The Role of Live, Virtual, and Constructive in Training

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Preface

The Cold War era (circa 1947-1991) was a period of history dominated by relations between nations comprising two giant war machines – NATO and the Warsaw Pact – that were defending opposing world views in Europe, and many parts of the globe. Military preparedness was geared towards a confrontation in Europe that would be devastating in nature for all concerned.

I joined the Royal Canadian Air Force (RCAF) in 1980. For me – a kid from Montreal, Canada – joining the RCAF was more about flying sleek high performance jets than facing the Soviets in Europe under the NATO flag on a one-way ticket. The arrival of a new generation of technologically advanced multirole fighters was irresistible and I wanted to fly these new machines. I spent two years graduating from single engine trainers to first and second generation jet aircraft to receive my wings, and finally fly the newly acquired Canadian F18 in 1986. Aside from having to stand alert in Northern Canada five days a month, my life on squadron consisted of flying training sorties to hone my skills. There was a continuous influx of new pilots to train and I quickly learned that constant training was my main job.

Modern multirole or "swing role" platforms required the acquisition and perfection of many new skills, and being able to exploit the full capabilities of these new fighter aircraft was more demanding than it had ever been in the past. New simulators were helpful, but could not replace the actual flying experience in most operational tasks. Still, we complemented the actual flying with spending 10 to 15% of our time in the simulated world.

It took a minimum of 500 hours to be considered an experienced pilot on squadron. Twenty five percent of the squadron was renewed every year, usually with brand new pilots that would take most of their first year to qualify as "combat ready". During their training, these non-combat ready pilots required experienced lead fighter pilots to teach them the ropes and shape them into productive pilots. Once combat ready wingmen, they spent another year gaining experience before training and qualifying as element lead (i.e., flying lead of a two-plane element). Another year was required for the next level, section lead (i.e., leader of a four-plane section). The constant renewal of squadron fighter pilots and maintaining the level of training and flying experience required to be effective as a combat unit was, and still is, the main effort and concern of every fighter squadron commanding officer – not just in the RCAF, but in aviation forces throughout western countries.

When the Soviet Union collapsed, many hoped for a more peaceful time. "Peace dividends" were sought early, and Canada, like many other countries, was quick at reducing its military budget in the early 1990s. I remember my squadron commander having to justify every F18 flight hour in order to protect an adequate flying rate if the government was to keep a viable fighter force in Canada. Minima were set to indicate proficiency in night flying, air-to-air combat, ground attack, low level flying, air-to-air refueling, etc. Almost magically, these criteria added up to 240 flying hours per pilot, per year, thereby protecting a share of the military budget judged excessive by many opponents – both in and out of the military. At the operational level, these standards quickly became an absolute minimum requirement in order to be qualified a "combat ready" pilot.

Advances in technology and a shift in ground attack tactics from low-level strike to high-level strike eventually led to a reduction in actual flying and an increase in training missions in the simulator. A reduction to 200 flying hours and, eventually, 180 hours was combined with an increase in simulator hours. A balance of 75% flying, 25% simulator time became an accepted norm in many western countries. Through this process, training was still felt and portrayed as the main requirement for flying these expensive fighter aircraft. The pressure to reduce flying hours was only stopped by the "minimum required" to be an effective force.

The first important deployment post Cold War of fighter assets during the first Gulf War brought along its share of questions and issues. For example, if our fighter pilots were deployed and only flying ground attack missions or air defense missions, how were they to maintain proficiency in other roles? In order to maintain their proficiency and qualification to fly, they had minima to fly in many types of flight operations and they would quickly lose this captaincy if unable to carry out training or actual missions in all categories of flight operations. Also, with a constant flow of new pilots arriving on squadron every year, who was going to train them and provide them with flying experience if experienced pilots were deployed on operations? At the time, we just considered rotating our pilots in and out of theatre every 30 days in order to maintain requirements for such all-around proficiency. Fortunately, the first Gulf War did not last long and was quickly considered an anomaly in our "training" fighter force.

But as we moved into the new millennium, operations abroad became more frequent with deployed operations in Iraq (once again), Afghanistan, Libya, and as of now, ongoing operations in Iraq/Syria. I was the Canadian operational commander in Winnipeg when we deployed on short notice in 2011 for operations in Libya. Issues identified during the first Gulf War quickly came back to haunt us. With forces constantly deployed in Afghanistan, a second operation in Libya was taxing our resources. I remember hearing the comment that "we could not go to war, Boss, we had to train back home…"; and the number of F18s to be deployed was only 8 out of a fleet of 78!

