitz intuitively identified that, at times, *deliberate bursts of leader-imposed stress (eustress) and passion could increase the performance of war fighters, especially in high-threat environments*.[34] However, the resulting burst of performance and consistency of application is not sustainable. Pushed too far (distress) for too long, individuals experience a significant drop in performance, create diminishing returns, and *increase* the amount of friction experienced. Again, a leader's ability to apply coup d'oeil is likely the difference between success and failure in this instance.

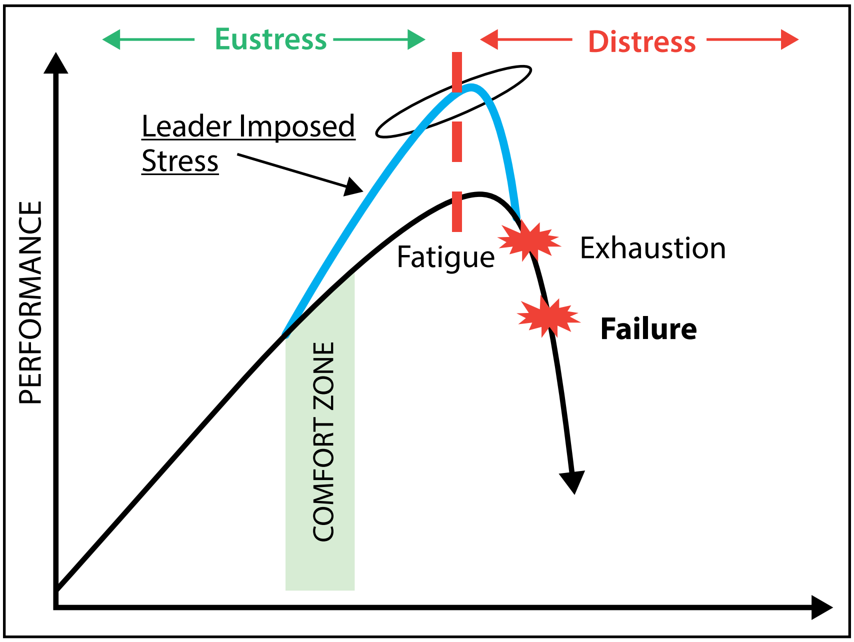


Figure 2. Yerkes-Dodson Law. (William McCollum and Matthew Broaddus, "Leader-Imposed Stress and Organizational Resilience," Fort Leavenworth, KS: US Army Command and General Staff College [August 2016]: 6.)

Recommendations

Adopting neuroscience education as a training concept is necessary—and it can be done. What is unclear, however, is whether it will be embraced in the face of tradition. Accumulating scientific knowledge indicates neuroscience education would benefit a wide range of trainees—from recruits to experienced war fighters.[35] However, additional institutional scaffolding is required to allow neuroscience education to enhance desired effects. Before leaders direct ad-hoc neuroscience education protocols to local training and leadership programs, I submit the following recommendations as *starting points* to facilitate holistic program development and long-term success:

1. *Leaders*. Neuroscience education should be woven into professional military education (PME) as a proactive performance element to improve war fighters' metacognition capabilities. Neuroscience evidence should inform the "why" behind the "what" of combat support procedures and decision-making processes. Creating awareness that limitations are present creates a natural internal motivation to want to reduce those gaps. I recommend each PME level—enlisted and officer alike—incorporate into the curricula tiered and tailored courses focused on the neuroscience of motivation, capacity, and effectiveness in an enhanced military. Tiered and tailored "Neuro 101" courses should progressively inform on the brain's structure, how its design affects enduring human elements of fog, fear, and friction, and why understanding it matters for future war. PME must prepare leaders to understand how human factors influence strategy alongside strategy itself.
2. *Trainers*. Creating awareness of biological functions and limitations using a tiered and tailored approach is the first step to elevating performance. The next step is to re-conceptualize unit training program templates. Unit training programs should specifically consider known neuro limitations while deliberately striving to "close the gap" between the young adults and their mature adult counterparts. Trainers should receive additional training describing effective training methodologies grounded in neuroscience to close existing neuro gaps. Beyond PME, I recommend career-fields develop specialized "train-the-trainer" programs tailorable to the needs of unit-level, readiness training center, and technical training instructors to develop specific and mutually supportive warfighter traits.
3. *Individuals*. Accounting for practical variations in training requires a framework to corral individual differences. Trainers should follow a simple assess-improvement-reassess model to determine specific skill proficiency. However, training variation *needs* are not so obvious from individual to individual. Personality inventories may offer clues to tailor training and improve performance at the individual level. Organizations most often use personality inventories as fringe team-building or novelty self-awareness tools. While successful as a team-building drill, training programs are not designed to translate personality inventories into meaningful training application aids. I recommend career fields develop routine personality inventory protocols to establish foundations of training variation requirements across individuals. As individuals change over time, so do their needs. Currently available trait tests (e.g., Myers-Briggs Type Indicator, DNA Behavior, Jung typology, DISC personality tests, and so forth) offer insights that, when leveraged effectively, may increase the effectiveness of a given training program.
4. *Research*. Beyond neuroscience applications, I recommend the Air Force and each career field develop a list of enduring "Future War-fighting Challenges." Career-field directors should offer topics needing solutions to officers and se-

nior noncommissioned officers before attending mid- and late-career PME. The intent of Future War-fighting Challenges is to identify problems in need of research, both neuroscience- and nonneuroscience related, and to translate existing concepts into viable applications. Air Force functional leaders should require graduate degree completion for students who attend an in-residence graduate-level PME course where the degree program is optional. The institutional requirement to continuously adapt alongside an ever-evolving operating environment should necessitate increased returns on investment in the form of target-focused research from the Air Force's brightest strategic thinkers. PME institutions must also evolve to support the research needs for predicted future war.

Conclusion

In predicted future war, our military becomes a weak link system.[36] In recent decades, the military succeeded as a strong link system. Superior weapons and technology supplanted service member focus and end-strength numbers. But the military sovereignty that got us here does not entitle us to future victories. The uncertainty of digital superiority in predicted future war compels us to reconsider war-fighter preparation efforts.

If we accept the premise that adversaries will have the motivation and capability to neutralize key nodes of our strong link advantages, the weak links—the individual Airmen—become the critical determinants to success. The *analog* superiority—the cognitive skills used to execute sound decision making while under great stress—demonstrated by tactical-level Airmen will be the decisive point between mission success and failure. For predicted future war, improving the skills of weak link elements may provide greater relative benefit than improving strong links with vulnerable nodes. This is not to say we should not seek to improve the capability and resilience of our strong links—we should. However, the commitment to retain our technological edge should be rivaled closely by our determination to optimize human dimension strategies. Our future military success will rely upon both technological and human cognitive domains.

Some will argue that each service component is already pursuing multiple approaches to build a better war fighter. While cursorily true, current programs are often niche, and many military leaders, especially at tactical levels, are resistant to seemingly "softer" approaches to change. Strategic- and operational-level leaders must embrace and advocate for neuroscience education and applications to become culturally accepted practices of our military systems, not just peripheral programs, to prepare now for predicted future war.

Clausewitz believed that the seeds of a nation's war-fighting success are sown in the limited and interwar periods. Our military leaders face an important choice. We can cling to a traditional view of war fighting grounded in past successes rather than future challenges. Or we can evolve the Western way of war by listening to emerging neuroscience research, embracing new approaches to war-fighter preparation, and developing or embracing an operating philosophy that helps future war fighters, organizations, and joint services operate a little better.

Better ways are within our grasp. Cultural change will neither be easy or happen overnight. However, change is favorable to irrelevance. Two assumptions for future war should guide our actions now—wars of *attrition* will favor our adversaries; wars of *cognition* should favor us.[37] Now is the time to link relevant neuroscience research to our strategic-, operational-, and tactical-level end-state objectives. ✪

> *Our true legacy is the ability to see and shape the future in order to win. It's time to get started—the future is closer than we think.*
>
> —Gen Terrence J. O'Shaughnessy

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Maj Michael J. Cheatham, USAF

Major Cheatham (MA, American Military University; MMAS, US Army Command and General Staff College; BA, University of Arkansas) is the commander, 374th Security Forces Squadron, Yokota AB, Japan. He is responsible for the protection of 11,000 military, civilian members, and dependents and more than $2 billion of DOD facilities, equipment, and aircraft. Major Cheatham also ensures the readiness of all assigned personnel to conduct security operations for air expeditionary force deployments and wartime taskings. He provides air provost services to the Yokota community, fly-away security teams for Pacific Air Forces and Air Mobility Command aircraft, and liaises with host-country police forces, defense forces, and other local agencies. Major Cheatham is a career security forces officer whose deployment history includes tours with the 586th Expeditionary Security Forces Squadron, Camp Bucca, Iraq, and the 450th Military Police Detachment, Forward Operating Base Fenty, Afghanistan in support of Operations Iraqi and Enduring Freedom. Before his current assignment, Major Cheatham was commander, 799th Security Forces Squadron, Creech AFB, Nevada.

Seize the Highest Hill

A Call to Action for Space-Based Air Surveillance

Lt Col Troy McLain, USAF
Lt Col Gerrit Dalman, USAF*

All armies prefer high ground to low.
–Sun Tzu, *The Art of War*

The Air Force must overcome area denial strategies not by engaging competitors in a technological tug-of-war in the air domain but by leaping over them to exploit the decisive high ground of the space domain. The fusion of airborne and spaceborne sensors will provide the decisive and enduring advantage in air domain awareness necessary to deliver air superiority in 2030 and beyond.

*The authors extend their gratitude for the support of the Utah State University Research Foundation Space Dynamics Lab in their editorial and conceptual critiques.

Joint operations rely heavily on the air component to provide the security of air dominance over friendly forces and air superiority over objectives. The resulting freedom to maneuver is essential to how our land and maritime forces conduct operations. A comprehensive, theater-wide, real-time surveillance picture is a vital prerequisite to control of the air in modern warfare. The success of US-led air campaigns of the 1990s and 2000s has made the rapid establishment and enduring sustainment of that picture so ubiquitous that it is now generally taken for granted. The joint force can no longer accept such a tacit assumption.

The joint force can no longer assume unimpeded access to the airspace or spectrum necessary to conduct air surveillance by current means alone. The air domain awareness advantage of previous generations was built on a technical edge that has eroded. Widely proliferated advanced air defense systems now enable many adversaries to effectively deny air surveillance systems their "god's-eye" view, undermining the air component's situational awareness (SA), complicating air superiority, and putting the joint force at risk. As part of a new disaggregated and distributed approach to command and control, the US Air Force must expand its means of air surveillance to include spaceborne sensors.

Eyes in the Sky

Surveillance as a military activity, and air surveillance, in particular, is often misunderstood. The DOD definition of surveillance— "systematic observation"—is broad.[1] In contemporary use, surveillance is most often crammed between intelligence and reconnaissance in the acronym ISR (intelligence, surveillance, and reconnaissance)—belying the value of systematic observation beyond the intelligence enterprise. For this article, *air surveillance* specifically refers to persistent wide-area surveillance (WAS) of the air domain of the kind currently delivered directly to the theater air control system (TACS) for airborne early warning and battle management, command, and control (BMC2).

Persistence is essential to providing the joint force with continuous coverage, leaving no gaps in observation over time.[2] Wide area means simultaneous coverage of a complete mission operating area, leaving no gaps in three-dimensional space. In major combat operations, the joint force has become accustomed to the TACS providing air domain awareness, measuring coverage in tens of thousands of square miles and persistence in days without interruption.

Radar remains the best tool for rapidly building a picture over such surveillance volumes large enough to cover modern operating areas. Using the Doppler effect, radars can pick out moving objects against background returns at hundreds of miles. When processed, location and vector data presented in this way are called moving target indicator (MTI) data. Surveillance teams use air MTI to detect and track air vehicles. They then layer cooperative identification systems and conduct sensor and intelligence fusion to create the authoritative air picture for all entities requiring SA of friendly air missions, air domain awareness, or "prediction of an adversary's behavior."[3]

For decades, the Air Force has generated that picture through a combination of ground-based and airborne radars. Ground-based radars provide several advantages, including persistence, flexibility, and a low operating cost. Despite these advantages, ground-based fixed and movable systems are not as rapidly deployable or tactically flexible as aircraft. Airborne systems are more expensive to operate but provide greater tactical flexibility and all the classical benefits of high ground. They can look down valleys to negate terrain masking and move in response to the current situation to optimize sensor coverage as the mission changes. These challenges have made expeditionary airborne surveillance platforms indispensable in the air surveillance role. Unfortunately, this dependence is rapidly becoming a vulnerability.

Losing Our Perch

> *The increasing lethality and reach of adversary weapons will significantly increase the risk to large BMC2 platforms like AWACS in 2030. This will limit their ability to see and manage activities in the contested and highly contested environments.*
>
> —Enterprise Capability Collaboration Team
> Air Superiority 2030 Flight Plan, May 2016

State-of-the-art air and spectrum threats pose grave risks to today's surveillance platforms. Spurred into action by the decisive air-land campaign of Operation Desert Storm, competitors worldwide have invested heavily and effectively in capabilities to contest the West's asymmetric air and spectrum advantages. Air defenses have advanced in lethality, forcing surveillance aircraft to operate ever farther from their areas of interest to survive (fig. 1). Meanwhile, air surveillance has remained fundamentally unchanged over the same interval. Even from the air, radars of sufficient fidelity are generally still constrained by the horizon. The lethality and proliferation of air defenses have tilted both the advantage and cost-benefit substantially in favor of the defender.

Highly accurate long-range surface-to-air missiles (SAMs) are especially lethal to surveillance platforms. Air surveillance radars continue to be flown primarily on modified airliners with no substantial improvements in altitude, speed, stealth, countermeasures, or any other method of self-defense. SAMs, however, have increased in range, accuracy, and affordability, driving lethality and proliferation. The introduction of very long-range air-to-air missiles (VLRAAM) and increased combat radii of leading interceptor aircraft make matters even worse.[4] The differential has grown so great that, in many cases, the air surveillance look into contested airspace has been reduced by more than half.[5]

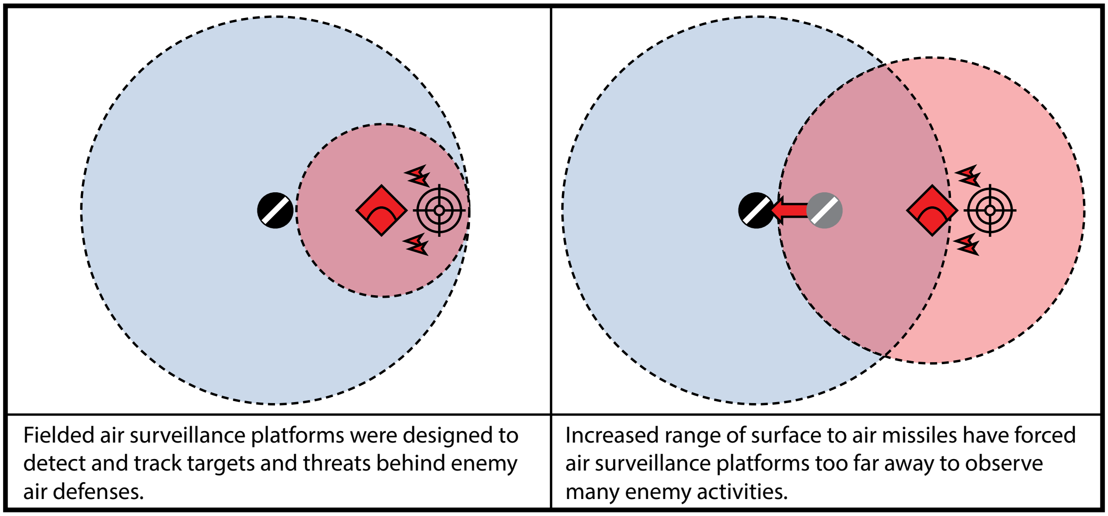

Figure 1. Impact of increased air defense ranges on air surveillance

Technology has also driven down the cost of air defenses, putting offensive capabilities on the losing side of the cost equation. Fielding incremental upgrades to air defenses is far cheaper than upgrading aircraft fleets, putting the offense on the losing side of the cost equation.[6] These systems, when integrated into a larger air defense system, can be an effective antiaccess strategy against surveillance platforms that cannot survive inside of missile engagement zones. This vulnerability is not confined to just one geographic combatant command. Many nations, including all four nation-states from the secretary of defense's "4 + 1" baseline threats, have fielded such advanced integrated air defenses.

The advantage air defenses have over airborne surveillance is an unacceptable threat to the US strategy of expeditionary engagement, which relies heavily on the agility and "inherently offensive" nature of airpower. The backbone of the air component's situational awareness has been pushed far enough back that they can no longer be effective where such threats are present. The resulting gap in air surveillance reduces early warning, limits support to the interdiction and deep-strike targets that are the Air Force's unique addition to the kinetic arsenal, and puts other joint missions at risk as well. This gap is a global and enduring risk for which a solution is overdue.

In Pursuit of Access, Coverage, and Persistence

The current platform-centric approach to the TACS relies on sensors that are too few, too vulnerable, and too far from the fight to be effective. The right solution is that there is no single solution. None of the headline-grabbing visions for solving this problem are sufficient on their own. A radical change in the means of air surveillance is needed to regain assured information advantage in contested airspace.

Incomplete Solutions

The simplest solution is to recapitalize legacy systems. Doing so would address platform longevity, availability, and cost concerns and may provide incremental upgrades to sensor range or platform survivability but would only be a continuation of business as usual. An evolutionary approach means engaging adversaries in a losing game of cat and mouse. The Air Force record in the air surveillance and command, control, and communication domain is full of failures, delays, half-measures, and wavering commitment to air surveillance and C2 platforms (e.g. E-10, the Three-Dimensional Expeditionary Long-Range Radar, E-3 Block 45, and Joint Surveillance Target Attack Radar System (JSTARS) recapitalization). In a global arms market defined by rapid evolution and proliferation, DOD acquisition is unlikely to outpace adversaries who can direct acquisition faster, accept more risk, and lean on cheaper defensive options. Sticking to familiar concepts would generate only fleeting advantages. Legacy models are insufficient to produce dominant capabilities or secure a lasting lead over adversaries.

Some concepts advocate saturating areas of interest with autonomous swarms to build situational awareness. Swarming unmanned aerial systems, with the potential to generate enormous amounts of data about the environment around them, are worthy of active investment for application to a variety of mission sets, including surveillance. By their nature, however, they are ill-suited for theater surveillance. There is an enduring need to detect and track the activity of interest anywhere and anytime in the area of responsibility, which requires wide-area coverage and persistence beyond the capability of today's swarm state-of-the-art. The limited size, weight, and power of current drone demonstrations and concepts constrain their altitude, range, speed, and endurance, as well as their sensor field of view and communications. Larger air vehicles are in development as well, but their expendable nature makes them poor platforms to carry expensive long-range sensors. Although they may be able to gain access to contested areas and provide high-fidelity local surveillance, the limited coverage and persistence of swarms will not scale effectively or affordably to theater-wide surveillance.

Knitting numerous sensors may be more effective with larger platforms such as fifth-generation (5G) fighters. They can achieve the needed access and carry larger sensor payloads higher and at sufficient speeds to provide some of the tactical flexibility that swarms lack. Despite advances in their multisensor suites, however, their air pictures continue to be local by design. Their bubbles of awareness are short-range relative to dedicated air surveillance solutions (e.g., SPY-1, APY-2, and TPS-75 radar systems). Even if shared, those rich islands of 5G situational awareness will only exist when and where those fighters are operating. Limited range and presence together mean that a 5G surveillance picture is too limited in both space and time. These gaps must be understood to avoid dependence on the dangerously oversold mantra that 5G fighters can be the lone "quarterbacks" of future air missions. Networked 5G surveillance solves the access problem, but can't provide a comprehensive, persistent picture.

It is increasingly accepted that air superiority will be ephemeral—only assured in localized time and space where and when needed. The tacit assumption seems to be that, because air superiority will be fleeting, the information superiority it relies on can be limited in time and space as well. That is a blatant false-cause fallacy.

Intermittent surveillance cannot be accepted as good enough. The freedom to maneuver and act may be taken and yielded as required by mission objectives, but accepting anything less than constant and pervasive situational awareness is tantamount to ceding the initiative to the enemy. The limitations of these concepts are not unknown but are often glossed over. Leaders must be aware of the limitations of these solutions and how they might be mitigated by combining with each other and with even more radical options. In this way, they can have at least a vision of a complete solution and, if necessary, assume risk consciously and at the appropriate level.

The Necessity of Netting Sensors

The air surveillance system of the future must constitute a system of systems that accepts disaggregated capabilities and distributed platforms. Disaggregated means embracing the flexibility to solve for surveillance, communications, and battle management capability categories independently or in various combinations on separate but networked platforms. Distributed means that those capabilities can be resident in platforms operating in more locations and from more domains, causing a transition from the current platform-centric mindset to a capabilities-centric approach. The surveillance capability of such a new system should include modernized "all-in-one" BMC2 platforms, dedicated surveillance platforms, and opportunistic sensor data from nonsurveillance platforms.

A disaggregated air surveillance system must have three defining traits to be successful. First and foremost, it must include dedicated, long-range, high endurance, look-down sensors as a "backstop" to ensure a minimum amount of continuous coverage over friendly and contested territory even if it cannot assure access to enemy territory. Second, it must be inclusive of all sensors regardless of platform so that no relevant enemy maneuver covered by a sensor goes unreported. Third, it must ensure interoperability between those diverse contributors to realize a cohesive surveillance network able to fuse disparate data into an air picture.

An air surveillance system that combines these traits will be more resilient, scalable, and flexible than the Cold War legacy construct, but will still fall short when engaged against determined adversaries with advanced air defenses. None of these solutions, even operating in concert, will provide sufficiently persistent surveillance in depth.

Space is the Ultimate High Ground

The final ingredient for a game-changing surveillance picture is space. The Air Force Future Operating Concept (AFFOC) urges the force to seek "increased contributions from space-based assets" and specifically acknowledges that "the joint force will increasingly rely on advantages provided by on-orbit assets for air superiority."[7] The AFFOC also warns against concentrating critical capabilities into any single platform or any single domain, lending support to both the distributed surveillance model and an objective consideration of surveillance from space.[8] Extending air surveillance to the space domain is the only mature concept that will grant persistent look-down coverage while bypassing advanced air defenses.

There has been interest in using space for air and ground surveillance since digital communications made real-time sensor feeds from satellites possible, but recent advances in space lift, miniaturization, and computing technologies demand a new look. Previous efforts encountered many roadblocks, but, fundamentally, each failed because the cost and risk of implementation outweighed the cost and risk of continuing the "business as usual" approach. Advances in technology and the increased need to bypass the evolving air threats dramatically change both sides of that equation. The balance has shifted and the time to field a space-based air surveillance system has finally arrived.

Getting to the Launch Pad

The US has been pursuing the use of radar in space since at least the 1960s (fig. 2). Many program details remain classified, but enough information is available to surmise why we do not already have operational space-based radar (SBR) constellations. A quick look at some past programs of record reveals a pattern of cancellations due to unanticipated costs and technical challenges, both stemming from complicated designs or immature technology, often coupled with a lack of political and military leadership commitment.

The US focused early radar satellite programs on synthetic aperture radar (SAR) to provide all-weather alternatives to imagery intelligence. [9]Some of these programs, such as the National Reconnaissance Office's (NRO) 1964 Quill program or the Navy's 1979 Clipper Bow, were limited for utility reasons. Quill's SAR imagery had to be processed on the ground similar to the early Corona photo reconnaissance satellites.[10] This lack of real-time information limited Quill's mission to a one-time test of SAR resolution from orbit. Clipper Bow, meant to provide radar imagery of Soviet ships to complement the electronic intelligence provided by the Navy's White Cloud satellites, was canceled before it flew. When new Soviet bombers became the primary threat to US naval vessels, the need for over-the-horizon detection of ships diminished and the Navy was no longer willing to fund Clipper Bow.[11]

While Quill and Clipper Bow provided little return on investment, the Onyx (also known as Indigo or Lacrosse) SAR satellites enjoyed some success. With five launches between 1988—2005, operational Onyx satellites gained publicity during the 2003 Iraq War when they were able to detect Baathist Army targets through sandstorms.[12] But the Onyx satellites highlighted a problem that continues to plague any large satellite architecture—large satellites are easy to detect and track, so that an adversary can counter them through simple evasion or deception tactics. Small constellations of large satellites are also extremely vulnerable to antisatellite (ASAT) weapons, which peer adversaries, such as Russia and China, have demonstrated and continue to develop.[13]

The first real attempt to use space for an MTI capability came in the form of the 1980s SBR program. The relatively new Air Force Space Command (AFSPC) championed what it envisioned as a supplement to the airborne warning and control system (AWACS) for even earlier warning of Soviet aircraft movements. The end of the Cold War, however, reduced the urgency for supplementing existing airborne air surveillance capabilities.[14] Despite rhetoric about the high priority that SBR held for Air Force acquisition, the secretary of defense and top USAF leadership never accepted it for development. Much like Clipper Bow, leaders could not justify its cost when developing circumstances diminished its primary mission. It is also worth noting that AFSPC was not the Air Force element of the NRO, and a lack of NRO support would significantly hamper the Air Force's next attempt at space-based MTI.

The next incarnation of space-based radar, also called SBR, began as a 1998 Defense Advanced Research Projects Agency (DARPA) proposal. The NRO, however, was tacitly in charge of all satellite intelligence programs and joined with the Air Force to lead the program. This SBR was re-envisioned to provide ground MTI (GMTI) as a space alternative to the JSTARS. The logic behind providing this capability remains sound today: JSTARS is a high-value airborne asset that is not survivable against modern air and missile threats.[15]

The initial phase of this SBR became the Discoverer II program. Again, cost became a factor, especially as the program showed slow progress due to lack of interest. The interagency NRO/USAF/DARPA program died in 2001 when the NRO withdrew its support. Large costs can also be linked to the efforts that developers had to undergo while trying to design a single, large satellite to perform GMTI. Small constellations require lightweight materials, large apertures, and a large field of view, resulting in huge satellite designs that require expensive, heavy-lift rockets to launch. Monostatic radars, with a co-located transmitter and receiver, also have formidable challenges when trying to reject clutter for a clean radar picture.[16] These same technical challenges would lead to exorbitant costs during the next iteration of space-based radar.

In 2006, another space-based GMTI radar was proposed under the name Space Radar (SR). This time, the Congressional Budget Office (CBO) produced a report analyzing the cost and effectiveness of several satellite constellation architectures. While larger, and therefore more expensive, constellations obviously led to better coverage and tracking capabilities, the report noted that "time gaps in covering a given area would probably occur for all of the constellations that CBO considered [and] those systems would be impractical for tracking," so that "constellations larger than the ones that CBO examined would be necessary to track individual ground targets."[17] The satellites also included a SAR capability "among other missions."[18] These were monostatic designs, requiring large apertures to optimize signal processing and improve clutter rejection. The CBO said their 40-square-meter radar arrays, which could not even reliably track targets unless larger constellations were considered, would likely be incapable of detecting any ground targets moving slower than 20 miles per hour.[19] Additionally, the CBO envisioned each satellite operating for 10 years, at which point each satellite would be replaced, resulting in a 20-year anticipated life cycle for the program. The requirements that a 10-year, multirole, large-aperture, SBR satellite demands resulted in an expected cost range of $35–$52 billion for the preferred alternative, and $66–$94 billion for the largest constellation.[20] The defense and intelligence community understandably deemed that cost, driven by architectures based on numerous, complicated, short service life satellites, was "not affordable."[21] While the official cancellation statement included hints that the program would be restructured and continue, no replacement for SR has been announced.

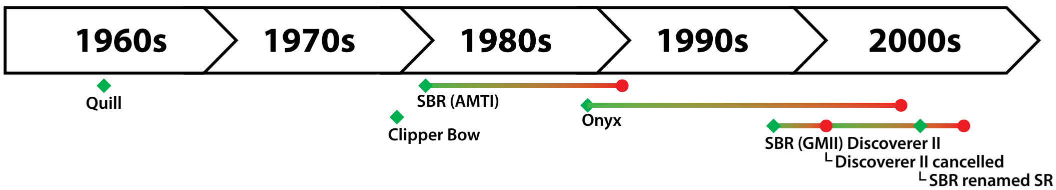

Figure 2. Chronology of US space-based radar programs

Despite previous failures to develop an affordable and capable space-based MTI capability, the idea continued to hold Air Force interest from the original 1980s SBR until the cancellation of SR in 2008. In 1999, Maj Kimberly Corcoran, then an experienced AWACS aircraft commander and student at the USAF School of Advanced Airpower Studies, reflected the optimism of space-based MTI development during the time of Discoverer II. Citing reports from the Air Force chief scientist, Dr. Daniel Hastings, in 1997 and the US Space Command space-based MTI concept of operations with Air Combat Command and Space-Based MTI Roadmap with the USAF Space and Missile Center, Corcoran and the Air Force space community believed that we would already have a GMTI capability in space now, with AMTI becoming operational by 2020.[22] While the 2008 cancellation of the SR has created a vacuum of formal SBR acquisition programs, the intent was not to cease pursuit of the capability. Rather, the NRO said it needed time to restructure the program to reduce the ever-increasing costs the program was generating.[23] Almost 10 years later, the program sits on the shelf as both the satellites and the enabling technologies that can make space-based MTI a reality have continued to mature.

The overall reason for the cancellation of past SBR programs has been unacceptably high cost compared to air domain alternatives for the anticipated gains. The costs have come from large bus satellites that require heavy launch vehicles. These busses are made even larger by requirements creep that adds search and rescue and additional seemingly-related missions, as well as the design requirements to ensure these satellites can operate for a decade or longer. The price per satellite has led to smaller constellation designs to reduce overall program costs. Smaller constellations reduce persistence, complicate tracking of slower targets, and generate a more cluttered picture. The resulting high costs for MTI satellites that can't reliably maintain the targets they were designed to track, and could potentially not even survive against an ASAT-equipped adversary, eliminated organizational will to back up claims of these programs' high priority. Researching and developing technologies that involve smaller busses, larger constellations, multistatic antennas, and virtual apertures has the potential to overcome the problems of the past.

Go for Launch at Last

> *If we don't invest in new ways of doing business now, we will not be competitors in the future.*
>
> Lt Gen VeraLinn "Dash" Jamieson
> ISR deputy chief of staff

Technologies for large constellations of smaller satellites have matured significantly in capability and feasibility in the past decade and offer increased resilience and reduced cost. Even before Discoverer II and SR fell victim to prohibitive cost, Corcoran proposed the use of large constellations of single-purpose small satellites (smallsats) as an alternative. The advantages of large constellations of smallsats over small constellations of large, multipurpose satellites are easy to see. Their great number complicates adversary targeting, their small size makes them more difficult to engage, and since capability is spread across the constellation, the system can degrade more gracefully when individual elements are attacked. A standardized design of numerous satellites could also be mass produced more cheaply, allowing quicker replenishment of damaged units.

In addition to increasing survivability and reducing cost, smallsats could mitigate technical challenges that crippled previous concepts. While previous MTI proposals required apertures so large they could not fit on a launch vehicle, advances in networking and processing could enable smallsats to create effective virtual arrays using existing spacelift options without on-orbit construction. Formation flying of smallsats to create a large virtual aperture for potential use in space MTI is not a new concept, but one that has only recently been tested. The Air Force's first major attempt at testing smallsat formation flying was through the Air Force Research Laboratory (AFRL) TechSat-21 program. The three-satellite system, intended for launch in 2006, was to be a proof of concept for a virtual aperture to perform GMTI. Technological advancements in sensors, antennas, satellites, electronics, and computing had finally enabled such a system to be created, and a lead researcher for the program stated, "we can implement advanced algorithms and dream up new approaches that weren't even possible five or 10 years ago."[24] Unfortunately, the program was canceled by 2003 for unspecified "technical challenges."[25] Still, TechSat-21 is worth mentioning for a few reasons. First, its 100 kg mass can give a general idea of the nominal size that AFRL believed could accomplish an MTI mission. Second, the fact that GMTI—and not the numerous other imaging, sensing, and communication missions that a formation of smallsats could perform – was chosen as the TechSat-21 primary mission shows the high level of interest involved in attaining that capability. Finally, TechSat-21 was seen as possible only through technological advancements that had occurred within the last five years. Since its cancellation, more than a decade of technological advancement has occurred with the potential to overcome the technical challenges of the past.

Improvements in timing, wireless linking, and signal processing are beginning to show success in other programs. In November 2014, the Canadian Advanced Nanospace eXperiment 4 (CanX-4) and CanX-5 satellites completed a very successful formation flying demonstration. The 6 kg satellites verified advanced drift recovery and station-keeping algorithms, "with relative position knowledge of better than 10 cm and control accuracy of less than one metre at ranges of 1000–50 metres."[26] More recently, the National Aeronautics and Space Administration was able to fly a quartet of magnetospheric multiscale mission satellites in a formation 4.5 miles apart, improving the scale at which it can take measurements of Earth's magnetic field.[27] These examples demonstrate both that the technology required for formation flying of smallsats is within our reach, and that this technique can allow several smaller satellites to accomplish the work of one large satellite and, further, the potential to achieve performance greater than any single satellite.

Technology has also delivered significant operational improvements and cost reductions in space lift. The potential for cheaper and more routine access to space has never been better and is consistently improving. The Air Force budget for fiscal year 2018 shows that the United Launch Alliance (ULA) launches range from $100 million for an Atlas V to $350 million for a Delta IV Heavy, and ULA costs are projected to rise to $422 million by 2020.[28] New competitors, however, are beginning to reverse the trend of rising costs. Elon Musk, the chief executive officer of SpaceX, responded to the high launch costs by noting that SpaceX has launched, on average, $300 million cheaper with its Falcon 9 than the ULA rockets, a difference which he boasts makes launching with SpaceX "basically free."[29] Then-Secretary of the Air Force Deborah Lee James recently testified to Congress that companies like SpaceX are significantly expanding Air Force capacity and reducing cost.[30]

Reusable space planes could drive even cheaper and more routine launches, especially for low-Earth orbit (LEO) smallsats. A mix between airplane and space launch vehicles, space planes could be launched into low orbit, deposit their payload, and then recover for a quick turnaround to be launched again as soon as the next day. Most clearly on the horizon is DARPA's XS-1 Experimental Spaceplane. The XS-1 is being designed to carry up to 1,360 kg per launch with the ability to launch 10 times in 10 days.[31] It is also being built with much higher technological readiness than previous ambitious space launch programs, including better airframes, propulsion, and commercial involvement.[32] In March 2017, DARPA announced it had selected Boeing to advance the design of the XS-1, and that launches could cost as little as $5 million. Using TechSat-21 as a guide, this means that the XS-1 could potentially orbit 130 MTI satellites in 10 days at the cost of just $50 million. A single Falcon 9 launch has the potential to carry a payload of 22,800 kg, or 228 TechSat-21 comparable satellites.[33] Combined, the Falcon 9 and XS-1 could initially launch a large constellation of MTI smallsats, then provide routine reconstitution to maintain those satellites at a fraction of the cost of the launch vehicles that were available only a decade ago.

Resilient by Design

Clearly, advancements in technology can be applied to mitigate fiscal concerns and enable new operational concepts, but they will also mitigate the ever-increasing threats to space segments of the system. High-altitude nuclear attacks and their resulting electromagnetic pulses can knock out whole constellations.[34] Conventional threats to current space-based systems are on the rise. Several adversary nations have demonstrated effective kinetic ASAT weapons to attack satellites and electronic attack capabilities to deny their sensors or disrupt communications. Even more sophisticated attacks could include adversary spacecraft designed to approach close enough to directly destroy, disrupt, degrade, or deny friendly satellites.[35] The use of any of these capabilities have legal and debris consequences that have been addressed by other authors, but the threats they pose are credible and must be considered regarding any new constellation, especially in LEO, where an air surveillance augmentation would be ideally located.

Many of the risks that have emerged can be mitigated by the same technologies that make the concept fundamentally more feasible, especially improvements in smallsats and space lift. Smallsats have the potential to overcome many of the current threats to today's space assets. Their size makes them more difficult to target, and the loss of one or even several satellites out of a larger constellation may only degrade rather than deny its capability. With cheaper and more responsive space launch systems deploying multiple satellites per launch, such constellations could also be reinforced, replenished, or repositioned more quickly than the large satellites conceived in previous concepts. The pairing of reusable launch and orbital vehicles with larger constellations of smaller satellites complicates adversary targeting, increases resilience through volume, which reduces the impact of attrition and enables more rapid reconstitution.

Ultimately, conducting surveillance from multiple domains is the best way to mitigate current and future threats. No technical solution is sufficient if it relies on a single domain vulnerable to denial. It is essential that space-based capabilities be combined with, not replace, air-, land-, and sea-based surveillance so that an attack in any one domain is both disincentivized and less effective.

Achieving Escape Velocity

The US cannot afford to take a back seat in the development of this technology. While not overtly pursuing a space-based MTI program, Russia and China are immediately behind the US in their development of the enabling technologies of smallsats and reusable space lift.[36] More efficient Chinese launch vehicles, such as the Long March 11, are not only enabling the launch of their own military smallsats but are also cutting into the domestic commercial launch market.[37] It is possible an adversary will seize on this opportunity for asymmetric advantage and erode US industrial capability in the process. Therefore, the Air Force must finish the countdown and immediately:

3. . . Commission a study on space radar. The time is right to deliver on the 2008 promise to revisit the feasibility of SR, including new alternatives and an assessment of the impact of technical advancements on cost and feasibility. Consideration should be given to space-lift cost, sustainment, single-mission smallsats, and hosted payloads on multirole missions platforms including the use of secondary payloads on planned programs. A comparison of a wider range of potential architectures should be included to provide the Air Force with a wide range of cost and capability alternatives. Opportunities for synergy and cooperation should be sought with other programs pursuing similar concepts for other missions across the intelligence and defense enterprises. MTI surveillance could be combined with other payloads on the same bus, in the same constellation, or in system-of-systems approaches.

2. . . Demonstrate new capabilities. A transition from theoretical to practical capability will do more than any previous effort to evaluate the validity of this long-debated capability. Objectives should include the demonstration of high-risk technologies and new concepts, including cooperative smallsat architectures, virtual apertures, and real-time delivery and fusion of spaceborne AMTI to TACS programs of record through standard existing fusion engines and using existing data standards. These objectives could be accomplished rapidly and at low cost through a partnership with an academic institution already pursuing smallsat research.

1. . . Prototype space sensors for programs of record. These efforts should be independent of, but informed by and supportive of, the Advanced Battle Management System or Advanced Battle Management and Surveillance (ABMS). ABMS is the Air Force's program of record for a modern TACS, including the replacement of AWACS air surveillance capabilities. The recently validated ABMS requirements could be used to update the SR parameters and the lessons learned from new space-based studies, and demonstrations could directly inform the ABMS analysis of alternatives. Demonstration hardware could even serve as the rapid prototypes or initial operational components of ABMS.

King of the Hill

The need for persistent, wide-area surveillance of theater operating areas will continue. As air defenses become more lethal, they push traditional airborne surveillance platforms beyond their effective range. The Air Force cannot allow competitors the ability to deny the joint force of persistent awareness of adversary air activity.

Radar remains a superior tool to overcome the tyranny of distance, but air surveillance must be disaggregated across more platforms in more domains. No combination of legacy surveillance platforms, drone swarms, and 5G aircraft will provide sufficient access, coverage, and persistence, nor will they satisfy strategic guidance to improve capability and present adversaries with all-domain challenges. Space must be a part of the plan.

By its very nature, space lends the best vantage to fill this capability gap and maintain critical situational awareness for theater commanders, especially in future highly-contested fights. Space MTI was unsuccessful in the past, but the technical challenges of yesterday have solutions today.

The solution cannot be intermittent in time or space, should guarantee access, and be derived from sensors in all physical domains. A disaggregated netted sensor grid augmenting air, land, and sea from space will enable the TACS to achieve the long-lasting and decisive edge in air domain awareness that is vital to deliver air superiority in 2030.

The Air Force must act now to overcome area denial strategies— not by engaging competitors in a technological tug-of-war in the air domain but by leaping over them to exploit the decisive high ground of the space domain. It should study new options for space radar, cooperate with academic and industry partners to demonstrate advanced capabilities, and leverage these practical lessons to improve existing systems and prototype surveillance components of ABMS.

The threat is present. The solution is available. The time is now. ✪

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Lt Col Troy McLain, USAF

Lieutenant Colonel McLain (MMOS, Air Command and Staff College; MS, American Military University; BA, Gannon University) is a senior air battle manager with more than 2,200 hours in the E-3 Sentry airborne warning and control system (AWACS) supporting the Pacific, Central America, and Middle East areas of operation. During previous assignments, he served as a director of operational test and evaluation for USAF command and control systems and was the senior officer for the Jordanian air defense liaison team. Lieutenant Colonel McLain currently serves at the North Atlantic Treaty Organization Airborne Early Warning and Control Force Headquarters.

Lt Col Gerrit Dalman, USAF

Lieutenant Colonel Dalman (MS, American Military University; MMOAS, Air Command and Staff College; BA, University of Alaska-Anchorage) is a senior air battle manager with more than 2,000 hours combined in the E-3 AWACS and E-8 Joint Surveillance Target Attack Radar System. He is a graduate of the USAF Weapons School. Lieutenant Colonel Dalman is currently assigned to the Joint Staff at the Pentagon.

The Long-Range Standoff Cruise Missile

A Key Component of the Triad

Dr. Dennis Evans
Dr. Jonathan Schwalbe

The US has initiated a major recapitalization of its strategic nuclear forces, including delivery platforms such as the B-21 Raider bomber and the *Columbia*-class ballistic missile submarine (SSBN), and both air-launched and ground-based weapons. Of the weapons that are currently funded, the Long-Range Standoff (LRSO) air-launched cruise missile (ALCM) is surely the most controversial. Many arguments have been proffered suggesting that this weapon is unnecessary, dangerous, or both. This article explains the program; describes why it is important based on the need for bombers in the nuclear role, the need for cruise missiles to make bombers effective, and the US–Russia mismatch in nonstrategic nuclear weapons (NSNW) and accurate, low-yield nuclear weapons in general; and discusses several leading criticisms of the LRSO ALCM. Our overall conclusion is that the continuation of the LRSO program is warranted.

The US has had a triad of land-based intercontinental ballistic missiles (ICBM), submarine-launched ballistic missiles (SLBM) on SSBNs, and long-range bombers since the 1960s. This triad has played a key role in US security for decades, but current US nuclear forces will reach end-of-life by about 2042, except for the B-2 Spirit and the B-52 Stratofortress bombers. The triad includes 14 *Ohio*-class SSBNs, 12 of which are normally operational. The *Ohio*-class SSBNs will begin reaching end-of-life about 2027. The program for the new *Columbia*-class SSBN has been underway for several years and is planned to deliver 12 new SSBNs. The Minuteman III ICBMs, of which 400 are operationally deployed in 450 underground silos, will reach end-of-life in the early to middle 2030s. The DOD has started a program to sustain the ICBM force, with a new ground-based strategic deterrent.

The US has 66 nuclear-capable bombers (47 B-52s and 19 B-2s), plus 29 B-52s and one B2 (a test aircraft) that have been modified such that they cannot carry nuclear weapons. The B-52 relies entirely on the AGM-86 ALCM in the nuclear role, whereas the B-2 currently relies on penetrating enemy airspace to drop unguided B61 nuclear bombs. A new stealth bomber, the B-21, has been under development for several years, and the Air Force plans to procure at least 100 B-21s, with initial operational capability (IOC) tentatively expected in the middle 2020s. Current plans call for some or all B-21s to be nuclear-capable, but the USAF has not announced how many nuclear weapons it will be able to carry or when nuclear IOC will occur relative to conventional IOC.

The Air Force is also developing two nuclear weapons for aircraft: the LRSO cruise missile to replace the AGM-86, which will reach end-of-life about 2030, and the B61-12 guided bomb. The new bomb is planned for use by stealth bombers, the F-15E Strike Eagle, and the F-35A (the Air Force variant of the F-35 Lightning II). The LRSO is planned for use only by bombers. The B61-12 program has been underway for several years and will reach IOC in the early 2020s. By contrast, very little funding has been expended on the LRSO program, and there have been numerous calls for its cancellation,[1] so additional analysis on the LRSO is warranted. The remainder of this article is devoted to discussing the rationale for the LRSO, cost issues pertaining to the LRSO, and various public arguments against the LRSO.

The Need for Bombers in the Nuclear Role

The importance of bombers in the nuclear role is heavily dependent on the scenario in which they might be used, but reliance solely on an ICBM–SLBM dyad would involve various risks—technical, programmatic, and operational—that nuclear-capable bombers might help mitigate.

The long-term survivability of ICBMs in the current, 1960s-era silos is uncertain (at least without the use of "launch on warning/launch under attack," which is a risky tactic), whereas bombers on a high state of alert might be more survivable against an enemy's first strike. (Bombers are not currently on nuclear alert during routine conditions. Bombers would likely be on alert only in the context of a prolonged crisis or a change in policy on the day-to-day alert level.) This is not an argument against ICBMs. ICBMs are invulnerable to any sort of small or inaccurate nuclear attack, whereas SSBNs in port and bombers that are not on alert are severely vulnerable to even a small nuclear attack. Further, US possession of ICBMs drives up the "price to attack" for a great enemy nuclear power and favorably influences the postexchange balance of weapons.

Nuclear-capable bombers could compensate for delays in the program for a new ICBM. The greatest risk for such delays comes from budgetary shortfalls, although the risk of technical problems cannot be excluded. Of course, the LRSO and the new ICBM potentially compete for the same funding, although the LRSO would be much less expensive than a new ICBM.

Existing SSBNs will start reaching end-of-life in a decade due to issues with hull fatigue, and there are budgetary and technical risks associated with the replacement program, as noted in the Government Accountability Office report GAO-18-158, *Columbia-Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals,* December 2017.[2]

Future improvements in foreign antisubmarine warfare could reduce the survivability of SSBNs at sea in the 2030s, relative to that of *Ohio*-class SSBNs today. The risk of this is small but perhaps not negligible. Bombers are not immune to the risk of improved enemy capabilities, but a more diverse portfolio of capabilities reduces US vulnerabilities to any single enemy advance. Further, bombers rely on different types of warheads, relative to ballistic missiles. Diversity in types of warheads helps to protect against problems with one type of warhead.

Also, the world of the 2040s likely will be more multipolar than the world of today, and thus a range of scenarios involving opponents other than Russia and also limited regional nuclear contingencies (i.e., short of all-out nuclear war) against great powers should be considered when determining requirements for nuclear forces. ICBMs are of doubtful utility against many non-Russian countries due to the need for overflight of Russia on the way to the country being targeted.[3] SLBMs can be better in terms of overflight, but it may not always be possible to avoid overflight without time-consuming transit to optimized launch points. Also, US ICBMs and SLBMs currently rely only on high-yield warheads, whereas lower yields would usually be preferred in limited contingencies. Hence, bombers may be the best option—within the current program of record—for operations against lesser adversaries and for any kind of limited nuclear exchange in a regional war. Improved US NSNWs—such as submarine-launched missiles and/or intermediate-range, forward-deployed ground-launched missiles—could, in principle, obviate the need for nuclear-capable bombers in some scenarios, but starting one or more programs for new and better NSNWs would be expensive and controversial.

Moreover, bombers force potential adversaries to devote major resources to air defense systems, which diverts resources away from offensive systems, although strategic nuclear arms might be limited by treaties and not just resources. This cost imposition factor also exists, to some extent, for US fighters, but geographically large adversaries do not need to worry about attacks by fighters deep in their territory. Bombers have much longer ranges than fighters, so air defenses deep inside the adversary's borders are needed for protection against bombers and long-range cruise missiles.

Finally, bombers are essential in conventional war, and the cost to make bombers usable in the nuclear mission is relatively modest. Consequently, bombers can be cost-effective in the nuclear role (depending somewhat on the counting rules in treaties) and also as a bargaining chip in arms-control negotiations.

Conversely, bombers suffer from some disadvantages in the nuclear mission. For example, if the bomber force is not on alert, and the bombers are at their normal operating bases, a small first strike could destroy the bombers on the ground, along with their associated nuclear weapons and base infrastructure. This could give an enemy an incentive to strike before the bombers are mobilized. Additionally, bombers provide a slow response relative to ICBMs and SSBNs that are on patrol.

The Need for Cruise Missiles for the Bombers

This section addresses the need for standoff weapons by each type of bomber, and also the benefits of a potential conventional derivative of the LRSO.

Because of the small number of B-2s, the B-52 will need to play a key role in the nuclear mission until the B-21 is operational in the nuclear role in significant numbers. The B-52 cannot penetrate adversary air defenses; therefore, it is totally dependent on long-range cruise missiles for survivability. Over the near term, the AGM-86 can fill this role, but it will reach end-of-life by 2030 and was not designed to penetrate state-of-the-art air defenses in the 2020s or beyond. Without the LRSO, the B-52 will cease to play a role in the nuclear mission once the AGM-86 is retired, and the retirement of this weapon might occur before the B-21 is operational in the nuclear role in significant numbers. If the AGM-86 becomes obsolete well in advance of retirement, then the B-52 could become irrelevant in the nuclear role by the late 2020s.

Apart from issues pertaining to the small size of the B-2 force, two factors are relevant to assessing the B-2's adequacy in the nuclear mission: in-flight survivability and range. Of these two factors, survivability has been the subject of more discussion. The B-2 is a highly stealthy aircraft by today's standards, but it will probably need standoff weapons for survivability against advanced air defenses at some point in the future. The LRSO is the only candidate for such a weapon on a timeline that supports the B-52. The range issue, however, could also be important. When carrying bombs, a B-2 has to fly directly over every target. When delivering conventional bombs, the bomber would probably drop all of its weapons within an area of a few thousand square miles. When delivering nuclear weapons against a geographically large country, by contrast, a B-2 would probably drop one bomb per target and might, therefore, need to use a large amount of fuel to fly over widely separated targets. Hence, range limitations could restrict the B-2 to striking a smaller number of targets than the number of bombs that it could carry. By contrast, a B-2 armed with long-range cruise missiles could strike a number of targets equal to the number of cruise missiles that it could carry. Moreover, these cruise missiles could complicate enemy efforts at defense by providing multiple attack vectors per bomber.[4]

It is too soon to know when the B-21 will be operational or how effective it will be, so it is prudent to hedge against the risk that the B-21 will eventually need standoff weapons for survivability. Moreover, even if the B-21 is highly survivable, it may need the LRSO for other reasons (like the B-2). Hence, it is premature to assert that the B-21 will never need nuclear cruise missiles, and the LRSO is the only candidate for such a weapon on a timeline that could also support the B-52.

To summarize, the LRSO may be critical to the utility of the current bombers in the nuclear mission in 2030 and remain important even after the B-21 is operational in the nuclear mission. That is, without the LRSO the US may have a nuclear triad only on paper by 2035.

Finally, if a conventional version of the LRSO is developed (a plausible but not certain eventuality), this conventional LRSO would probably be superior to existing conventional ALCMs in range, survivability, lethality, or some combination thereof. Hence, the termination of the LRSO would preclude the opportunity to reap whatever benefits might accrue from having this new missile.

Russian Advantages in Nonstrategic Nuclear Weapons

Open-source estimates suggest that Russia has 1,000–6,000 NSNWs of many types.[5] Russia is also modernizing these weapons, with a heavy emphasis on accurate, low-yield weapons that could combine substantial lethality with reduced collateral damage. In other words, these weapons are designed to be *usable*. Russian NSNWs, and other nuclear weapons potentially suitable for use in limited regional war, include bomber-launched ALCMs, submarine-launched cruise missiles (SLCM), and ground-launched cruise missiles (GLCM). Further, the new SSC-8 GLCM violates the Intermediate Nuclear Forces Treaty, according to the 2018 *Nuclear Posture Review* (*NPR*) and the State Department.[6]

Moreover, Russian nuclear doctrine has apparently become more aggressive since the Cold War.[7] Russia abandoned the Soviet pledge of "no first use" of nuclear weapons in the 1990s. Open-source articles indicate that under its current "escalate to de-escalate" strategy,[8] Russia may use nuclear weapons under a variety of conditions that are not well-known in the West. These accurate, low-yield weapons could inflict major military damage on other countries without causing tens of thousands of civilian casualties, at least if usage were restricted to military targets outside of urban areas. To quote page xi of the 2018 *NPR*: "Russia's belief that limited nuclear first use, potentially including low-yield weapons, can provide such an advantage is based, in part, on Moscow's perception that its greater number and variety of nonstrategic nuclear systems provide a coercive advantage in crises and at lower levels of conflict. Recent Russian statements on this evolving nuclear weapons doctrine appear to lower the threshold for Moscow's first use of nuclear weapons."

By contrast, current US NSNWs are limited to unguided bombs carried by nonstealth short-range fighters at several bases in North Atlantic Treaty Organization countries. These aircraft have questionable survivability against modern air defenses and provide limited geographic coverage without aerial refueling, which is feasible only in safe airspace. The bases are also vulnerable to preemptive attack without improved defenses, especially against cruise missiles. Hence, current US NSNWs probably do not provide survivable, proportionate retaliatory options to limited Russian use of low-yield nuclear weapons, so improved US capabilities are needed, such as better NSNWs, improved regional capabilities for strategic delivery vehicles, conventional prompt strike (as an adjunct to NSNWs), and/or better defenses for NSNWs. To again quote page xi of the *NPR*: "To address these types of challenges and preserve deterrence stability, the US will enhance the flexibility and range of its tailored deterrence options. . . to include low-yield options."

US options will eventually evolve beyond unguided bombs on nonstealth fighters. The B61-12 is under development for use by the B-2, F-35A, F-15E, and B-21. The B61-12 will be more accurate than current US nuclear bombs, but the F-15E has a poor ability to deliver bombs against heavily defended targets, and even the F-35 may have survivability issues against advanced air defenses in the future. Bombers coming from the US can be used in a limited regional nuclear war, but the B-2 may have survivability issues without standoff weapons, and the B-52 lacks survivability against modern air defenses, so it relies on the ALCM. At present, the ALCM may possibly provide a "good enough" response option, but the missile will be gone by about 2030 due to structural fatigue issues.

If fielded, the LRSO likely will be more survivable than the ALCM, due to major advances in technology since the ALCM was developed, and it has the potential for improved yield–accuracy combinations. Information on the LRSO's yield options and accuracy is not publicly available, but analyses done by the Johns Hopkins University Applied Physics Laboratory (JHU/APL) indicate that a nuclear weapon with a yield in the 1- to 10-kiloton range and a circular error probable (CEP) in the 50- to 100-foot range would be highly lethal against almost all point targets.[9] With CEP values of 50 feet or less, subkiloton weapons can also be effective against many, or perhaps most, targets. To illustrate this phenomenon, the figure shows the probability of kill, as a function of CEP, for weapons of three parametrically varied yields against a target with a hardness of 100 pounds per square inch (psi), which may be appropriate for a nonburied or slightly buried weapon storage bunker.[10]

Of course, the extent to which a US nuclear response is proportional or escalatory depends greatly on the nature and location of the target selected, and the population density around the target, and not just the characteristics of the US weapon employed. Nevertheless, accurate, low-yield weapons would reduce collateral damage, relative to higher-yield weapons, while still achieving major effects on the intended target. These weapons could enhance the credibility of US response options, with a favorable impact on the ability to deter adversaries from engaging in the limited use of nuclear weapons.

Moreover, should the US decide to field new NSNWs, it might be possible to leverage the LRSO for this mission, and LRSO termination would eliminate the possibility for such a spin-off weapon. For example, the National Defense Authorization Act for Fiscal Year 2018 directs the development of a dual-capable GLCM with a maximum range between 500–5,500 km, in response to Russia's fielding a new GLCM that violates the Intermediate Nuclear Forces Treaty.[11] The easiest way to field a nuclear GLCM might be to add a boost motor to the LRSO to allow the launch of the cruise missile from a ground vehicle.[12] If the LRSO has a conventional variant, then a ground-launched LRSO would fulfill the intent of the legislation. If the LRSO does not have a conventional variant, then it would be necessary to develop two GLCMs or to have the new GLCM be single-role. It might also be possible to integrate the LRSO—possibly with modifications to reduce its range—on the F-15E and the F35A.[13] Finally, the 2018 *NPR* directs the development of a nuclear SLCM. The use of an LRSO derivative on submarines is more speculative than use as a GLCM or on fighters, but cannot be ruled out at present.

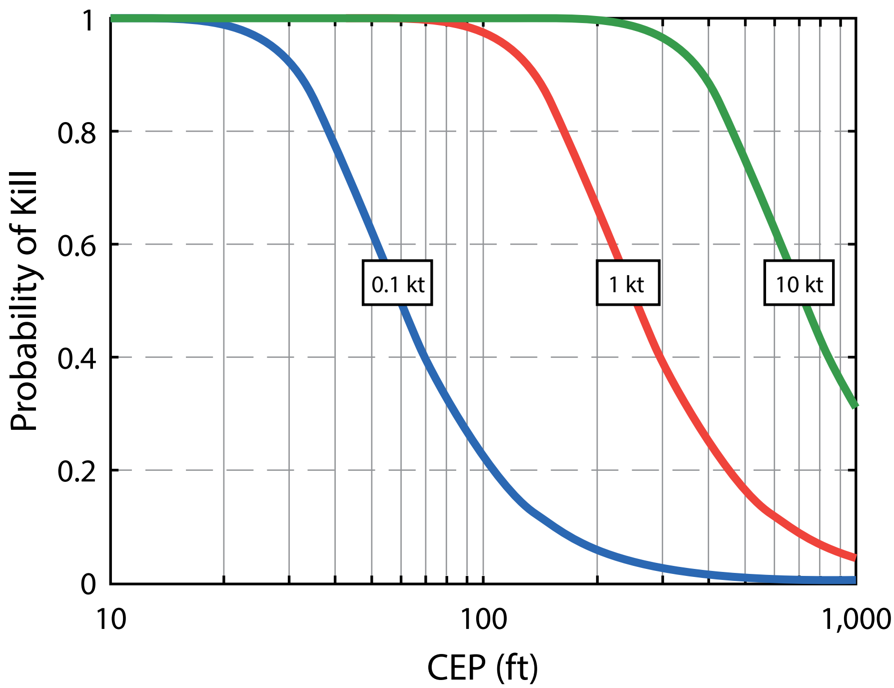

Figure. Probability of kill versus CEP for a target with a hardness of 100 psi. Note: *x-axis*=accuracy of weapon (in feet), as measured by CEP; *y-axis*=probability of destroying the target. Each curve represents a warhead of the indicated yield (range of 0.1–kilotons), with a reliability of 100 percent. (Reprinted from the Johns Hopkins University Applied Physics Laboratory.)

Thus, within the program of record, the LRSO will probably be the best US nuclear weapon in terms of the ability to provide a survivable, proportionate response to a Russian attempt to exploit its advantages in "usable" nuclear weapons. US possession of such a response option might help deter Russian use of accurate, low-yield nuclear weapons in a previously conventional war. The LRSO also has potential for spin-off use as an NSNW, which could further enhance US flexible response options.[14]

Other Issues Pertaining to the LRSO

This section deals with two topics: cost and various open-source arguments against the LRSO.

The LRSO is too expensive. Cruise missiles tend to be inexpensive in comparison to submarines, large ballistic missiles, or major combat aircraft. The table quantifies this in a rough manner, by bounding development and procurement costs for an entire force of new cruise missiles versus comparable figures for a new ICBM, a new bomber, and a new SSBN. The table suggests that canceling the LRSO would result in only a minor percentage reduction in the cost of the nuclear modernization program (2 percent of total nuclear costs, according to the Congressional Budget Office), or even of the bomber portfolio.[15]

Table. Order of magnitude costs for several types of nuclear systems

System	*Development cost*	*Unit cost*	*Number needed*	*Total cost*
Cruise missile	$3–6B	$4–8M	500–1,000	$5–14B
ICBM	$15–25B	$40–60M	500–600	$35–61B
Bomber	$15–30B	$500–700M	100–150	$65–120B
SSBN	$10–20B	$5–6B plus	10–13	$60–100B

Source: *JHU/APL*

Note: Costs are approximate and do not include infrastructure costs (which could be large at the ICBM bases) or operating costs (which tend to be large for SSBNs and bombers, but low for cruise missiles). The costs for the nuclear cruise missiles and the ICBMs include a rough estimate of the number of missiles procured for routine annual flight tests.

The LRSO is not needed because the overall need for US nuclear weapons is declining. *US conventional superiority implies that the US can get by with many fewer nuclear weapons and fewer types of nuclear weapons.* Assessing the validity of this argument would be a major endeavor. For the purposes of this article, it may suffice to say that the recent heavy Russian emphasis on NSNWs and general nuclear modernization, and the nuclear build-up by North Korea, cast doubt on this idea. Moreover, this assertion could also be used to argue against other elements of the US nuclear modernization effort.

The LRSO is destabilizing. *The LRSO offers the potential for a no-warning decapitation strike and, as long as the US has nuclear cruise missiles, an adversary might mistake a conventional cruise missile attack for a nuclear attack.* This argument has some merit, but it is not unique to the LRSO. Further, this also implies that no country should have either nuclear cruise missiles or highly stealthy nuclear-capable aircraft, because such aircraft also offer the potential for a no-warning decapitation strike. We are not convinced that real US aircraft will provide such a no-warning decapitation capability, but some potential adversaries may indeed fear that the LRSO and stealth bombers are destabilizing, and this could be a legitimate source of concern regarding nuclear stability. However, fully acting on this concern would require a major reshaping of the US nuclear modernization effort (LRSO cancellation plus elimination of nuclear capability for the B-2, F-35A, and B-21), possibly combined with the early retirement of the AGM-86 ALCM. Unfortunately, moving away from the LRSO and stealthy nuclear-capable aircraft in this manner would further reduce US flexible deterrence options and exacerbate US disadvantages relative to Russia in nuclear weapons that are useful in a regional context. In other words, the disadvantages of trying to accommodate this possibly legitimate concern are too severe to accept.

If the B-21 needs the LRSO in the nuclear role, the B-21 should be canceled. This point is tangential to the need for the LRSO per se, but the argument is designed to place the LRSO in direct competition for funding with the B-21 bomber—a key national priority. The B-21 is being developed primarily for conventional war, which involves striking many thousands of targets, and it would likely be cost-prohibitive to rely on cruise missiles launched from nonstealthy aircraft for destroying thousands of targets. In addition, conventional war generally involves a protracted air-defense suppression campaign, and it is not necessary to be able to strike all targets while enemy defenses are intact. Hence, if the B-21 needs to use cruise missiles for a few days at the start of a war, this is not a severe drawback. The B-21 has only a secondary nuclear mission. The nuclear mission for bombers involves striking no more than a few hundred targets, and it is essential to be able to carry out this mission against advanced, fully intact air defenses without the benefit of support from radar-jamming aircraft. Hence, while it might be desirable for the B-21 to rely exclusively on direct-attack weapons in the nuclear role in the 2030s and beyond, reliance on the LRSO against some targets in the nuclear mission is not a major drawback in terms of the actual role of the B-21 in US strategy.

Killing the LRSO could help lead to a global ban on nuclear cruise missiles.[16] Such a ban would require extremely intrusive inspection procedures to verify compliance. The US, Russia, and China all have large inventories of conventional cruise missiles, and a conventional cruise missile is typically suitable for carrying a nuclear warhead. Consequently, the potential conventional–nuclear ambiguity could lead to a ruinous breakout where a large, and supposedly purely conventional, inventory of cruise missiles turns out to contain nuclear weapons. In addition, Russia is producing modern nuclear cruise missiles of several types. Consequently, it is extremely unlikely that Russia would agree to eliminate these weapons in exchange for US cancellation of a single program that is far away from IOC and that faces significant opposition within the US.

Conclusions

There is a solid basis for proceeding with the LRSO program, for several reasons. First, the US needs the full triad of bombers, ICBMs, and SLBMs. Second, the LRSO is critical to the long-term viability of the bomber force in the nuclear role. Without the LRSO, the US will have a triad on paper, but perhaps not in any meaningful sense, in 2035. Also, if there is a conventional variant of the LRSO, this weapon would enhance bomber utility in conventional war. Finally, Russia has major advantages over the US in NSNWs and in accurate, low-yield, survivable nuclear weapons. While it is not certain that better US nuclear weapons are necessary for dealing with this situation, the LRSO would probably be the best currently funded US nuclear option for deterring such nuclear usage by Russia or responding to an actual limited Russian attack using accurate, low-yield weapons. Further, the LRSO has the potential for spin-off use as an NSNW, which could further enhance US flexible nuclear response options and US abilities to deter the limited first use of nuclear weapons by adversaries. ✪

Notes

1. Examples include: Dianne Feinstein and Ellen O. Tauscher, "A Nuclear Weapon That America Doesn't Need," *New York Times*, 27 June 2016, https://www.nytimes.com/2016/06/18/opinion/a-nuclear-weapon-that-america-doesnt-need.html; William J. Perry and Andy Weber, "Mr. President, Kill the New Cruise Missile," *Washington Post*, 15 October 2015, https://www.washingtonpost.com/opinions/mr-president-kill-the-new-cruise-missile/2015/10/15/e3e2807c-6ecd-11e5-9bfe-e59f5e244f92_story.html?utm_term=.4675c966b34d; Kingston Reif, "Overkill: The Case Against a New Nuclear Air-Launched Cruise Missile," *Arms Control Association Issue Brief* 7, no. 13 (19 October 2015), https://www.armscontrol.org/Issue-Briefs/2015-10-19/Overkill-The-Case-Against-a-New-Nuclear-Air-Launched-Cruise-Missile; Stephen Young, "Kendall's Telling Mistake on the LRSO," *All Things Nuclear* (blog), 4 May 2016, http://allthingsnuclear.org/syoung/kendalls-mistake; Cora Henry and Noah Williams, eds., "Policymakers Condemn New Cruise Missile," Ploughshares Fund, 21 June 2016, http://www.ploughshares.org/issues-analysis/early-warning/policymakers-condemn-new-cruise-missile; and Steven Pifer, "Cancel the Long-Range Standoff Missile," *Order from Chaos* (blog), Brookings Institution, 28 June 2017, https://www.brookings.edu/blog/order-from-chaos/2017/06/28/cancel-the-long-range-standoff-missile/.
2. US Government Accountability Office (GAO), *Columbia Class Submarine: Immature Technologies Present Risks to Achieving Cost, Schedule, and Performance Goals* (Washington, DC: GAO, December 2017), https://www.gao.gov/assets/690/689133.pdf.
3. This is not an argument against intercontinental ballistic missiles (ICBM). In a non-Russian scenario, the US could rely on bombers, ship, submersible, ballistic missile, nuclear-powered missiles, and nonstrategic nuclear weapons (if applicable), while keeping ICBMs as a strategic reserve for deterring Russia later.
4. The president's FY 2019 Federal Budget proposes to retire the B-2 Spirit shortly after the B-21 Raider becomes operational. If this proposal—which will likely be very controversial—is enacted, then the question about the B-2's need for the Long-Range Standoff Weapon is moot. Our discussion is based on the assumption that the B-2 will still be involved in the nuclear role in the early 2030s.
5. The article by Hans Kristensen and Robert Norris, "Russian Nuclear Forces 2016," *Bulletin of the Atomic Scientists* 72, no. 3 (2016): 125–34, estimated the number at 2,000, https://thebulletin.org/2016/05/russian-nuclear-forces-2016/. The report by Amy Woolf, *Nonstrategic Nuclear Weapons* (Washington, DC: Congressional Research Service, 21 February 2017), estimated the number at 1,000–6,000.

6. *Nuclear Posture Review* (Washington, DC: Office of the Secretary of Defense, February 2018), https://media.defense.gov/2018/Feb/02/2001872886/-1/-1/1/2018-NUCLEAR-POSTURE-REVIEW-FINAL-REPORT.PDF. The statement about the SSC-8 is on page 10.

7. Mark B. Schneider, "Escalate to De-escalate," *Proceedings Magazine* 143, no. 2 (February 2017): 1368, https://www.usni.org/magazines/proceedings/2017-02/escalate-de-escalate.

8. *Escalate to de-escalate* is a Western term that may be derived from the title of a June 1999 article in the prestigious Russian journal *Military Thought*. The title of the article was "The Use of Nuclear Weapons to Deescalate Military Operations."

9. Open-source articles (on *Wikipedia*, for example) attribute yield options in the 1.5 to 10 kiloton range to several US nuclear warheads.

10. National Research Council, *Effects of Nuclear Earth-Penetrator and Other Weapons* (Washington, DC: The National Academies Press, 2005: 30–50), https://www.nap.edu/read/11282/chapter/6.

11. This treaty bans the deployment or flight testing of ground-launched ballistic missiles and cruise missiles, nuclear or conventional, with a maximum range of 500–5,500 km. According to the State Department and the 2018 *Nuclear Posture Review*, Russia has fielded a cruise missile, the SSC-8, which violates the Intermediate Nuclear Forces Treaty. The State Department and the *Nuclear Posture Review* did not specify the exact range of the Russian missile, nor did they say whether it is for a nuclear, conventional, or dual role.

12. The Long-Range Standoff Weapon (LRSO) is designed to be launched from an aircraft, a technique that does not subject the missile to high acceleration. It would be necessary for the boost motor to get the LRSO above stall speed without exceeding the acceleration limits for the missile. This might or might not be easy. In the submarine-launched cruise missile role, it would also be necessary to investigate whether an LRSO could survive being pushed through water. If not, a submarine would have to come to the surface to launch a naval LRSO, or the naval LRSO might be restricted to use on surface ships (which are less survivable than submarines).

13. The use of the LRSO as a ground-launched cruise missile would violate the Intermediate Nuclear Forces Treaty if the range of the LRSO exceeds 500 km, which is highly likely. If New Strategic Arms Reduction Treaty (START) limits and counting rules remain in force indefinitely, then LRSO integration on fighters would cause those fighters to count against New START limits if LRSO, or an LRSO derivative for fighters, has a range exceeding 600 km. (The current AGM-86 Air-Launched Cruise Missile has a range of about 2,300 km, so it is likely that the planned bomber version of the LRSO has a range greatly exceeding 600 km, according to Gareth Jones, *Janes 360*, 10 April 2018, https://www.janes.com/article/79170/usaf-to-launch-lrso-and-b-52-integration-in-2019. Carriage by ships or submarines would not face any arms control issues but might be more technically challenging than usage on land or by fighters.)

14. The *Nuclear Posture Review* concluded that flexible US nuclear response options, including options beyond the current program of record, are essential for deterring adversaries from engaging in the limited first-use of nuclear weapons. However, additional analyses may be warranted on whether US advantages in conventional forces, possibly augmented by improved capabilities that are not yet in the program of record, could fill this deterrence role or whether US advantages in conventional forces and missile defense would merely incentivize enemy first-use of nuclear weapons.

15. For example, see *Approaches for Managing the Costs of U.S. Nuclear Forces, 2017 to 2046*, Congressional Budget Office, 31 October 2017, https://cbo.gov/publication/53211. This paper estimated that the LRSO accounts for 2 percent of planned nuclear expenditures in 2017–46.

16. For example, see Reif, "Overkill;" and Aaron Mehta, "Democrats Renew Attack on New Nuclear Cruise Missile," *Defense News*, 8 March 2017, https://www.defensenews.com/space/2017/03/08/democrats-renew-attack-on-new-nuclear-cruise-missile/.

Dr. Dennis Evans

Dr. Evans (PhD, University of Virginia) is a member of the senior professional staff at Johns Hopkins University Applied Physics Laboratory (JHU/APL). Before joining the JHU/APL in June 2013, he was with the Department of Defense from 1982 through May 2013. For the last 18 months of his government career, he was head of the Tactical Air Forces Division in the Office of the Secretary of Defense Cost Assessment and Program Evaluation (OSD CAPE). Before moving to the Tactical Air Forces Division, Dr. Evans was head of the Strategic, Defensive, and Space Programs Division in OSD CAPE from 2003–11. He was an analyst in the Strategic, Defensive, and Space Programs Division from 1994–2003 and worked for the US Army National Ground Intelligence Center from 1982–94.

Dr. Jonathan Schwalbe

Dr. Schwalbe (PhD, Northwestern University) is a member of the senior professional staff and a program manager in the JHU/APL Force Projection Sector, a position he has held since 2013. He has managed projects with scopes ranging from nuclear force structure, strategic stability, nuclear weapon effects, and rapid prototyping of flight hardware within the strategic deterrence mission area. Before joining JHU/APL, Dr. Schwalbe was a member of the senior staff at the MITRE Corporation and a national research council postdoctoral fellow in the National Institute of Standards and Technology Materials Science and Engineering Laboratory.

Science and Technology Enablers of Live Virtual Constructive Training in the Air Domain

Dr. Christopher Best, Defence Science and Technology Group
FLTLT Benjamin Rice, Royal Australian Air Force

Preface

Training is an essential component of military capability. In the air domain, the history of Exercise Red Flag provides an illustration of the critical role of training in enhancing war-fighter effectiveness. Red Flag evolved as a response to investigations that were conducted following the war in Vietnam. Those investigations revealed that many USAF pilots were not well prepared for some elements of real-world combat such as dissimilar aircraft tactics and potent surface-to-air threats. They also revealed that an operator's chances of survival in combat substantially grew after they had participated in about 10 missions characterized by the presence of such threats. Red Flag was conceived as a means of providing operators with their first realistic combat missions in a training environment that was relatively safe but also representative of real-world conditions. Since its inception, Red Flag has become known as the world's premier air-combat training event and the benefits of the lessons learned during Red Flag have been realized in combat operations.[1]

Live-flying exercises such as Red Flag can provide excellent learning opportunities. However, they are expensive and logistically challenging. Environmental, regulatory, and safety constraints also place limitations on the kinds of learning experiences that can be provided during live training. Simulation provides a means by which to address some of these shortcomings. Since the 1990s, significant programs of research and development across coalition nations demonstrated that similar training benefits can be obtained by connecting distributed simulation systems.[2] Large networks of simulators are now used regularly to provide complex and realistic training for air combat. Recently, attention has turned to the possibility of integrating live aircraft into simulation networks. This has led to a great deal of discussion about the importance, potential benefits, and underpinning science and technology of live-virtual-constructive (LVC) integration.

Introduction

LVC integration refers to the use of three different kinds of systems to generate operationally realistic scenarios for training and experimentation. The *live* component of an LVC federation typically includes operational platforms, real mission systems, and personnel who are trained in their use. The *virtual* component includes similarly trained personnel and human-in-the-loop simulation systems that represent the capabilities and interfaces of operational systems in a manner that affords real-time interaction. These are often referred to simply as simulators. The *constructive* components of an LVC federation are those that represent the capabilities and behavior of operational platforms, systems, personnel, or organizational units as computer-generated entities whose actions are determined by predefined scripts, rule sets, or adaptive behavioral models.[3]

With respect to training, what distinguishes LVC from concepts such as Distributed Mission Training, Distributed Mission Operations, and Mission Training through Distributed Simulation is a specific emphasis on the integration of live platforms.[4] The use of integrated live, virtual, and constructive systems for training is expected to provide a range of benefits, such as: (1) enhancing the training outcomes obtained from live flying, (2) enabling the generation of scenarios of sufficient scale and complexity to exercise fifth-generation capabilities fully,[5] (3) augmenting existing training ranges to provide electronic and cyber warfare effects, (4) better supporting the large footprints of modern sensors, networks, and weapons, and (5) allowing new platforms to be exercised in a secure environment so as not to reveal the sensitive aspects of their capability.[6]

Despite the emphasis that is typically placed on the integration of live platforms in LVC, we believe there are several reasons to question the specific utility of the live component. For example, while it is almost certainly true that some skills are best learned during live training (e.g., those relating to the physical aspects of high-G fighter maneuvers), we are not aware of any analysis demonstrating that the augmentation of live training with virtual and constructive threats or electronic, and cyber-warfare effects, for example, increases the effectiveness or efficiency of training for *those particular skills* to an extent that would justify the significant investment that would be required. Also, as the scale and complexity of exercises grow, so do the constraints on live training associated with the requirement to maintain safe aircraft separation. This can lead to artificialities in live training. Furthermore, it is not clear how any solution that would enable the generation of scenarios of sufficient scale and complexity to properly exercise fifth-generation capabilities in the live environment would not also present problems associated with revealing sensitive aspects of those capabilities. And finally, if representing cyber and electronic warfare effects and exerting influence over large geographic areas are key objectives of training, it does not necessarily follow that the integration of live platforms provides a better solution than improved virtual and constructive training capabilities.

In light of these issues, we propose a reconsideration of the emphasis that has typically been placed on live integration in LVC training for the air domain. Specifically, we propose that the benefits of integrating live, virtual, and constructive systems may not arise as a direct result of the inclusion of live platforms or the augmentation of live training per se, but rather from the additional scope that LVC integration could afford trainers to represent friendly and threat entities and effects using *whichever* kinds of systems are most useful and practical, given their desired outcomes and the resources they have at their immediate disposal.[7] This flexibility is important not just because it could enable trainers to exercise their preferences, but also because in situations characterized by resource constraints or high operational tempo, the ability to choose between live, virtual, and constructive systems could mean the difference between being able to provide high-end training and not being able to do so. This article next examines the implications of this perspective for LVC capability development.

The Role of Science and Technology

While some of the components required for LVC integration in the air domain already exist, a great deal of development will be needed to make the most of the capability.[8] Science and technology have a critical role in helping the military to realize the potential of emerging capabilities and concepts of operation such as LVC integration.[9] To effectively align science and technology support it is necessary to have some concept of how LVC technologies are likely to be used as well as how, in combination with other concepts or technologies, they could lead to new opportunities.[10]

The conceptualization of LVC integration as a means of affording greater flexibility in the design and delivery of training may assist in: (1) clarifying the role and importance of live integration, (2) defining a developmental trajectory for the capability, and (3) aligning science and technology support to capability development. This concept suggests that the goal of LVC capability development should be to provide a broad range of options for representing friendly and threat entities and effects, thereby enabling trainers to exercise maximum flexibility in tailoring the design and execution of training events to desired outcomes and available resources. In turn, this goal suggests two roles for science and technology, which are to (1) expand the range of options that are available, and (2) help inform the choices trainers make about the use of those options.

In this article, we explore the consequences of this conceptualization with a specific focus on LVC training in the air domain and with consideration for how the combination of a range of technologies could support transformations in training capability. We do this by drawing out the details of three potential use cases for LVC integration and considering the science and technology challenges each presents. Each use case builds on those preceding it in terms of the degree of flexibility it offers to trainers. These use cases are not intended to be exhaustive or mutually exclusive but by highlighting the need for a significant amount of research and development across a wide variety of disciplines, we believe they help to clarify the requirements for science and technology support and could serve as the foundation for more detailed planning.

Use Case One: Large-Scale LVC

The importance and likely impact of LVC integration for training are often thought of in terms of broadly defined future use cases that serve to illustrate how a mature capability could be employed. One such use case that we will refer to as *large-scale LVC* provides a suitable starting point because it represents a straightforward extension of existing training practices. We use the term *large-scale LVC* to refer to the use of secure, wide-area networks to connect many diverse, geographically-distributed LVC systems to bring together large numbers of personnel to participate in complex exercise scenarios.

There is little doubt of the value of preparing personnel to operate as members of a large, integrated force in complex mission environments.[11] Existing large-force employment exercises such as Pitch Black, Talisman Sabre, and Red Flag can provide valuable learning experiences. It is possible that integrating LVC elements into large exercises could enable these experiences to be delivered just as effectively, while also reducing logistical costs and enabling more complex scenarios to be generated than would be possible using live assets alone. However, even this straightforward vision of LVC integration presents many science and technology challenges.

The Science and Technology Challenges of Large-Scale LVC

Large-scale LVC represents an extension of live exercise practices that takes advantage of emerging connectivity between live, virtual, and constructive systems.

Although connectivity between virtual and constructive systems is relatively well understood, many fundamental science and technology challenges remain in relation to establishing common, interoperable, and verifiable models of the full range of modern platforms, sensors, and weapons as well as effects such as weather and cyber and electronic warfare. LVC integration presents a particularly difficult challenge in relation to the verification and validation of such models. In part this is because interactions between systems can lead to a vast number of possible overall system states and the composition of LVC federations is unlikely to be stable over extended periods of time.[12] Nevertheless, accurate modelling of friendly and adversary systems, effects, and their interactions will be a critical driver of the realism of LVC training environments and therefore development in this area represents an important science and technology challenge.

Significant science and technology challenges also exist in relation to achieving secure and reliable integration of live platforms. To link live platforms with virtual and constructive systems in the air domain, infrastructure is required both on the aircraft and on the ground. Current solutions such as the P5 Combat Training System (Cubic Global Defence) involve the use of aircraft-mounted pods which enable the transmission and receipt of real-time air-combat parameters through encrypted communication channels. While these devices provide a baseline capability, methods for handling data at multiple levels of classification, dealing with bandwidth and range limitations, and integrating synthetic data with live aircraft systems are yet to be well established.

The challenges related to classification may prove to be particularly difficult in the context of large-scale LVC because they involve issues of policy as well as technology. Integrating platforms at multiple levels of classification requires so-called cross-domain solutions to guarantee that sensitive information is not passed inappropriately between platforms of relatively high and relatively low classification. Some products of this general kind are currently available. However, existing systems can be laborious to configure and manage and they typically operate by simply blocking data. Data diodes provide an example of this approach. These devices enforce a one-way flow of information; usually from systems at a low level of classification (the "low side") to systems at a high level of classification (the "high side"). While the simplicity of this approach is appealing, it introduces something of a paradox in relation to large-scale training. By ensuring that participants on the low side see little or nothing of what takes place on the high side, sensitive information can be protected. However, the extent to which such groups can be said to be training together, or that valid lessons can be expected to emerge from their interactions, is questionable. Methods for passing useful but declassified information to the low side have been trialed. However, much remains to be done to clarify how such approaches should be managed within exercises from the perspective of balancing security, realism, and training outcomes.

Development is also required in relation to safely and effectively integrating simulated data into live aircraft systems. Since the mission systems of most live aircraft do not enable the simulation of effects relating to virtual and constructive entities on their primary sensors, current techniques used to integrate live platforms typically involve passing datalink tracks. Research and development are required to allow on-board aircraft systems to be realistically and securely stimulated by external signals relating to virtual and constructive entities. Initiatives such as the Secure Live, Virtual and Constructive Advanced Training Environment (SLATE) project are attempting to resolve some of these issues to give live aircrew an experience similar to that which would be expected during a real battle.[13] Considerations related to safety of flight and negative learning will be critically important as these solutions develop, as will the security implications of opening gateways to aircraft sensors and mission systems.[14]

Beyond the challenges associated with the technical integration of live platforms, the large-scale LVC use case also highlights science and technology challenges related to human learning and performance. For example, as the number and diversity of exercise participants grows and as training scenarios grow in their scale and complexity, it becomes more difficult for trainers to ensure that all objectives are addressed and all learning points are identified. It is also difficult to design large-scale exercise scenarios that provide consistently beneficial training for personnel across a diverse range of operational specializations. Because of this, participants in current exercises often participate as role players or as so-called secondary training audience.[15] This can lead to the ineffective use of resources and missed opportunities for individual, team, and organizational improvement.

There are at least two points in the training development cycle that present opportunities for science and technology to help trainers extract greater benefits from large-scale LVC events.[16] The first is through advanced methods for aligning learning requirements with the design of training systems and exercise scenarios. To provide greater clarity in defining and addressing high-end training requirements, the Air Force Research Laboratory developed the Mission Essential Competencies framework (MEC).[17] MECs define the knowledge, skills, and developmental experiences required for operators to become fully combat-mission ready. MECs also characterize existing training environments and training gaps, which can help capability managers to target the investment of training resources more effectively. Emerging applications of the MECs hold promise for improving the design of large-scale training events. For example, MEC "crosswalk" methods aim to make it easier to identify and leverage opportunities for sympathetic training across different participant groups and MEC-based live-synthetic blend analyses aim to optimize the allocation of live, virtual, and constructive training assets.

The second point in the training development cycle where science and technology could have a positive impact on large-scale LVC is in the evaluation of training effectiveness and the provision of feedback. To ensure that all learning points are identified in large, complex scenarios, advanced data capture and analysis tools are required. Examples include tools for automatically identifying key mission states and state transitions in near-real-time, scoring critical mission performance parameters, and alerting exercise staff to significant occurrences as they unfold.[18] Advanced after-action review systems are also required to enable trainers to quickly and easily organize media-and-data-rich debriefs. Prototype systems of this kind have been fielded in activities like Exercise Black Skies.[19] However, science and technology challenges remain in relation to tailoring automated metrics to different training contexts, better supporting distributed debriefs, integrating information related to cyber and electronic warfare effects, and facilitating the use of training effectiveness data to guide iterative capability improvement.[20]

While large-scale LVC is likely to afford greater flexibility than existing live exercises, the scale that characterizes this use case could mean that some similar constraints will apply. For example, it may be difficult to bring large numbers of personnel and their systems together for LVC exercises due to scheduling and workload factors, even if they do not all have to travel to one location. Because of this, it may only be possible to conduct large-scale LVC exercises with approximately the same frequency as existing live exercises. Without the ability to iterate rapidly, the pace of LVC capability development is likely to be slow. Furthermore, if LVC exercises are conducted infrequently, the technology will do little to make high-end training experiences more readily available. Next we consider another use case for LVC integration that addresses some of these problems and provides even greater flexibility to trainers for choosing how to design and manage complex training events.

Use Case Two: Small-Scale LVC

A use case for LVC integration that addresses some of the practical problems associated with large-scale LVC entails the integration of LVC systems to add complexity to the training provided for a relatively small training audience. An example of this concept in the air domain could involve the use of LVC integration to present a scenario composed of a mix of virtual and constructive friendly and threat entities to a relatively small number of aircrew operating live or virtual platforms. This use case is distinct from large-scale LVC in that it emphasizes the use of LVC systems as a way to present operationally realistic scenarios, while also reducing the number of exercise participants, the ratio of role players and secondary training audience to primary training audience, and potentially the size of the exercise staff. To contrast with large-scale LVC, we will refer to this use case as *small-scale LVC*.

Because of its potential to have a smaller footprint in terms of personnel and platforms, small-scale LVC may have advantages, including: (1) a lower cost, (2) being achievable with greater frequency, and (3) enabling training to be designed in such a way that it targets the immediate learning needs of the smaller training audience. However, for the potential of this concept to be fully realized, additional science and technology challenges will need to be addressed.

The Science and Technology Challenges of Small-Scale LVC

The small-scale LVC use case relies on the use of realistic, constructive models of the behavior of friendly, neutral, and threat entities to facilitate reductions in the number of exercise staff and role players required to generate operationally-realistic scenarios. Models of this kind are often called computer-generated forces (CGF). Many existing commercial-and government-off-the-shelf CGF packages are interoperable, at least in principle, with other LVC systems through their use of standard networking protocols.[21] However, significant challenges remain to be addressed for these systems to deliver the degree of autonomy and behavioral sophistication that would be needed to substantially reduce the number of human role players while also maintaining or increasing the scale and complexity of training scenarios. This is particularly so in relation to the representations of friendly entities, which in an idealized case would demonstrate realistic tactical behaviors and also be capable of communicating and coordinating effectively with human training participants as teammates or even instructors.[22] A recent demonstration at the Google 2018 I/O Developers Conference provided a striking illustration of how advances in speech recognition and synthesis are making interaction with synthetic agents via natural language more useful and reliable.[23] However, challenges remain in the domain of modelling human decision making.

One potentially promising approach to improving the utility of CGFs involves the use of machine learning (ML) techniques to tune CGF behavior. It is possible that using ML to "train" CGFs on the basis of large numbers of simulation runs or recordings of demonstrated behavior may provide an effective adjunct to traditional approaches that involve hand-coding scripts and/or decision rules.[24] However, challenges exist in dealing with the labor-and-data-intensive nature of ML and with extending the applications of these techniques to complex task environments. Despite the positive outcomes of recent experiments in the domain of air combat,[25] most applications of ML have thus far been limited to relatively simple, constrained tasks. While the potential payoffs from science and technology in this area are high, a great deal more work is required.

If the behavioral sophistication of CGFs can be increased to the point that the replacement of large numbers of human participants is possible, this would present an opportunity to achieve gains in LVC training effectiveness through adaptive training (AT). AT refers to training strategies in which content is tailored to participants' aptitudes, learning preferences, or styles before training and adjusted in real time or at the end of each training session to reflect on-task performance.[26] There is evidence to suggest that AT is more effective than fixed training in many circumstances.[27] In current military training practice, it is the role of exercise controllers to modify scenarios based on their perception of the performance or workload of participants. However, when there are dozens or even hundreds of participants, modifications to scenarios that are made to tailor training to the requirements of some participants necessarily have an impact on others. This limits the utility of formal AT methods in large-scale settings. The small-scale LVC use case is likely to represent a more appropriate context for the application of adaptive training techniques.

AT methods that involve modifying training in real time (so-called "micro-adaptation") depend on measures of task performance as well as current and predicted future trainee states.[28] Therefore, the development of automated, near-real-time measures of operator and team state will be a key enabler of adaptive training in LVC. Promising approaches to monitoring team states in near-real time involve the capture and analysis of the dynamics of communication flows, gaze, postural regulation, and cardiac rhythms.[29] However, few of these techniques have been implemented in near-real-time or in direct support of training delivery in operationally-representative settings.

A small-scale LVC capability, incorporating solutions to the challenges described above, would provide a great scope for trainers to choose how to represent friendly and threat entities and to tailor training to required objectives and available resources. However, a way in which the scope of options could be expanded even further is captured in the third use case described below.

Use Case Three: Universal LVC

Teams are the fundamental building blocks of the military.[30] In many situations, learning to work as an effective team member during the planning and execution of complex missions is a key objective of training. In the air domain, personnel often work in close quarters with their teammates; for example, on board command-and-control platforms or in ground-based surveillance or air-traffic control roles. Much of the science and technology goal described in relation to large-and small-scale LVC above is to reduce the requirement for human role players in training. In the case of entities that are physically remote from the training audience, this can be achieved through the development of technologies such as CGFs and speech recognition and synthesis. However, for collocated team members, the processes of direct, interpersonal coordination involving visual and even tactile perception is critical. Given the conceptualization of LVC as a way of providing flexibility to trainers, it is meaningful to ask what is required to enable the substitution of collocated human teammates with realistic synthetic agents or representations of remote human participants? The answers to this question define a third use case, which we call "universal LVC."

The Science and Technology Challenges of Universal LVC

Advanced human-machine interfaces, including virtual reality, augmented reality, and haptic technologies, are likely to be key requirements for accurately representing the constellation of visual, auditory, and physical cues associated with face-to-face interpersonal coordination. While the availability of products—such as the Microsoft HoloLens and the HTC Vive—have recently made virtual and augmented reality more accessible, there remain significant challenges associated with improving the resolution, field-of-view, and portability of these devices, as well as making them comfortable and safe to use for relatively long periods of time.

In some situations, the development of haptic technology will also be required to simulate physical interactions with; synthetic teammates, representations of remote, live teammates, and shared virtual objects. Using a combination of motion tracking and force feedback to provide haptic interfaces dates back to the 1960s. However, only relatively recently have these technologies delivered useful, believable interfaces at an affordable cost.[31] An example of promising recent developments in this area is the HaptoClone system, which allows users to "touch" virtual copies of objects from adjacent workspaces.[32]

While improvements in display technologies will assist in representing remote human teammates, much more remains to be done to support realistic interactions with synthetic entities. Recently, significant progress has been made in the representation of human bodies and faces via computer graphics and in the face and body tracking technologies required to reproduce human behavior. Now synthetic avatars can mimic the behavior of human role players, more or less in real-time[33] However, long-term challenges remain in relation to taking human role players out of the loop and driving realistic avatar behavior using constructive agents.[34] Just as an accurate understanding of the performance of real sensors and weapons is necessary for simulating those systems, the processes of interpersonal coordination during learning and task execution must be well understood before it is possible to represent them accurately using synthetic entities. The research literature on team effectiveness—and particularly that on virtual teams—provides good starting points for science and technology in this area. This research highlights the multiplicity of cognitive, behavioral, and affective factors underlying team coordination processes, the importance of subtle behavioral cues in facilitating effective teamwork, and the effects that electronic media can have in disrupting those cues.[35]

If the science and technology challenges associated with supporting realistic, face-to-face interactions with virtual and constructive entities can be overcome, along with the challenges described earlier in relation to large-and small-scale LVC, the resultant capability could provide trainers with tremendous flexibility in designing and managing training. Ultimately, this could afford trainers the ability to choose to represent almost any role, platform, or system—whether friendly or adversarial, collocated or remote—using a live, virtual, or constructive entity. Training could be tailored to address a wide range of learning requirements and practical constraints and opportunities. This would represent a truly game-changing transformation in training capability. We refer to this use case—which is centered on the idea of providing maximum flexibility in the use of LVC systems for training—as *universal LVC*.

Given the relative costs of including LVC systems in training, one might imagine that if almost any option were available, it could be difficult to justify choosing some options over others (e.g., live over virtual or constructive). Nevertheless, it's probable that the integration of systems and personnel across LVC domains will likely be required for the foreseeable future. For example, it is clear that there will always be some knowledge and skills best learned in the live environment. Undoubtedly, there will always be certain learning experiences using human participants as role players that will be more effective, reliable, or realistic than using CGFs. Similarly, the lack of suitable models—of particular roles, systems, or platforms—might arise during training with joint or coalition partners, or when the development of tactics outstrips the pace at which models can be updated or validated. Or it may be desirable to bring together particular individuals to take advantage of opportunities for synergistic training, mentoring, mission rehearsal, or to build trust and cohesion within teams. In these situations, the promise of a concept like universal LVC lies not in the advantages of one particular kind of system over another, but in the flexibility that the integration of systems affords trainers to deliver the training that is needed with the resources they have at their disposal.

The universal LVC use case is admittedly ambitious. Addressing the challenges required to achieve a capability of this kind would involve a long-term, multidisciplinary science and technology effort underpinned by enduring collaborative partnerships between the military, defense research organizations, academia, and industry. Nevertheless, we believe universal LVC represents a desirable and tractable long-term objective for LVC development and a logical goal state given our premise that the key benefit of LVC integration in training is to provide flexibility in training design and delivery.

Summary and Conclusion

The use of LVC integration for training is expected to provide a range of benefits in the air domain. This article has proposed a conceptualization of LVC integration as a flexible means of designing and delivering complex training. By describing three potential use cases for LVC integration, we have identified many areas of science and technology where challenges will need to be overcome to expand the range of options available to trainers and to help inform how options are selected. While these challenges are significant, it is our hope that the analysis presented in this article may serve as the foundation for the development of more detailed LVC science and technology plans. Ultimately, LVC science and technology will be crucial for enabling the military to fully realize the transformational potential of LVC integration. ✪

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Dr. Christopher Best

Dr. Best (PhD, BA, Deakin University [AU]) is a senior research scientist in the Australian Department of Defence, Defence Science and Technology Group Aerospace Division. His research interests include aerospace human factors, human perception and cognition, team effectiveness, simulation, and training. He is the Australian leader for international collaborative research programs in the areas of training and team performance measurement and the lead editor of the book *Fundamental Issues in Defense Training and Simulation*, published by Ashgate Publishing.

FLTLT Benjamin Rice

FLTLT Rice is the Royal Australian Air Force air liaison officer embedded within the Australian Department of Defence, Defence Science and Technology Group Aerospace Division. He has a background in airborne command and control, flying the E-7A Wedgetail, and ab-initio aviation instruction at the School of Air Warfare. In his current role, he provides specialist input into air warfare simulation development and training research programs.

Operation Vengeance

Still Offering Lessons after 75 Years

Lt Col Scott C. Martin, USAF

The spring of 2018 marked the 75th anniversary of the execution of the first high-value individual (HVI)/target of opportunity (TOO) operation by airpower in history. On 18 April 1943, 18 Army Air Corps P-38 Lightning fighters took off from an airfield on Henderson Island in the south Pacific Ocean, slated to target Adm Isoroku Yamamoto, the commander of the Japanese Imperial Navy. Based on the successful intercept of the admiral's itinerary via the codebreakers working at Station HYPO (also known as Fleet Radio Unit Pacific) in Hawaii, the US knew of Yamamoto's plans to visit the Japanese base at Bougainville Island in Papua, New Guinea. The US fighters, maintaining radio silence and flying low over the ocean to evade Japanese radar, successfully ambushed the two Japanese bombers and six escort fighters, shooting down both bombers, one of which held the admiral. With the loss of only one plane, the US managed to eliminate one of the top military commanders in the Japanese military and score a huge propaganda victory.

Dubbed Operation Vengeance, this World War II operation set the precedence for modern HVI/TOO operations. Some of the core questions for targeting an HVI, especially via air assets, facing US military personnel in 1943 still apply in 2018 and will most likely apply to planners in the future. At present, most of these HVI/TOO operations occur in environments where US military dominance, particularly air superiority, is not at risk. Yet, as the American military attempts to evolve its warfighting capabilities beyond the counterterrorism (CT) wars of the 2000s and move toward engaging peer/near-peer states, the core questions first faced in 1943 require answers for any chance of success with the HVI/TOO operation. Those questions are:

1. Can America successfully target an HVI where air superiority is not verified?
2. Can American forces obtain, utilize, and protect the vital intelligence necessary to achieve a desired effect on an HVI?
3. Can American forces plan and execute such an HVI operation within a constrained time frame?
4. Will America have a full understanding/assessment of the impact of targeting an HVI? Operation Vengeance proved that airpower could prosecute an HVI

target, but it also established lessons and criteria that current and future air planners and operators need to answer.

Can America successfully target an HVI where air superiority is not verified?

Since the start of the CT wars, air superiority, whereby the US has achieved "that degree of control of the air by one force that permits the conduct of its operations at a given time and place without prohibitive interference from air and missile threats," is all but a planning fact.[1] In truth, most operations against HVIs have air supremacy, which is "that degree of control of the air wherein the opposing force is incapable of effective interference within the operational area using air and missile threats."[2] In Afghanistan and Iraq, the area of responsibility (AOR) of most of the recent HVI operations, air supremacy is a constant, as all types of air coverage, from remotely piloted aircraft to fixed-wing aircraft, operate with freedom unencumbered by adversary threat capabilities. Recent operations in Syria, where there are more air defense capabilities from the Syrian regime and Russian air assets, fall under the guise of air superiority. While some of those assets, particularly the newer Russian equipment such as the Sukhoi Su-35 and the S-400 Triumf launch vehicle (SA-21 Growler), could pose a significant threat to air operations, the deconfliction between the respective forces enables the US to exercise air superiority over its desired AOR.[3]

For the US in April 1943, planners and fliers could not assume air superiority. While US forces had successfully driven the Japanese out of Guadalcanal in February 1943 and established Henderson Air Field, the Japanese still possessed the capability to threaten US air operations in that region of the Pacific. As the planners at Henderson Field started work in their headquarters building, known as "the Opium Den," they made their plans to target Yamamoto flying in a G4M "Betty" bomber.[4] The Betty possessed some self-defense capabilities—with a 1 x 20 mm cannon and 4 x 7.7 mm machine guns—but that was not enough to ward off fighters on its own. The more concerning fact would be the expected presence of fighter escorts. The Japanese Mitsubishi A6M Zero, while not the dominant fighter it was at the start of the war, still presented a significant air threat, with its legendary maneuverability and 2 x 20 mm cannon and 2 x 7.7 mm machine guns.[5] To attack the Japanese, the US went with the P-38, a twin-engine fighter with long-range and heavy firepower (1 x 20 mm cannon and 4 x 0.50 machine guns). The P-38 could successfully compete with its Japanese Zero counterpart in a dogfight, which other US fighters in the Pacific at that time could not.[6]

Yet, air superiority is more than just weapons. The US faced the daunting challenge of flying over Japanese-held airspace en route to Bougainville.[7] The Japanese maintained various radar and listening posts throughout the region, which could result in detection and a threat to the mission. At that time, US fighters did not have airborne radar, and thus, had to rely on navigation via charts and flight discipline.[8] If the P-38s ran into any trouble, they could not communicate for assistance, and even if they could, they couldn't expect additional support to arrive in a timely fashion. Given that most of the flying was over ocean, and the fighters had to fly barely 50 feet above the water to avoid Japanese detection, the US also ran the risk of running into a stray Japanese ship, which, armed with various antiaircraft weapons, could disrupt the planning and timing of the air operation.[9]

If the US entered into a conflict with a peer/near-peer today, the American forces would bring more capabilities to achieve air superiority. Advances in navigation, weaponry, communications, and overall battlespace awareness make the mission planning in the Opium Den seem prehistoric. Air-to-air refueling offers considerably more flexibility with the use of fighter aircraft, enabling more time for combat operations. The use of space-based assets and the evolution of cyber offer ways for American forces to track adversaries, as well as a more accurate and timely picture of target and threat movements for such HVI operations. This can also enable a faster and more accurate battle damage assessment (BDA) against the target.

However, the increase in technological advancements comes with its own set of vulnerabilities. Even with modern capabilities, the fog and friction of warfare can leave modern air planners and operators as uncertain about adversary threat activity and capabilities as in 1943. Additionally, American dependency on its space-based capabilities, while offering a decisive edge in air operations in Iraq and Afghanistan, may prove a critical vulnerability in an engagement with a peer/near-peer. Nations such as Russia and China continue to evolve their counterspace capabilities, and if the US found itself in an engagement with such a nation, the degradation—if not outright loss—of its space-based capabilities could seriously limit American air operations.[10]

Additionally, while the aviators in 1943 might have longed for radar, they likely would not have wanted to fight in an electronic warfare environment with jamming and electronic attacks disrupting radar and communications. Doctrinally, the US attempts to train to fight in a degraded environment but did not face many of those threats in the CT wars. With the shift toward countering "peer/near-peer" threats, the DOD stated a goal to counter what it sees as a significant vulnerability in future combat.[11] The potential for future engagements with technologically more advanced adversaries will likely grow in the future, so US aviators need the ability to operate in less-than-optimum conditions, especially when it comes to HVI/TOO operations.

Currently, few HVI operations occur in areas where air supremacy is not a given, but if the HVI in question was rated critically that American aviators needed to deal with significant air-to-air and surface-to-air threats, could American forces manage? This is not to say that American forces do not train to engage and defeat peer/near-peer adversaries in aerial engagements, but the US has few combat aerial engagements since 1991 to leverage for experience.[12] In 1943, the pilots selected for Operation Vengeance all possessed air-to-air combat experience against the Japanese.[13] While the US can consider itself fortunate not to have many significant air-to-air engagements in recent wars, the lack of combat experience is not a benefit. Planners and operators need to be mindful of the threats and challenges as the US shifts from the CT wars to potential engagements against peers/near-peer adversaries.

Can American forces obtain, utilize, and protect the vital intelligence necessary to achieve a desired effect on an HVI?

When dealing with the threat capabilities of an adversary to engage an HVI, intelligence is a critical component. For Operation Vengeance, the genesis of the operation sprang from an intelligence coup. For the duration of the war in the Pacific, the US possessed a significant advantage over the Japanese in the realm of signals intelligence. In particular, US cryptologists broke the Japanese military naval code—JN-25—in 1940.[14] It was through the efforts of these analysts, living in the basement of Commander in Chief Pacific Fleet Headquarters at Naval Station Pearl Harbor, Hawaii—Station Hypo—that the US leveraged its intelligence advantage to swing the critical Battle of Midway in June 1942.[15] Ten months later, that same office intercepted a message from a member of Yamamoto's staff, indicating his plans to visit the island of Bougainville on 18 April.[16] The intercepted itinerary provided an outline of the timing of his visit from his headquarters in Rabaul to Bougainville, as well as the mode of transportation, recommended uniform wear, and instructions for commanders on Bougainville.[17] Station HYPO worked feverishly to complete the intercept and translation of the message and finished on the night of 14 April 1943, leaving only a few days to authorize, plan, and execute such a mission.[18]

The planners targeting Yamamoto took advantage of the US military's decent understanding of the patterns and tendencies of the Japanese admiral. During the interwar years, Yamamoto spent multiple assignments in the US, attended Harvard from 1919–21, and returned in 1925 as a naval attaché in Washington, DC. While it gave Yamamoto the chance to learn more about a potential adversary, the US also came to learn about Yamamoto. People who worked with him noted that Yamamoto was a punctual person who maintained timelines and schedules, thus earning the nickname of the "On-Time Admiral."[19] Along with punctuality, Yamamoto's penchant for taking risks—from his love of gambling at card games or in operational planning, as seen at Pearl Harbor and Midway—further aided the planners because Yamamoto seemed unlikely to abort his risky flight to Bougainville. Thus, when the planners saw the time frame of when it would be best to try to intercept him (en route to the island), they felt confident that Yamamoto would make every effort to meet that schedule, regardless of the dangers.

In modern HVI operations, the study and long-term collection of Yamamoto's tendencies qualify as establishing patterns-of-life (PoL). PoLs call for an analysis of "the specific set of behaviors and movements associated with a particular entity over a given period of time."[20] Many of the HVIs in the CT wars drove US forces to establish PoLs in a condensed timeline. Obtaining information about Yamamoto's personal tendencies, such as his punctuality and his risk-taking nature, came through years of interaction and collection of biographic data. Yamamoto did not start World War II as a confirmed target for action; the knowledge and understanding gained in the years before the war served as a form of PoL, vital in the target development of HVIs. In Yamamoto's case, when the TOO arose after the intercept of his itinerary, the long-established understanding about his patterns saved the US military critical time in planning such a risky venture.

Few could argue about the changes in intelligence collection and analysis methods since Operation Vengeance. The basic requirements for intelligence have not changed, but now the availability and accessibility of information offer both advantages and disadvantages. What would the planners in 1943 have given to have access to the resources of 2018? Imagery of the airfields for the Betty flights, intercepts of communications devices, geolocation of planes based on transmission emanating from the plane all could have made the operation go smoother. Yet, what if the Japanese also had access to the same resources? What if the Japanese knew about the flights of P-38s leaving Henderson Field in near- real-time? While this was a possibility even in 1943, access to modern technology could see a real-time change to the flight plans of the two bombers, even up to their final approach to Bougainville.[21]

Leveraging and securing an intelligence advantage is a significant challenge in modern warfare. In 1943, the Japanese still did not accept that the US had broken their naval codes.[22] However, the Japanese periodically altered their ciphers and issued new codebooks two weeks before Operation Vengeance. However, due to logistical challenges, the codebooks did not make it to Rabaul and Bougainville. Had the Japanese managed to get the new ciphers out, it is unlikely the US could have deciphered the new codes in time for the 18 April mission.

Additionally, when word got out about how the US successfully engaged and killed Yamamoto, some of the reporting of the story offered potentially damaging insight into just how the US managed to execute the intercept.[23] As the men in the Opium Den started to plan the mission to kill Yamamoto, officials briefed the military personnel at Henderson Field that Australian coast watchers intercepted the itinerary that proved the basis for the mission.[24] Even as the Navy and US government cracked down on some journalists and some of the fliers involved for potential compromise of national secrets, the Japanese did not delve too deeply into the reporting.[25] The concern about the possible leaking of "special intelligence" dogged the US military since the victory at Midway, when within days of the decisive victory, driven as much by the success at Station HYPO, several US newspapers carried headlines that implied the Navy had advance information on the Japanese attack at sea.[26] In particular, the *Chicago Tribune* came under legal proceedings from the Navy, but eventually, the USN dropped the charges with the US intelligence advantage still maintained, however precariously.[27] The fear of another leak of US capabilities after Operation Vengeance terrified the Navy, with allies infuriated about the raid. So instead of receiving a hero's reception, the men who led the mission faced the wrath of an especially riled-up Adm William Halsey Jr.[28]

In modern times, there is a fine line between revealing too little or too much. Many point to Osama bin Laden, noting that after the 1998 cruise missile strikes that missed him by a couple of hours, he learned that the US could track his movements via personal communication devices.[29] Thus, he came to rely on human couriers, complicating targeting efforts against him.[30] HVIs in the CT wars attempted to limit their signatures, limiting mobile communication usages and reducing their public interactions with groups such as al-Qaeda resorting to human couriers for communication, a time- and resource-consuming effort to track by American forces.[31] Adversaries at the peer/near-peer level have greater resources for countering US intelligence efforts. Additionally, the multiple disclosures of classified capabilities in the past decade further complicate all types of operations, including HVI planning and execution.

However, the use of equipment on-board air assets is one area where modern forces far exceed their predecessors even if US forces found access to adversary operating environments limited/degraded. The P-38s used for this mission did not come equipped with cameras, even though there were models of that airframe used for such purposes. Nowadays, air assets, such as the F-16s that engaged Abu Musab al-Zarqawi in 2006, come equipped with a vast array of sensors that can aid in target engagement and initial postmission assessments. A major controversy about the Yamamoto operation centered on who exactly shot down the admiral's bomber. Initially, the US could only go on the word of the pilots engaged in the operation with no corroborating information. While the Japanese discovered the admiral's body a day after the engagement, they did not make a formal announcement until a month after his death. A faster processing capability of BDA in modern times, even in a degraded environment, is one advantage modern planners and operators can use in the execution of HVI operations.

Can American forces plan and execute such an HVI operation within a constrained timeframe?

One of the more remarkable aspects of Operation Vengeance centers on the timeline of the mission. By the time Station HYPO decrypted and translated Yamamoto's itinerary, and the Pacific Fleet chain of command determined that they could and would attempt to intercept Yamamoto, the aviators at Henderson Field had less than 48 hours to plan and execute this unprecedented mission.[32] While the Navy held overall command of Guadalcanal, the Opium Den at Henderson Field held representatives from the Army, Army Air Corps, and the Marine Corps. At first, the Navy planners sought a navy solution to this mission, debating whether to use a destroyer or frigate to try to intercept the admiral. That plan did not develop further, as it became more likely that the planners would have to make the intercept by plane. However, the expected range of the mission eliminated any available Navy air assets, thus, leaving the planners to turn to the P-38s. By the time the leadership at Henderson Field turned to the air intercept solution, the planners had less than 24 hours to develop and execute this short-notice mission.[33]

Once the mission planning began, despite the secrecy of the source material, the base gradually learned about the mission and the intended target. In the frantic hours to get the mission ready for execution, the Opium Den became crowded with an array of aviators and other military personnel seeking to be a part of the mission that would get the man who led the attack on Pearl Harbor.[34] Given the distance, timing, and threat concerns, the aviators faced a difficult task. To avoid detection, the fliers could not use their radios. Additionally, they needed to fly approximately 30 feet above the ocean to stay below known Japanese radar coverage.[35] Once at the target area, with only enough projected fuel for 10 minutes of combat time, the fliers could not spend much time waiting if the target was late.[36] Much had to go right and depended on matters outside of the planner's control. In this case, with the loss of only one plane, the Opium Den succeeded.

When it comes to mission planning and the execution of HVI operations, a lot has changed since 1943. The combined efforts of 1943 are codified today as a joint operation. The US armed forces rarely deploy into combat or any significant military operations as a single service, as some sort of joint command or joint task force gets set up to cover the planning and operational requirements of the mission. For air operations, the individual squadrons would still do mission planning for their specific assets, but some of the decisions that the planners at the Opium Den made would have been decided at a higher level. For example, where the planners at the Opium Den needed to decide what type of asset could support the mission (air or naval) and then when they decide on an air asset, they had to determine the optimum air asset. Today, those decisions happen at a higher echelon with the primary air apportionment occurring at the air operations center (AOC), where representatives from all the services can make inputs on planning and executing air operations in support of operations. Additionally, the AOC would resolve many of the concerns that the Opium Den planners had to deal with, such as the current threat picture. In some cases, it might have made the job of planning and executing the mission simpler for the Opium Den.

However, the additional changes can also bring their share of problems. There are significant vulnerabilities within the current system. The effectiveness of relaying information up and down the chain of command is only as strong as the interconnectivity between echelons. Systems issues, whether from latency or possible outside disruption, can severely hamper planning timelines, and for missions such as this, timing is critical. Additionally, the current military environment is far more complex and integrated than in 1943. The Opium Den planners only had to worry about their planes getting to the target, engaging, and getting back. Now, they would have to account for deconflicting with other assets, airspace restrictions, space-based capabilities, aerial refueling, integrating with other intelligence, surveillance, and reconnaissance assets to relay information/updates, and all of this while dealing with a dangerous and capable air adversary.

Along with deconflicting with other tactical and operational assets, air planners have to contend with the blessing and curse of a more interconnected command structure. In 1943, when the Pacific Fleet relayed its request to higher leadership in Washington for permission to execute the mission, and when the approval came back down the chain, the higher command left it to the planners to execute the mission. Part of that was the fact that communication methods for situational awareness lacked the capabilities that currently exist. Now, from the Situation Room in the White House to the respective combatant command headquarters, admirals and generals can observe—and at times direct—tactical missions in near real-time. Occasionally, it can help, as tactical planners can receive confirmation about command intent and approval in a rapid fashion. It can also lead to delays and claims of micromanagement, as one individual further up the chain can derail the success of the mission.[37]

Additionally, with more people in the know of a given operation, the greater the chance for some sort of compromise, which proved a significant concern in the post-Operation Vengeance euphoria. In the success of the bin Laden mission, many details leaked out shortly after the raid, to include the newer design of a helicopter that flew the men in the Abbottabad compound and the compromise of a human intelligence asset that aided in the location of bin Laden.[38] This highlights the dangers of too many people in the know of a given operation; what worked once may not be able to work again, as adversaries become familiar with newer tactics, techniques, and procedures.

While the technology and doctrine of planning and executing air operations evolved in the 75 years since Operation Vengeance, ingenuity and determination remain important for current time-sensitive mission planning. Given a task and pressing requirement, air planners and operators will work to come up with a solution. Could higher command deal with the lack of situational awareness they faced in 1943, especially if going after a target like Yamamoto? Not easily, but if the situation required it, they could adapt. The risks might be greater, but if command gives the approval and accepts those risks and the planners receive their guidance, they will do what they can to execute the mission.

Will America have a full understanding/assessment of the impact of targeting an HVI?

While there is a significant increase in the resources required and used for modern HVI operations, especially when leveraging airpower to support and execute the missions, there is still a classic question associated with any HVI: Why are we going after the target and after a successful engagement of that target, and what is the impact of that move? Killing or incapacitating key leaders can sometimes throw adversary forces into chaos. Many targeting strategies look to hit at the center of gravity for an adversary, and for a number of foes, it is leadership. In the case of Yamamoto, most viewed him as a key leader in the Japanese fight.[39] His innovative and aggressive style of command directed the Japanese Navy to its stunning defeat of the US Navy at Pearl Harbor and in subsequent engagements until Midway. Additionally, Yamamoto became the face of the Japanese military as far as most Americans were concerned. The alleged quote of Yamamoto "marching down the streets of Washington to dictate peace terms," combined with his role in the surprise attack at Pearl Harbor, made him the ultimate villain for many Americans.[40] While the US did not have a deliberate strategy or process for going after HVIs in World War II, the US military improvised quickly. There is some debate as to who ultimately authorized the strike, but it was a precursor to the processes of today, when certain levels of authority are given to decision makers about engaging a target, especially an HVI.[41]

However, the death of Yamamoto did not result in a significant collapse or change in the decline of the Japanese military. After Midway, the Japanese Navy never regained the offensive initiative, and while it still managed to score some tactical victories in the battle of Guadalcanal, it could not overcome the losses in men and materials. Yamamoto still inspired confidence from his subordinates and fear from his American counterparts.[42] Yet, it is unlikely he could have completely reversed the American offensive momentum. The Japanese Navy still fought on for two years after the loss of its commander. Perhaps if Yamamoto had been at the Battle of the Philippine Sea, nicknamed the "Great Marianas Turkey Shoot" or the Battle of the Leyte Gulf, some outcomes might have changed, but if he had lived, Yamamoto, the consummate card player, would come to see that he held a losing hand. Additionally, while it was a great morale boost for Americans to see the death of the man behind Pearl Harbor, it did not significantly alter American military actions in the Pacific.

Much like Yamamoto, one can question the impact of successfully targeting HVIs via airpower. In the CT wars, Air Force fighter assets (F-16s) delivered the coup de grâce on al-Zarqawi, the leader of al-Qaeda in Iraq (AQI).[43] It received international headlines as the US eliminated the most visible leader of AQI. Yet, much like Yamamoto, al-Zarqawi's death did not result in the immediate decline in the potency of AQI. Even when the US changed strategy in 2007, adding more US troops and increasing cooperation with Iraqi Shia and those tired of AQI, AQI did not disappear. Eventually, AQI evolved into the Islamic State in Syria and Iraq, which arguably became more powerful at its peak. It was important to try to eliminate the threat of al-Zarqawi, but the death or incapacitation of an HVI does not automatically mean that it will automatically lead to rapid glory.

Depending on the adversary, the targeting of HVIs via airpower can potentially achieve the desired effects. Against an adversary with a centralized command structure, the elimination of the top echelon or leaders can potentially lead to significant degradation of an adversary's fighting capacity, if not outright collapse. Concurrently, the elimination of an HVI could eliminate the main target, but sometimes, planners and operators may not be aware of the second- or third-order effects of such an action.

Conclusion

The targeting and prosecution of key individuals in warfare is an old concept, going back to the beginnings of armed conflict. Given that much of the fighting was within visible range, the targeting of key individuals happened right on the field of battle. However, as warfare evolved, key leaders found themselves moving farther away from the front lines. By World War II, advancements in radio and radar enabled key leaders to direct operations hundreds of miles away from the actual fighting. At Midway, Yamamoto's flagship never got closer than 300 miles of the main engagements, and a major reason for his travel to Bougainville was to engage directly with his fighting forces. Given those conditions, airpower proved the only way for the US to engage an HVI like Yamamoto.

Much of what transpired with Operation Vengeance reveals itself in modern HVI operations. The basic requirements of target development, via research, PoLs, focused and successful intelligence collection, and analysis, which all enabled the US military to make its plans against Yamamoto, still remain requirements for modern HVI operations. Planners and operators should account for threats to the mission, as well as determine the impacts of said operations. Additionally, given the perishable nature of most intelligence associated with HVIs, planners and operators should be ready to plan and execute on extremely short timelines. Determining the appropriate level for decision making to engage an HVI and acting decisively after receiving that information is also critical, as the decisiveness that Adm Chester W. Nimitz and his subordinates took in executing that mission remains a requirement for HVI operations today. ✪

Notes

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4. Donald A. Davis, *Lightning Strike: The Secret Mission to Kill Admiral Yamamoto and Avenge Pearl Harbor* (New York: St. Martin's Press, 2005), 237.
5. Maj Adonis C. Arvanitakis, *Killing a Peacock: A Case Study of the Targeted Killing of Admiral Isoroku Yamamoto*, School of Advanced Military Studies Class 2015-01, (Fort Leavenworth, KS: US Army Command and General Staff College, 2015), 22.
6. Ibid.
7. Davis, *Lightning Strike*, 234.
8. Ibid., 241.
9. Ibid., 243.
10. Aaron Bateman, "In Outer Space, the US is Vulnerable to China and Russia," *The Hill*, 20 July 2017, http://thehill.com/blogs/pundits-blog/defense/342992-in-outer-space-the-us-is-vulnerable-to-china-and-russia.
11. Jim Garamone, "DOD Must Train for 'Degraded' Environments," *DOD*, 9 February 2011, http://archive.defense.gov/news/newsarticle.aspx?id=62750.
12. John Stillion, *Trends in Air-to-Air Combat: Implications for Future Air Superiority*, Center for Strategic and Budgetary Assessments, 14 April 2015, 23, http://csbaonline.org/research/publications/trends-in-air-to-air-combat-implications-for-future-air-superiority.
13. Davis, *Lightning Strike*, 244.
14. John T. Wible, *The Yamamoto Mission: Sunday, April 18, 1943*, (Fredericksburg, TX: The Admiral Nimitz Foundation, 1988), 7.
15. Stephen Budiansky, *Battle of Wits: The Complete Story of Codebreaking in World War II* (New York: The Free Press, 2000), 16.
16. Davis, *Lightning Strike*, 222. The Japanese transmitted the message about Yamamoto's itinerary on 13 April 1943, eschewing recommendations to hand-carry the itinerary to Bougainville.
17. Ibid., 222.
18. Ibid., 227. Upon completion of the intercept, the officer leading the decryption/translation of the message exclaimed "We've hit the jackpot. This is our chance to get Yamamoto."
19. Ibid., 8.
20. The State and Future of GEOINT of 2017," United States Geospatial Intelligence Foundation, 2017, 24, http://usgif.org/system/uploads/4897/original/2017_SoG.pdf.
21. Davis, *Lightning Strike*, 242.
22. Budiansky, *Battle of Wits*, 319.
23. Joseph Conner, "Have You Heard?" *World War II* 31, no. 5, January–February 2017, 36.
24. Arvanitakis, *Killing a Peacock*, 11. The idea to attribute the intercept to Australian coast-watchers worked not only to reduce compromise from American forces, it also fit into Japanese assessments, as they held the capabilities of these coast watchers in high regard, and thus, the US had some plausibility in the source of the intercept without compromising they had cracked the Japanese codes.
25. Ibid., 38.
26. Budiansky, *Battle of Wits*, 255.

27. Ibid., 257.

28. Arvanitakis, *Killing a Peacock*, 39–40. In the case of the Allies, Winston Churchill was particularly upset, as any potential revelation about US cryptologic capabilities against Japan could reveal the Allied successes against the Nazis. With the infamous meeting with Bull Halsey, the admiral noted that the fliers, instead of being considered for the Medal of Honor, should be held for a court-martial. As it was, the admiral downgraded the Medal of Honor citations to Navy Crosses, an honor that is a mere step down from the Medal of Honor.

29. Benjamin Runkle, *Wanted Dead or Alive: Manhunts from Geronimo to Bin Laden* (New York: Palgrave MacMillan, 2011), 210.

30. Ibid., 210.

31. John Keegan, *Intelligence in War* (New York: Vintage Books, 2002), 316.

32. Arvanitakis, *Killing a Peacock,* 24.

33. Ibid.

34. Davis, *Lightning Strike*, 243.

35. Adam Leong Kok Wey, "Special Operations by Airpower: Strategic Lessons from World War II," *Air Power History* 64, no. 1 (Spring 2017): 38, http://www.afhistory.org/air-power-history/2017-air-power-history-archive/.

36. Arvanitakis, *Killing a Peacock*, 26.

37. Micah Zenko, "Does the Military Need a Micromanager?" *Foreign Policy*, 12 September 2017, https://foreignpolicy.com/2017/09/12/does-the-military-need-a-micromanager/.

38. Mark Bowden, *The Finish: The Killing of Osama Bin Laden* (New York, Atlantic Monthly Press, 2012), 226, 257.

39. Davis, *Lightning Strike*, 229.

40. Conner, "Have you Heard?" 32.

41. Davis, *Lightning Strike*, 231. Once aware of the significance of the message and the confidence that his intelligence personnel had in the work, Adm Chester W. Nimitz forwarded his concerns about direct targeting to Washington. History is not sure if the call went all the way up to President Franklin D. Roosevelt to authorize the mission. Still, Nimitz gave Adm William Halsey Jr., who commanded naval forces at Guadalcanal, the go-ahead, noting, "It's down in Halsey's bailiwick." Originally, the strike against Adm Isoroku Yamamoto was to use naval assets until the ranges involved forced the use of the P-38 Lightning. In turn, this led to Halsey's headquarters sending the message to his subordinate commanders, "Talleyho X, let's get the bastard."

42. Ibid., 228.

43. Runkle, *Dead or Alive*, 203.

Lt Col Scott C. Martin, USAF

Lieutenant Colonel Martin (BA, Trinity University; MS, Troy University) serves on the Cyber National Mission Force Headquarters Staff, US Cyber Command. He has served in a variety of unit-level, air operations center, and combat support agency assignments. Lieutenant Colonel Martin also served on the staff of Air Force Global Strike Command. He was the director of operations for the 424th Air Base Squadron at Chièvres AB, Belgium and the 34th Intelligence Squadron, Fort George G. Meade, Maryland.

Three Competing Options for Acquiring Innovation

Lt Col Daniel E. Schoeni, USAF

The DOD's technological edge is eroding.[1] Since 2015, the department has pursued a strategy to regain the lead. During the Obama administration, it was called the Third Offset.[2] The Trump administration has abandoned that nomenclature, but it is pursuing the same objective.[3] The DOD seeks dominance in robotics, artificial intelligence, autonomous systems, and three-dimensional printing, among other fields. It recognizes, however, that such innovation will not come from the usual sources—government labs or the defense industrial base.[4] Nondefense firms have a decisive lead: "the center of gravity in cutting edge, military applicable research is shifting abruptly away from the defense establishment to relatively new commercial firms."[5] The DOD must engage with these nondefense firms to build the next generation of weapon systems. But how should it do so?

Two decades ago, defense economists David Parker and Keith Hartley, mapped the options for procurement along a continuum. On the far left, managerial diktat determines sourcing, and prices have little role in the process. On the far right is a fully competitive market, where the "relationship between buyer and supplier is transitory, non-committal beyond the current purchase, and arm's length"; between these extremes are, from left to right, subsidiary purchases, joint ventures, partnerships, networks, preferred suppliers, and adversarial competition.[6] Parker and Hartley later quote Keiran Walsh, who distilled these options down to three:

> [T]here are three basic ways of getting people to do what one wants done. One can force them to behave as one wishes them to. One can give them a set of incentives that aligns their interests with one's own. Finally one can try to shape the values that they hold so that they will naturally want to do what you wish them to do.[7]

Walsh's three alternatives, Parker and Hartley explain, correspond to coercion, competition, and long-term partnering.[8] Of course, the same option needn't be chosen for every procurement, and perhaps different alternatives may work better in some cases than in others. But the DOD must choose from these options as it determines how to buy innovation from nondefense commercial suppliers and perhaps should identify a default that works best in most cases.

Four judge advocates recently published articles putting forward three options for engaging with newcomers to defense procurement. Although uncoordinated, these articles neatly cover the range along the Parker-Hartley continuum—coercion, partnerships, and competition. This article dismisses the first, unpacks the second, and advocates the third, competition via open-systems architecture. This isn't merely an esoteric legal debate. Effectively buying innovation from nondefense sources matters. Unless the DOD learns to do so, it will be unprepared for the next war.

National Security Law Writing Competition

Before coming to the question at hand, a short explanation is in order. Why did four Air Force lawyers take an interest in the same subject in the same year? The answer is that the Air Force Judge Advocate General School held its first national security law writing competition in 2016. The subject was public-private partnerships' (P3) potential for stimulating innovation and cutting costs:

> Since its inception, the Air Force has been on the forefront in developing and incorporating cutting-edge technologies to enhance its mission effectiveness, from aircraft to spacecraft to capabilities in cyberspace. However, in an era of constrained resources, the Air Force has had to explore other avenues by which it can *retain its technological superiority while also managing costs. One attractive methodology for accomplishing these goals is the public-private partnership*, which brings public agencies and private entities together to combine resources to achieve common goals and objectives.[9] (emphasis added)

Four judge advocates' submissions have since been published, two in the *Air Force Law Review*, one in the *Army Lawyer*, and the last in the *Administrative Law Review*.[10] Given how the question was framed and the Air Force's high hopes for P3s,[11] two articles, not surprisingly, take for granted that P3s answer the DOD's innovation challenges. A third ignores P3s and advocates additional measures for coercing private industry. The last takes a different tack, arguing that P3s are overrated and are particularly ill-suited for innovation, favoring instead the advent of arms-length competition through wider use of open-systems architecture.

Coercing Private Industry

Col Linell Letendre finds troubling the fact that the nondefense commercial sector has outpaced the defense industrial base in certain technologies.[12] As her article's title suggests, she is especially alarmed by Google's dominance in autonomous systems.[13] Her concerns are not without merit. As she notes, Google has recently acquired eight of the field's leaders, several of whom had previously competed for Defense Advanced Research Projects Agency contracts.[14] She argues Google's uncooperativeness with subpoenas for prosecuting child pornographers suggests it will not prove the stalwart member of the arsenal of democracy that Ford was.[15] Corporate values have surely changed since World War II; this is no small problem.[16] But Letendre's cure is less persuasive than her diagnosis.

Letendre's remedy is the proverbial iron hand in a velvet glove. She advises that the DOD "appeal to a common set of values" with companies like Google.[17] Where that fails, however, she would have the president use his already formidable wartime powers to compel the private sector and would also recommend the expansion of such powers.[18] Indeed, her "main takeaway" from the examples of Apple and Google declining to voluntarily cooperate in law enforcement matters "is the necessity for strong tools."[19] This signifies coercive sourcing or what falls on the far left of the Parker-Hartley procurement continuum.[20] What the government needs, it takes.

Letendre's model for an effective industry relationship is the subservient role that industry played from the attack on Pearl Harbor to the close of the Second World War. Yet World War II presents a special case. America was ill-prepared for a two-front war, especially with two highly capable industrialized nations.[21] Industry came to heel because America faced existential threats. But what worked in the medium-term for a war that would last less than four years would make a dubious policy for a long-term innovation strategy. Worse, she argues that the Selective Service Act should be extended to give the DOD power to seize intellectual property.[22] That is precisely what the private sector fears most about doing business with the DOD.[23] Granting such expansive powers would not only irreparably damage the DOD's already fraught relationship with industry but could also chill investment in innovation generally.[24] In short, Letendre's proposal would kill the goose that laid the golden egg.

Public-Private Partnerships

Sliding toward the middle of the Parker-Hartley continuum is the public-private partnership.[25] While the definition of P3s is notoriously hard to pin down,[26] P3s are essentially long-term government contracts.[27] Savings are thought to accrue from the reduction in transaction costs, greater economies of scale, and efficiencies that arise from bundling.[28] On this basis and because P3s are said to provide a new revenue stream, P3s have become fashionable.[29] Indeed, a bipartisan consensus is forming that P3s are the answer to all manner of public policy challenges.[30]

Capt Matthew Ormsbee and Maj Nicholas Frommelt both posit that P3s are the best way to buy innovation.[31] That premise is unexamined. They devote their attention to explaining how existing authorities can be used or expanded upon to enable greater use of P3s.[32] Undoubtedly such legal authority already exists and could be expanded on, but their articles beg the question considered here. Namely, what is the best way to buy innovation?

Setting aside general problems with P3s that are often ignored given the irrational exuberance for this fashionable policy tool, the premise that P3s are consistent with innovation is false.[33] P3s are ill-suited to innovation in part because they work best in sectors where uncertainty and risk are low, and purchasing defense innovation is just the opposite. P3s have a solid record for projects in transportation, energy, and water, where requirements are typically stable and well-defined. But they have proven less useful when applied to sectors with rapidly changing requirements such as information technology.[34] Innovation is more like the latter in the sense that its requirements are unstable and uncertain.

Most new technologies are a bust; no one knows in advance which of these will pay off. Thus, few private-sector partners will want to assume the level of risk that uncertain long-term contracts would entail.[35] Alternately, many would be more than happy to enter into long-term relationships as long as there is no genuine risk transfer and the government effectively privatizes profits and socializes losses. It is unclear, however, how the government would benefit from such an arrangement.

Ormsbee commends such arrangements. He argues that P3s are an ideal "*marriage* of expertise and assets" (emphasis added).[36] The problem with his marital metaphor is the *Blade Runner* curse. Ridley Scott's 1982 film predicted a dystopian future in which Atari, RCA, and Bell Telephone still dominated the business world in 2019. The fact that these companies have ceased to exist or lost their edge has nothing to do with a film's curse.[37] Today's technological leaders are tomorrow's losers.[38] Case in point, mighty General Electric recently fell off the *Fortune* 500 list.[39] Suppose that innovation P3s had been locked in with IBM in the 1960s or Microsoft in the 1990s. These would have seemed like sensible choices at the time but would have appeared foolish in hindsight.[40] Public officials tend to unduly favor incumbents over new entrants. P3s exacerbate this tendency, lengthening and deepening public-private contractual relationships. In a word, marrying today's leaders will not buy tomorrow's innovation.

In a similar vein, Frommelt relies on a Defense Acquisition University study finding that both public officials and incumbent contractors are generally content with the results of long-term contracts.[41] That is precisely what economists would predict.[42] Each group has its reasons for preferring the status quo. Public officials are not only subject to principal-agent problems, meaning they have the incentive to pursue their own interests instead of their employer's (for example, avoiding the extra work that awarding to a new entrant would entail by choosing the incumbent).[43] They also prefer to stick with the devil they know.[44] And few incumbents are clamoring for more competition that would disrupt a steady revenue stream.[45] *Of course* both sides are happy. Their mutual felicity, however, is a poor measure of effectiveness. In a word, insulating incumbents from pesky new competitors does not constitute a sure recipe for innovation.

Competition Through Open-Systems Architecture

On the far right of the Parker-Hartley procurement continuum lies spot pricing.[46] One step to the left is what some pejoratively call *adversarial* competition.[47] Such competition is unfashionable in private-sector sourcing, and government has sought to emulate efficiencies that arise from long-term, amiable relationships between buyers and sellers.[48] Hence, the widespread enthusiasm for P3s. Parker and Hartley are skeptical. They argue that incentives in the public sector differ to such a degree that what works in the private sector can create perverse incentives when applied to public sectors.[49] Short of coercion, therefore, competition is the only viable alternative to collaborative relationships.

DOD acquisition leaders emphasize that defense procurement's most pressing need in is "more innovation and more competition."[50] Far from advocating closer alliances with a clique of prime contractors or today's technology leaders, these leaders see competition and innovation as compatible, interactive, and even causally related.[51] Competition, in short, yields innovation. Such innovation will come from the wider commercial sector and even from beyond our shores, from "global allies, friends, and trading partners who share our values and can assist us in pursuing innovation and technology superiority."[52]

OSA enables "competitors with superior technology to win their way into our programs."[53] DOD leaders are not alone in recognizing OSA's potential. Congress's procurement watchdog, the Government Accountability Office (GAO), has long proclaimed the value of OSA, "to increase competition throughout a program's life cycle to save taxpayer dollars while providing the best available technology to the warfighter."[54] And, the Defense Science Board's Task Force on Open Systems issued a clarion call in its 1998 report, arguing that while the DOD's challenges are enormous, "significant relief [is] close at hand[.]"[55]

On paper, OSA is a cornerstone of the DOD's innovation strategy. In practice, however, the DOD has been a slow adopter. The GAO has repeatedly issued reports criticizing the armed forces, especially the Army and Air Force, for their failure to implement OSA.[56] It would seem there is much more enthusiasm for P3s than for OSA. Significant relief to vexing problems may be close at hand,[57] but for reasons that are not immediately clear, progress toward OSA has been limited.

What is OSA? Answering this question requires a step back to explain a persistent problem in defense economics. Market forces yield vendor lock: even if the DOD initially employs competition, it eventually becomes dependent on the original manufacturer.[58] When vendor lock is coupled with rapid technological growth, systems are "antiquated before they are fielded, parts are obsolete and unobtainable, support is a nightmare, costs soar, and the program becomes only marginally viable."[59] But one commercial practice offers a "glimmer of hope."[60]

OSA promises to disrupt vendor lock, enable competition, and spur innovation. Here's how. First, OSA is modular. *Modular* refers to goods that are discrete, self-contained units.[61] Second, OSA is open. *Open* goods have public standards, enabling third-party vendors to compete with the original manufacturer for spare parts and upgrades.[62] Thus, OSA signifies an interoperable, connectible approach.[63] It thereby fosters "collaborative innovation of numerous participants."[64]

What is most intriguing about OSA is that it seems to incorporate the same principles as platform economics, a business model that is revolutionizing the private industry. Two Massachusetts Institute of Technology economists recently described this phenomenon in their book, *Machine, Platform, Crowd: Harnessing Our Digital Future*,[65] which *The Economist* summarized in a book review:

> The largest cab company owns no vehicles (Uber), the biggest hotelier has no property (Airbnb), the most comprehensive retailer holds no inventory (Alibaba), and the most valuable "media" company creates some content but not much (Facebook).[66]

Consider two examples. Apple and Microsoft invented platforms that transformed personal computing, but they were not themselves responsible for the outpouring of technology that ensued.[67] Most innovation came from third-party vendors whose brands are not household names. "There are important parallels for the DoD."[68]

"In like manner," the author argues in his previous article, "OSA would have the DoD function as a systems integrator that would purchase the components for its weapon systems from competing commercial suppliers."[69] "This would relegate incumbent contractors to competition with wider industry and commoditize what was previously a highly specialized niche market."[70] Introducing competition analogous to platform economics would establish OSA as an "innovation enabler."[71]

Conclusion

The DOD's current approach to buying innovation is schizophrenic. P3s seek longer-term, more collaborative relationships with private industry. OSA pulls in the opposite direction. It seeks to disrupt vendor lock by stimulating competition from the wider industry, especially from new entrants. Insofar as policymakers seek to pursue innovation simultaneously using both procurement methods, such a policy would be misguided and self-contradictory. Given the concurrent enthusiasm for both P3s and OSA, it is surprising is that no one seems to have noticed that the two strategies are mutually exclusive, or at least that they would engage with industry in incompatible ways.

The DOD can, of course, choose conflicting procurement strategies for different programs—and perhaps sometimes ought to do so to experiment and see what works best. But it should not choose conflicting strategies for the same acquisition simultaneously. Further, the strategy that works most often should be the default.

Returning to the Parker-Hartley continuum, will the DOD choose coercion, partnerships, or competition? Coercion is a dead-end and antithetical to free enterprise; it should be a last resort, not a standing acquisition policy. The siren song of P3s is alluring because collaborative relationships work well in private industry. The public sector, however, is different. P3s would exacerbate the defense market's natural flaws, locking in long-term contracts with a few firms and crowding out new entrants. They would effectively codify vendor lock. That is just more of the same. But OSA's untapped potential has been recognized for decades. It promises to stimulate competition and innovation on an unprecedented scale.

To repurpose G. K. Chesterton's observation, "[competition] has not been tried and found wanting. It has been found difficult and left untried."[72] Long-term partnering with a few firms, by contrast, has definitely been tried. Calling such partnerships P3s is clever rebranding, but it is old news. Why not try something new? ✪

Notes

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2. Chuck Hagel, secretary of defense (keynote address, Defense Innovation Days, Newport, RI, 3 September 2014), http://www.defense.gov/News/Speeches/Speech-View/Article/605602.

3. DOD, *National Defense Strategy*, 3; and Jon Harper, "New National Defense Strategy Prioritizes High-Tech Equipment, Acquisition Reforms," *National Defense*, 19 January 2018, https://www.nationaldefensemagazine.org/articles/2018/1/19/new-national-defense-strategy-prioritizes-high-tech-equipment-acquisition-reforms. This explains that the Trump administration's innovation strategy will no longer be called the Third Offset but that there will be significant continuity with that program.

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11. USAF, *Air Force Future Operating Concept*, 15 September 2015, 22, 26, 40, https://www.af.mil/Portals/1/images/airpower/AFFOC.pdf.
12. Letendre, "Google . . . It Ain't Ford," 56–57.
13. Ibid., 57–58.
14. Ibid., 57.
15. Ibid., 53, 58–59.
16. Regarding Google's willingness to share artificial intelligence and autonomous systems technologies with the DOD, which seem to be Linell Letendre's primary concern, Google has a mixed record. On the one hand, it signed a contract in 2017 that would use these technologies to increase the accuracy of drone strikes. On the other, it has struggled with a revolt from employees who hail from computer science programs at top universities and "bring liberal, anti-war views from the academia with them." "Playing with Fire: Google Runs into More Flak on Artificial Intelligence," *Economist*, 16 June 2018, 55–56, https://www.economist.com/business/2018/06/16/google-runs-into-more-flak-on-artificial-intelligence.
17. Letendre, "Google . . . It Ain't Ford," 60.
18. Ibid., 54–56, 61–63.
19. Ibid., 59–60.
20. Parker and Hartley, "Economics of Partnership Sourcing," 116–17, 124.
21. William B. Burnett and William E. Kovacic, "Reform of United States Weapons Acquisition Policy: Competition, Teaming Agreements, and Dual Sourcing," *Yale Journal on Regulation* 6 (1989): 249, 257–59.
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31. Ormsbee, "Silicon Symbiosis," 240, 248–50; and Frommelt, "Better Buying Power," 16–18, 23.

32. Ormsbee, "Silicon Symbiosis," 250–53; and Frommelt, "Better Buying Power," 19–22.

33. Schoeni, "Whither Innovation," 443–44.

34. Elisabetta Iossa and David Martimort, "The Simple Micro-Economics of Public-Private Partnerships" (working paper, Brunel University, 2009), 2–3, http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.554.755&rep=rep1&type=pdf.

35. Elisabetta Iossa and David Martimort, "Risk Allocation and the Costs and Benefits of Public-Private Partnerships," *RAND Journal of Economics* 43 (2012): 442, 464.

36. Ormsbee, "Silicon Symbiosis," 240.

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43. Parker and Hartley, "Economics of Partnership Sourcing," 118; and Steven L. Schooner, "Contractor Atrocities at Abu Ghraib: Compromised Accountability in a Streamlined, Outsourced Government," *Stanford Law and Policy Review* 16 (2005): 549, 565, attributing lack of competition to considerations of "speed, convenience, personal preference, and human nature" that affect the contracting officer's decision.

44. William S. Cohen, "The Competition in Contracting Act," *Public Contract Law Journal* 14 (1983): 1, 21–22, describing the tendency to rely on the same contractor again and again; Michele Estrin Gilman, "Legal Accountability in an Era of Privatized Welfare," *California Law Review*, 89 (2001): 569, 599–600, reporting that once they are chosen, contractors become entrenched due to close relationships with government officials; and Janna J. Hansen, "Limits of Competition: Accountability in Government Contracting," *Yale Law Journal* 112, no. 8 (2003): 2465, 2471, observing that incumbents "cozy up to risk-averse government administrators."

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47. Ibid., 115, 121, 124.

48. Ibid., 115–16.

49. Ibid., 119–22.

50. Borowski, "The Inchoate Mistake," 183–84, citing Frank Kendall, under secretary of defense, *Better Buying Power 3.0* Interim Release, white paper (Arlington, VA: Defense One, 19 September 2014), 6–8.

51. Frank Kendall, under secretary of defense, *Implementation Directive for Better Buying Power 3.0—Achieving Dominant Capabilities Through Technical Excellence and Innovation* (Arlington, VA: Defense

One, 19 April 2015), https://www.acq.osd.mil/fo/docs/betterBuyingPower3.0(9Apr15).pdf, 8–10, 14–15, 23–24.

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55. Wayne L. O'Hern, Jr., under secretary of defense, cover letter, *Report of the Defense Science Board Task Force on Open Systems* (Washington, DC: October 1998), 2.

56. For example, see US Government Accountability Office, GAO-13-651, *Defense Acquisitions, DoD Efforts to Adopt Open Systems for Its Unmanned Aircraft Systems Have Progressed Slowly,* 2014, 4–5, 12–16, https://www.gao.gov/products/GAO-13-651.

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Lt Col Daniel E. Schoeni, USAF

Lieutenant Colonel Schoeni (BA, Brigham Young University; MA/JD, University of Iowa; LLM, University of Nottingham; LLM, George Washington University) is chief of international law at Twelfth Air Force (Air Forces Southern) at Davis-Monthan AFB, Arizona, and has served as assistant staff judge advocate, trial and appellate defense counsel, program counsel, and deputy staff judge advocate. He is a doctoral candidate in public procurement law at the University of Nottingham.

The Cold War They Made: The Strategic Legacy of Roberta and Albert Wohlstetter by Ron Robin. Harvard University Press, 2016, 376 pp.

Roberta and Albert Wohlstetter were two of the most prominent architects of the Cold War intellectual edifice. Their influence emerged from their dual intellectual partnership that centered first around the RAND Corporation, where both worked on strategic issues of the nuclear age, and later, at the University of Chicago. It was there where Albert became an advisor and intellectual mentor to several DOD insiders who occupied the political stage in the 1990s and the early years of the third millennium.

The Cold War They Made, Ron Robin's historical biography of the Wohlstetters and their acolytes—Paul Wolfowitz, Zalmay Khalilzad, and Richard Perle—is redolent of other Cold-War era personality-driven historical/biographical works, such as Walter Isaacson and Evan Thomas' *The Wise Men* (about Dean Acheson, Charles Bohlen, Averell Harriman, George Kennan, Robert Lovett, and John McCloy), Nicholas Thompson's *The Hawk and the Dove* (Paul Nitze and George Kennan), and the more contemporary *Rise of the Vulcans: The History of Bush's War Cabinet* by James Mann, which costars Paul Wolfowitz, along with Dick Cheney, Colin Powell, Condoleezza Rice, Donald Rumsfeld, and Richard Armitage.

In contrast with the other works, Robin is much more critical of the Wohlstetters and particularly so of his students Wolfowitz, Khalilzad, and Perle, who went on to occupy important positions in the George W. Bush administration as architects of the neoconservative movement.

> [These] three close collaborators. . . were, in essence, institutional gate-crashers proclaiming questionable omniscience: an academic bereft of the trappings of peer-reviewed publications, a sword bearer who cowed opponents through scare tactics, and an ambitious immigrant from the ethnic peripheries of American society who skillfully rode the coattails of his mentor to the center of American power.
>
> They filled the public sphere with predictions about the impact of their mentors' discoveries on the future of humankind, affecting an air of knowledge while constantly courting disaster. Showing little concern for empirical evidence aside from the odd historical anecdote, the Wohlstetters' mentees promoted an arbitrary and contested construction of the enemy (p. 301).

Robin shows how the Wohlstetters promoted two strategic themes that dominated both their writing and their intellectual musings—musings that were frequently attended by other RAND colleagues at the Wohlstetters' famous and opulent Laurel Canyon, California home. One of those themes came from Roberta's best-selling book, *Pearl Harbor: Warning and Decision* (Stanford University Press, 1962), Introduced in this book and echoed in both Roberta's and Albert's later writings, Roberta warned the US national security apparatus that it should maintain vigilance and preparation, lest another surprise attack be mounted against the United States. Such an issue became of prime importance in the nuclear age, where our very existence as a nation could be in doubt if caught by surprise. Vigilance, for the Wohlstetters, always carried the additional meaning of substantial increases in spending on national defense.

Another recurring theme was from Albert's magnum opus, *The Delicate Balance of Terror*, a RAND document published in 1958, one of whose effects was the elucidation of the Wohlstetter doctrine. In short, the Wohlstetter doctrine was a refutation of mutually assured destruction and promoted the notion that the combination of "an offensive nuclear strategy and . . .[a] military spending spree aimed at hemorrhaging a flawed Soviet economic system (p. 5)" were likely to be more effective as a Cold War strategy.

Albert was equally known for his famous feuds with other defense intellectuals of the time—feuds with luminaries as bright as they came—Bernard Brodie, Henry Kissinger, and Robert McNamara, among others. In fact, his feud with Bernard Brodie led to his dismissal from RAND, and to his later career at the University of Chicago where he came to have an influence on a new generation of combative intellectuals.

This combativeness was summarized by the author in stark terms:

> Albert did not shrink from confronting those he deemed either fainthearted or lacking in rigor, often choosing to ridicule, hector, and denounce. He usually placed his intellectual rivals on the defensive through the sheer weight of his argumentation. Failing that, he found other means to win the day. He had no qualms about transforming the principle into the personal or belittling his opponents. He was a prolific and persuasive writer, a formidable debater, and a compulsive verbal brawler (p. 283).

Albert would employ a full armada of diverse methods to fight his intellectual battles, and whichever method that suited his end goal would be the one that he would choose. He is celebrated as one of the fathers of the science of operations research analysis, though he was not above twisting these methods to his own ends.

Robin writes:

> By hinging his defense of Safeguard (ballistic missiles) on the esoteric calculation of theoretical possibilities that could not be disproved, Albert had successfully reframed the debate. The issue was now integrity and mathematical competence. To bolster his case, Albert mobilized his extensive network in the burgeoning professional field of Operations Research (OR). He successfully demanded that an ad hoc committee of the Operations Research Society of America (ORSA) be convened to adjudicate the conflict of opinions over the question of Minuteman's theoretical survivability rates. At stake, Albert urged ORSA, was the professional misconduct of his debating rivals, who had transgressed fundamental academic norms of transparency and objectivity in pursuit of ideological goals (p. 184).

Fully one-fourth of the book is dedicated to the Wohlstetters' intellectual successors, with a separate chapter for each one. The titles of these chapters are revealing in and of themselves: "Paul Wolfowitz: Fin de Siècle All Over Again (chapter 9);" "Zalmay Khalilzad: The Orientalist (chapter 10);" and "Richard Perle: Prejudice as a Cultural Weapon (chapter 11)."

An epilogue, entitled "The Hamlet of Nations," refers to Roberta and Albert's fixation with the hesitant avenger's character as a metaphor for what they considered to be what is wrong with American defense policy—a hesitance that could have dire consequences in the nuclear age.

Overall, the book is an informative history of a fascinating couple who framed the debate about America's nuclear and Cold War policy, and who influenced a new generation of defense intellectuals who continue to have influence today.

Dr. Clark Capshaw
Military Sealift Command
Norfolk, Virginia

We Kill Because We Can: From Soldiering to Assassination in the Drone Age by Laurie Calhoun. Zed Books, 2015, 416 pp.

Laurie Calhoun's *We Kill Because We Can* sets out to tackle a range of complex questions about national security policies. What interactions govern technology and policy, particularly on the MQ-1 Predator program? How do we reconcile legal implications in combating the work of militants in light of domestic and international frameworks? What is the value of *not killing* a particular individual, even if involved in planning terrorist acts against the United States? Calhoun does not just claim that the Predator's mechanics pose a difficulty for just war theory, she goes much further to challenge the just war tradition itself, essentially asking whether there is such a thing as a just war.

First, the author asserts that in the case of remotely piloted aircraft (RPA), "technology is driving policy, not the other way around."[1] As evidence, she cites the use of linguistic artifacts meant to clarify the status of America's enemies in the post-9/11 environment, specifically the terms *unlawful combatant*, *imminent threat*, and *hostile*.[2] Since the terms are not unique to RPAs but represent a larger legal question about how to define the status of those engaged in hostilities against the United States, it is not clear what this observation has to do with the link between RPAs (or any other technology) and policy development processes. Yet by chapter 10, she states, "The means to kill by remote control was sought by the Pentagon. . . ."[3] It is unclear whether she claims the emergence of technology drives policy (as initially quoted) or people making policy drive technology (as later stated). If she wished to describe the relationship between technology development and policy goals as interdependent or endogenous, she never stated as such. The phrase the author seeks is "technological determinism," but does not appear to be familiar with it.

An adequate literature review might have led to "Karl Marx and the Three Faces of Technological Determinism," Bruce Bimber's 1990 paper on the disambiguation of the term, and then to "Do Machines Make History?," Robert Heilbroner's 1967 discussion of society evolving along a predetermined course of technological discoveries.[4] With conflicting claims, no evidence of a causal mechanism and no literature review of the phenomenon or use of relevant terms from authoritative works, her discussion of technology is inconclusive.

On policy arguments, Calhoun takes deep exception to the 2001 Authorization for the Use of Military Force but does not address the complications of combatting nonstate armed groups that see themselves as transnational.[5] There is no formal discussion of geopolitics: no reference to Sir Halford Mackinder's work, no response to Samuel P. Huntington's "clash of civilizations," or any other influential text on the subject. There is no indication that Calhoun considered the work of Mao Zedong or how al-Qaeda sought to adapt his principles of insurgency to build its "unassailable base" in zones of lawlessness where it had freedom of operation against the "near enemy" (what Ayman al-Zawahiri saw as the Egyptian regime and more broadly as corrupted Muslim governments) and the "far enemy" (the United States).[6] One very powerful and noble direction she might have taken her research would have been to develop a systematic approach for a nonviolent basis to combat terrorism, one based on international legal norms and emphasizing primarily police (rather than military) responses. Unfortunately, there is no analysis of international legal frameworks in the text. The author seems unaware of legal positivism, or Harold D. Lasswell's and Myres S. McDougal's policy-prescriptive approach, or any other well-known framework, making only one secondary source citation from an online interview of a professor of law and presuming that a sufficient basis to prove "drone strikes" are illegal.

Shockingly, Calhoun's writing appears sympathetic to *jihad* against America, arguing that US inattention to al-Qaeda's demands prior to 9/11 are to blame for the attacks and goes so far as to say that the right course of action was not to retaliate at all, but to "stop doing what it was that led the perpetrators to react with their own shock and awe."[7] She even praises Osama bin Laden as "clever and charismatic" and calls 2 May 2011 the day "he was irrevocably silenced."[8] Calhoun commits the classic error of treating all of Sunni Islam as monolithic—an ironic misstep when criticizing others for cultural insensitivity. Just as she was unable to identify distinctions in Western jurisprudence, she did not differentiate the Sunni schools of law (Maliki, Shafi'i, Hanafi, and Hanbali). There is no evidence she noticed that al-Qaeda and its affiliates represent a specific, violent sect of Wahhabism, *Salafi Jihadis*, or that they have deep disagreements with the rest of Islam, yet exhorts the US government with paraphrased advice from Sun Tzu: "Know thine enemy."[9] Should the United States work diligently to improve its cultural competence and promote mutual respect in discussing matters of foreign policy? Absolutely—and so should the author.

Calhoun apparently located the causes of war definitively at the individual (head of state) level, which was remarkable considering that a century of international relations scholarship debates that very question, none of which she addressed. She proceeds from an untested assumption, that if rephrased as a legitimate research question would read: "Does the presence of personal risk to leaders who are deciding on war inversely correlate with the frequency of wars?" She assumes so, and her untested assumptions couple with substantial bias in selecting and responding to sources. Notably missing is a 2015 RAND report that concluded from an econometric analysis that patterns in US strikes in Pakistan *did* correlate to reductions in levels of terrorist violence.[10] She provided no response to Daniel Byman's "Why Drones Work," and cited it simply saying there continues to be "heated debate."[11] Breaking her original 328 endnotes into distinct statements, there are 464 substantive entries, shown in the table.

Table. Frequency analysis of citations

Note Type	*Composition*
Books	130 (28 percent of total)
Scahill, *Dirty Wars*	18 (13.8 percent of books)
Ahmed, *The Thistle, and the Drone*	8 (6.2 percent)
Martin and Sasser, *Predator*	8 (6.2 percent)
Geraghty, *Soldiers of Fortune*	7 (5.4 percent)
Johnsen, *The Last Refuge*	6 (4.6 percent)
Klaidman, *Kill or Capture*	6 (4.6 percent)
Hastings, *The Operators*	5 (3.8 percent)
48 others cited fewer than five times	(Average of 1.5 citations)
News Articles and Periodicals	116 (25 percent of total)
New York Times	29 (25 percent of news and periodicals)
Washington Post	17 (14.7 percent)
Guardian	8 (6.8 percent)
CNN	6 (5.1 percent)
BBC	5 (4.3 percent)
31 others cited fewer than five times	(Average of 1.4 citations)
Comments/Conjecture by the Author	99 (21.3 percent)
Film and Television References	64 (13.8 percent)
Other (government documents, activist journals, nongovernmental organization reports, and opinion journals, reports, activist websites, blogs, etc.)	51 (10.9 percent)
Scholarly Articles	4 (1 percent)
Total	464 (100 percent)

It is possible to extract insights out of film and television sources with an interpretive process that others can examine and reproduce, for example, the *symptomatic approach* that investigates films as cultural artifacts.[12] What is less acceptable in serious writing, however, is to cite film and television as primary source evidence or unqualified "insights," which the author does throughout the book. Her interpretation of the words and writings of former members of the RPA community is likewise skewed by massively reductionist logic. She concludes Lt Col Matt J. Martin and Charles W. Sasser's *Predator* is credible evidence of the culture of the community because Martin "is an active duty officer in the US military—indeed, a lieutenant colonel—his work must have been vetted by the powers that be. Martin's is not just some outlier piece of screed scrawled by a "bad apple" or low-level grunt. . . *Predator* is a book-length account which has been approved by some of the very administrators who decide when and where other people should die."[13]

Calhoun is the victim of a cruel joke: someone let her believe that Martin's ridiculous writing was vetted or taken seriously anywhere. In reality, Martin's book is the target of an aircrew tradition called "A Reading from the Good Book," where one stands before the squadron and reads in overly dramatic tones to mock the book's laughably unrealistic and self-aggrandizing substance. Poor source selection and unverified assumptions cripple Calhoun's book from cover to cover. For example, "A consideration of the counterfactual scenario, *had weaponized drones never been developed*, reveals that they make killing more, not less, possible, in perfect conformity with the military's longstanding quest for maximum lethality."[14] Counterfactuals are hypothesis-*generating*, not hypothesis-*testing* tools. Logically, had technology taken another path, war would still be an extension of politics, and casualties might be lower, higher, or relatively the same. The book ends with the same question begun in her critique of the philosophy of war, but offers no suggestions for improvement, leaving the reader wondering what philosophic system for managing violence she would instead recommend.

Speaking emotionally and repetitively into papers and books may be protected constitutionally, but it does not constitute legitimate public debate. To find a scholarly contribution, we must examine her worldview through a research question: why are certain antiwar activists so acutely frustrated by RPAs? We might derive a hypothesis from Calhoun's essay "The End of Military Virtue,"[15] and restate it this way: radical activism parasitically relies upon friendly casualties to survive—they *leverage* domestic bereavement to support their cause—thus all weapons that minimize friendly casualties are existential threats to the identity of the movement. Make no mistake, peace *is* the most noble end, but there are no shortcuts to achieving it, and this book failed to conduct rigorous analysis to advance our understanding of how to do so. Instead, it brazenly linked the jihadi agenda to radical antidrone groups (with whom Calhoun is closely aligned), claiming, "Insurgents who rise up in response to criminal wars differ from antiwar activists only in their tactics."[16] The author does not seem to understand the deadly seriousness of expectations for rigor and self-disciplined research when contributing to public policy debates, but connects readily with film and television, so perhaps an accessible explanation resides in dialog between actors Benicio Del Toro and Emily Blunt in the 2015 drama *Sicario*. Del Toro cautions, "*You are not a wolf. . . and this is a land of wolves now.*"

Notes

1. Laurie Calhoun, *We Kill Because We Can: From Soldiering to Assassination in the Drone Age* (London: Zed Books, 2015), xiii.

2. Ibid.

3. Ibid., 227.

4. Bruce Bimber, "Karl Marx and the Three Faces of Technological Determinism," *Social Studies of Science* 20 (1990), 333–51, and Robert L. Heilbroner, "Do Machines Make History?," *Technology and Culture* 8, no. 3 (July 1967): 335–45.

5. Authorization for Use of Military Force, Public Law L. 107–40, 14 September 2001.

6. Fawaz A. Gerges (reviewed by L. Carl Brown), "The Far Enemy: Why Jihad Went Global," *Foreign Affairs* (November/December 2005), accessed 10 January 2017, https://www.foreignaffairs.com/reviews/capsule-review/2005-11-01/far-enemy-why-jihad-went-global.
7. Calhoun, *We Kill Because*, 17.
8. Ibid., 18.
9. Quintan Wiktorowicz, "Anatomy of the Salafi Movement," *Studies in Conflict and Terrorism* 29, no. 3 (September–October 2006): 207–39.
10. Patrick B Johnston and Anop K. Sarbahi, *The Impact of U.S. Drone Strikes on Terrorism in Pakistan*, RAND Report, (Santa Monica, CA: RAND), 21 April 2015.
11. Calhoun, *We Kill Because*, xviii.
12. David Bordwell, *Making Meaning: Influence and Rhetoric in the Interpretation of Cinema* (Boston: Harvard University Press, 1991): 71–104.
13. Calhoun, *We Kill Because*, 167.
14. Ibid., 226.
15. Laurie Calhoun, "The End of Military Virtue," *Peace Review* 23, no. 3 (2011): 377–86.
16. Calhoun, *We Kill Because*, 311.

Capt Michael W. Byrnes, USAF
Fletcher School of Law and Diplomacy
Medford, Massachusetts

The Big Book of X-Bombers and X-Fighters by Steve Pace. Zenith Press, 2016, 360 pp.

In *The Big Book of X-Bombers and X-Fighters*, freelance aviation history writer Steve Pace attempts to showcase the history of the US Air Force's fighter and bomber X-plane inventory in a lushly illustrated compendium of aircraft and program details. To label such an endeavor as grand would be understated, yet Pace does a fine job of exposing the reader to not only the stories of the service's most endearing aircraft, such as the F-86, F-15, and B-52, but also those of aircraft that never saw operational use, let alone production. Relying largely on his previous primary source research for other projects, Pace weaves a story starting from the Air Force's first X-plane—the XP-59A—and ends by examining the F-35A, as well as potential future projects. Overall, his message is clear: today's bomber and fighter pilots owe their combat capability to the numerous engineers and other professionals in the developmental world—many of whom lost their lives—who willingly sought to expose Mother Nature's secrets tucked away in the sky (p. 9, 352).

The fact that Pace includes the details of some of the individuals responsible for taming many an exotic aircraft is refreshing. In contrast to the myriad aircraft books available, the author expertly blends the history of a plane's development with data about its performance and experimentation in design, along with short anecdotes of the test pilots who flew these new aircraft. Pace's book seems to be unique in that his work is about more than just airplanes, but people as well, which makes sense in light of his overall message.

Unfortunately, while Pace's effort is laudatory for its detail, there are areas where the reader would likely desire better accuracy and precision. For instance, while Pace explains with great care the tragic accident of XP-79B test pilot Harry H. Crosby, he completely fails to discuss a similar accident involving Capt Glen Edwards during the test of the XP-79B's offspring, the YB-49 (p. 26–32, 91–92). Such an omission is notable if for no other reason than Captain Edwards is the namesake of the home of Air Force flight testing–Edwards Air Force Base (AFB), California. There are other minor inaccuracies, such as the statement that the F-15E is still in production (p. 299). Perchance, it is the test pilot behind this review, but it would have been nice if Pace had discussed some of the anomalies discovered during the testing of more modern aircraft, something he did quite well in his review of many of the Air Force's earliest experimental aircraft. To wit, during testing, there is a well-known case where the YF-22 exhibited objectionable pitch response during the landing phase. The pilot was able to back out of the control loop preventing a fully developed pilot-induced-oscillation mere feet above the Edwards AFB runway.

Still, despite these minor inaccuracies and omissions, Pace accomplished what few others have; he has written a genuinely interesting history of the Air Force's fighter and bomber fleet with enough detail to satisfy most aviation buffs while also including the stories of many of the people behind these amazing technological innovations. This book should appeal to many different readers because of Pace's unique blend of writing that is accompanied by wonderful illustrations. Overall, this reviewer recommends *The Big Book of X-Bombers and X-Fighters*.

Lt Col Ryan A. Sanford, USAF
Las Vegas, Nevada

Rocky Boyer's War: An Unvarnished History of the Air Blitz that Won the War in the Southwest Pacific by Allen D. Boyer. Naval Institute Press, 2017, 352 pp.

One might build a good-sized collection of books by and about World War II pilots and aircrews, but a collection of books about support troops wouldn't endanger the structural integrity of anyone's bookshelves. That's why this present volume is an important addition to United States Army Air Forces (USAAF) historiography. Allen D. Boyer, an attorney, author, and historian, has used his father's diary to craft a well-written book about the experiences of one such support troop. The author's father, Roscoe "Rocky" Boyer, was born in rural Indiana in 1919, and he was inducted into the Army fresh out of Franklin College in June 1941. He was commissioned a second lieutenant in the USAAF in November 1942 and made his way to New Guinea as a communications officer assigned to the 71st Tactical Reconnaissance Group a year later. Rocky began keeping a diary on the day he was inducted into the Army. But this book is much more than an annotated copy of that diary. The author has recounted the history of the Southwest Pacific air war as experienced by Rocky and the men with whom he served.Using the diary and other primary and secondary sources, Boyer describes the air war as experienced by reconnaissance crews flying from New Guinea air bases. Accounts of air raids, missions, and even single sorties, help us to understand the flow of the war on a smaller scale, while accounts of top-level discussions and decisions show us the view and perspective of Gen George Kenney, commander of Fifth Air Force, and Gen Douglas MacArthur, supreme commander of allied forces in the Southwest Pacific.

Boyer doesn't shy away from issues not often discussed in World War II histories. For example, by 1944 combat fatigue among aircrew members manifested itself in such avoidable accidents as wheels-up landings, short landings, and collisions on the ground. Ground crew and support personnel were subject to the same general stresses. The author relates an episode where ordnance men loaded regular gravity fragmentation bombs on aircraft flying a mission that called for parafrag bombs. No pilots thought to check their own bombload, and they dropped the bombs from too low an altitude. Most of the planes suffered damage from their own bombs, and it is fortunate that no pilots were killed.

Rocky's dealings with his superiors, peers, and his men could be friendly or fraught with misunderstanding and pettiness. The diary is truly a human document. Officers quibbling and enlisted men griping are common occurrences, and Rocky's diary, and his son's supporting narrative, contains a good number of accounts of dissatisfaction in the ranks. Indeed, it seems that the enlisted men had plenty of targets in the panoply of poor officership.

All military veterans know that "rank has its privileges." Most of us understand and accept the concept, for better or worse. However, at times, the principle can be taken too far. This seems to have happened regularly in Rocky's unit. There were frequent complaints from enlisted men about the excessive privileges enjoyed by officers. Consider these few instances cited by Rocky: enlisted men made to wait on tables in the officers' mess; enlisted men eating from their mess kits (and washing them in a common can of hot water) while officers used plates, knives, and forks; officers appropriating lumber and other items for their personal use; enlisted men made to dig and build an officers' latrine first; and the eternal complaints about officers getting preference for dating nurses and Red Cross workers.

Rocky's last diary entry was in November 1944. This is a shame because shortly thereafter Rocky experienced ground combat at Dulag in Leyte when Japanese paratroopers attacked the airstrip. As a USAFF support officer engaged in ground combat, Rocky's impressions of this event would have been interesting and valuable. After the war, Rocky returned home and married his college sweetheart, Margaret Anne Dillard. He earned a doctorate in psychology from Indiana University and taught at the University of Mississippi from 1955 to 1989. Rocky died in 2008.

There are no major weaknesses in this book, although this reviewer, who has a penchant for memoirs of soldiers who served in rear-area support units, would have liked to read more about the details of Rocky's day-to-day work. Of course, the author was constrained by the source material he had on hand, and such an undertaking was probably not possible.

Twenty-eight fine photographs depicting the people, places, and things that Rocky saw enhance the text. Two maps—one of New Guinea and one of the Philippine Islands—are adequate to put the account into geographical perspective. The bibliography lists the author's impressive array of primary and secondary sources; this is enough to satisfy those who seek more information on this aspect of the war.

This is an easily readable account of the Southwest Pacific air war woven together with the diary entries of a support officer who experienced that war. I recommend this to anyone interested in World War II USAAF history in general and to those who are interested in the Pacific air war in particular.

Maj Peter L. Belmonte, USAF, Retired
O'Fallon, Illinois

El Dorado Canyon: Reagan's Undeclared War with Qaddafi by Joseph T. Stanik. Naval Institute Press, 2002, 308 pp.

Since 11 September 2001, the United States and its allies have undertaken antiterrorism campaigns around the world. However, one of the most significant battles against state-sponsored terrorism occurred 25 years before 9/11. This battle was the confrontation between the United States and Libya in the 1970s and 1980s.

Joseph Stanik, a retired US Navy officer and Middle East scholar describes this conflict in his book, *El Dorado Canyon: Reagan's Undeclared War with Qaddafi*. His meticulously well-researched book includes more than 700 citations from various sources. The subject is Libya's relations with the United States leading to Operation El Dorado Canyon and the events following the raid. Also included is a history of Libya and summaries of Libya's relations with its neighboring countries and Arab allies. Finally, Stanik expertly analyzes the planning and execution of the US bombing raid.

In his preface, Stanik emphasizes five key components of the US-Libya conflict. The first three points are that: (1) developing a comprehensive strategy for Libya was a long and difficult process for the United States; (2) the US Navy and Air Force "planned and trained with exceptional skill and precision;" and (3) the US Sixth Fleet played a crucial role in the prolonged confrontation with Libya (p. xiii). Stanik's final two assertions are that President Ronald Reagan acted with restraint in dealing with the Libyans and that the operation resulted in a ". . . devastating political and psychological defeat for Qaddafi [that] . . . undercut his ability to carry out or support further acts of terrorism" (p. xiii). These two points deserve critical examination.

That President Reagan acted with great restraint in dealing with Libya could just be a history lesson, yet Stanik provides an analysis of how one state can respond to an asymmetric threat from another state. The advice of Reagan's advisors, including, among others, Secretary of State George Shultz, Secretary of Defense Caspar Weinberger, National Security Advisor John Poindexter, Central Intelligence Agency Director William Casey, and White House Chief of Staff Donald Regan, provides insight into the policy decision-making. After other measures failed to deter Qaddafi, this advice led Reagan to authorize the airstrike against the Libyan regime. This is an excellent study as the United States attempted various military and diplomatic measures to deter Qaddafi before using offensive military force.

Stanik's other contention is that the US raid "undercut" how Qaddafi supported terrorism, specifically, that Qaddafi reduced his support and resorted to covert methods (p. xiii). Terrorist attacks attributed to Libya decreased in the years after the air strike, supporting this point. However, as Stanik admits, Libya was implicated in the bombing of Pan Am 103 in 1988, killing 243 people. This act of terrorism, only two years after the raid, casts doubt on the idea that Qaddafi truly reduced his support. The author highlights the changes in Qaddafi's rhetoric and attitude toward terrorism in the 1990s and post-9/11 era. However, 15 years after the bombing raid, this cannot necessarily be connected directly to the operation.

El Dorado Canyon is an excellent analysis of two decades of US-Libyan relations and how the United States dealt with a state sponsor of terrorism. Joint air operations planners will benefit from reading this book due to the complex nature of the operation and detailed planning. Also, students of national policy processes can gain insight into how national-level policy is shaped. Finally, after 9/11 Qaddafi pledged his support for the United States, and his intelligence apparatus assisted the war on terror. This cooperation would not result in more favorable ties with the West. In 2011, the United States, North Atlantic Treaty Organization, and other allies conducted operations Odyssey Dawn and Unified Protector in the wake of the Arab Spring, ultimately resulting in the downfall and death of Qaddafi. A study of these operations would make an excellent follow-on to *El Dorado Canyon*.

Maj Brian R. Huston, USAF
Naval Postgraduate School, Monterey, California

The Prometheus Bomb: The Manhattan Project and Government in the Dark by Dr. Neil J. Sullivan. Potomac Books, an imprint of the University of Nebraska Press, 2016, 296 pp.

Dr. Neil Sullivan's *The Prometheus Bomb* covers roughly six to seven years of history from the infamous Albert Einstein letter to President Franklin D. Roosevelt to the Harry S. Truman presidency. However, the detail he goes into is sufficient for the reader to gain an understanding of many different factors at play and the circumstances that led to very difficult decisions without becoming overwhelmed by the many different characters and personalities involved.

Dr. Sullivan uses real examples from the lives of the scientists and decision makers to get his point across and humanize them. For example, instead of saying how secret the nuclear proof of concept at Chicago Pile-1 was, he explains how the scientists threw a party, and none of the spouses knew why they were celebrating, a relatable example for most married people of the secrecy in which these people operated. To his credit, Dr. Sullivan takes these personified gods and brings them back to earth.

While this is a book about "The Bomb," it separates itself from the pack as Dr. Sullivan takes the reader through the much less discussed topic of how managerial decisions were made by people, who frankly lacked a background in nuclear physics or much science at all, for that matter, to make educated, informed decisions. He provides countless examples of the constant daily dilemmas FDR faced and how he overcame them. This is different from many of the other books regarding nuclear science, be it weapons or energy, as he does not delve into nearly anything technical, which I believe, allows for a much larger audience. In my opinion, this is a must-read for anyone who will ever manage *smart* people, anyone who is a program manager of a technical program, or any policymaker—basically, any (acquisitions) officer in the military, congressman, or truly good leader.

Additionally, Dr. Sullivan presents a fluid book where each topic progresses and builds upon the next, but he stylistically does so in a way that each chapter could be taken and studied individually, and the reader would have enough information to understand the conveyed point. In this sense, his approach to writing chapters comes off slightly as academic, in the sense that he is assembling the legs to a stool (building the case to his argument) with each subsequent chapter and concludes by tying everything together. Furthermore, Dr. Sullivan writes at a much higher education level than the local newspaper or usual author, which was refreshing, but keeping a dictionary close was needed every once in a while.

Lastly, the topic of nuclear weapons quickly became a heated debate. Should they be used, are they relevant, were they necessary, and so forth? As complicated as this discourse can become, Dr. Sullivan presented several points of view and presented the facts. He does not call for every nuclear weapon to be destroyed; nor does he call for an arms race. He logically and rationally presents the information. The only thing Dr. Sullivan calls for is an educated population since he acknowledges that science and technology are only improving, and we need policymakers who can make sound decisions.

At the end of the day, this is not a book so much about bombs as it is about public affairs and international relations with the obvious nuclear bomb as the centerpiece of the discussion. This was a quick read that educated and told a good story.

1st Lt Glenn R. Peterson, USAF
Minot AFB, North Dakota

Sidewinder: Creative Missile Development at China Lake by Ron Westrum. Naval Institute Press, 1999, 352 pp.

The Sidewinder air-to-air missile has proven itself a staple of air combat for more than half a century. In *Sidewinder: Creative Missile Development at China Lake*, Ron Westrum chronicles the development of the AIM-9 Sidewinder, skillfully dissecting the intricate web of personal, organizational, and technical factors that led to the success of what would become a vital US weapons program. Westrum argues that China Lake, during the early development of the Sidewinder, was a unique phenomenon in the US government. It was a government-owned laboratory, operated by the Navy, but it had the heart of a Silicon Valley startup. Under the tenacious leadership of Bill McClean, the lab was a hotbed of budding technical talent, leadership, and innovation. Creativity and an entrepreneurial spirit that defied the bureaucratic norms of the military acquisitions process defined the success of China Lake.

Despite being described as a veritable Camelot for forward-thinking engineering, Westrum dutifully highlights the real struggles that the lab and the Sidewinder program endured along the way. As Sidewinder was not originally conceived from a published operational requirement, the lab suffered from gridlocks in Washington over issues such as funding and necessity. There seemed to be a constant battle between those in Washington, DC and the teams on the ground in the Mojave Desert. On several notable occasions, the program was nearly cancelled by the skepticism of a certain admiral or civilian who controlled funding. These struggles are largely paralleled today, as the ever-increasing cost of weapon development continues to drive fiery debate in Congress. A definite degree of luck was enjoyed by the lab during these critical phases of the program, but a lot more can be attributed to the hands-on leadership approach taken by the senior lab directors. They directly engaged the higher echelons of command with personal visits and powerful live demonstrations of the missile's potential. The reader is quite able to get a holistic picture of the tribulations and triumphs of those at China Lake, thanks to the diligence of Westrum in gathering first-hand accounts from the lab's major players.

The effort of Westrum to capture a thorough and near-complete narrative picture of China Lake is the book's main strength. A lauded airpower academic, Westrum further develops extensive research notes that ground the storytelling with both primary and secondary source research. However, the narration does tend to stray at certain points throughout the book, which could be attributed to poor signposting of the book's organization at the beginning and the occasional abrupt swing between chapters. Furthermore, to get the full benefit from reading *Sidewinder*, the reader should have some knowledge of basic engineering concepts. Although Westrum is able to keep the technical discussion of the missile to an appropriate level for a broad audience, there are some points at which technical terminology is not defined in context, which could mean the reader may have to do some additional external reading to more fully understand what exactly is being talked about.

The concluding chapters of *Sidewinder* are the most poignant for the contemporary airpower professional. Westrum is resigned to maintain that another government-owned lab could not operate in the same manner and spirit today as China Lake did during its heyday. The weapons development process has been largely outsourced to the private sector, with government labs serving as middlemen between them and Pentagon funding. Because the principal engineering efforts are accomplished elsewhere outside of government, the government loses its ability to be a "smart buyer." As he emphasizes in the text, "*There is no substitute for the actual practice of engineering*." (p. 267; italics are retained from original text.) However, the book was first published in 1999, and since then the military has created new initiatives to innovate and be more creative within its ranks yet again. Therefore, the reader should use this book as a launch point to understand where we have been to better grasp where we are going. In a modern battlespace where the technical capabilities of aeronautical, space, and cyberspace weapon systems are the drivers of everything from tactics to geopolitics, getting the right systems at the right times is critical to success in meeting national objectives. The acquisition process influences the war fighter now more than ever; therefore, this book should be required reading for all operators of modern weapon systems as well as those involved in requirements writing or acquisition programs. This book also comes recommended for casual readers of military literature, as the narration and general storytelling is strong in its own right.

2nd Lt Scott T. Seidenberger, USAF
Tyndall AFB, Florida