The challenge of producing and retaining enough fighter pilots is not just a Canadian issue. I had discussions about this with Chiefs in the UK, Australia, France, Denmark, Belgium, and the Netherlands. RAND Project AIR FORCE identified many of the same issues in their 2007 and 2015 studies of the United States Air Force (*Absorbing and Developing Qualified Fighter Pilots* and *Reducing Air Force Fighter Pilot Shortages*). Most western countries involved operationally in the last decade have experienced the same pressures and continue to look for solutions. How can we train better and faster, produce qualified and effective pilots, and still be able to carry out operations when needed?

When I became Commander of the RCAF in 2012, I carried this baggage of training and operational readiness issues with me. Having to manage and balance a budget that never covers everything required, nor expected; caring for our people while ensuring we had combat capable assets for the government to deploy; and building the RCAF for the future, were each and all constant challenges that were difficult to address and resolve. It was clear to me that new technologies could help, and we could push more training into simulation, but selling investment in old fleets and old simulators was difficult to justify if they would no longer be required in ten years.

It became obvious to me, and to many of my colleague Air Chiefs of most allied countries that after more than 30 years of flying pretty much the same generation of fighter aircraft and using the same simulation assets, the advent of a fifth generation of fighter aircraft actually provided a tremendous opportunity to modernize our training system, and that a better combination of live, virtual and constructive flying training – using the latest technologies – could enable more rapid and efficient training of "combat ready pilots" at a lower cost. In fact, this fifth generation aircraft necessitated an updated training system to support an enhanced virtual training ground for the aircraft's advanced capabilities.

When I left my post in 2015, most of my allied counterparts and I were contemplating our future pilot training structure and the best way to increase virtual and constructive flying in this new operational equation. Most of us were contemplating these changes because we would be both graduating to a fifth generation fighter force and simultaneously purchasing new training assets for this next generation fighter force. At the same time, a new generation of training aircraft was actually being proposed for the USAF TX program, bringing with it new possibilities to embed live, virtual, and constructive (LVC) simulation and emulation in basic flying training, and thereby providing a unique opportunity to revamp the whole pilot training system.

I remember having to qualify as a section lead in 1988. We flew a four-plane formation of CF18s north of Bagotville to engage a simulated enemy force of four "red" CF18s for 1.5 hours. Half of the squadron was flying the mission on that day. It was challenging maintaining visual contact with my section, and situational awareness of my formation movements, enemy movements, and fluid engagements.

All of this was absolutely required to produce a qualified lead.

With the right equipment and investment, a similar mission in 2025 in a F35 could be done differently. Formations no longer fly in visual range; situational awareness is maintained on the main screen that provides a "God's eye view" of the operational area – inclusive of friends and foe. Members of my formation will be 20 miles apart and I'll maintain track of their movements on my screen. Enemy aircraft are engaged at longer range or simply avoided at distance. I'll be engaged by ground threats and have to react as part of my training. And again, long range engagement or avoidance will be key. My main screen is now my principal situational awareness tool; and this scenario can now be simulated with ease.

I will direct and monitor my wingmen's actions on my display, but they are actually flying from a simulator in two different bases, networked with each other and with my aircraft. There is no difference to the inputs I will receive and the training mission I carry out. Enemy aircraft and ground threats are actually constructed by my computer. If they come close enough, I will actually see them in my helmet display; I can use my defensive systems, but no emission comes out of my aircraft in a training mode. Pilots in the simulator can see a representation of my aircraft and are getting the same operational training I am getting in flight; but only one aircraft is flying instead of eight.

Not all training missions can be simulated, and pilots will still require flying experience. Yet, I am convinced that many more training missions and training support missions can – and need to – be pushed into the virtual and construced realm. In a more capable aircraft, the virtual world will become a better training ground for many missions that require defense against multiple threats that today can only be replicated during large and expensive exercises, such as the Red Flag series. Larger flying training areas will be required for the more capable fifth generation flight capabilities and the ability to engage enemy threats at longer range. Some advanced defensive systems may not be allowed to be operated during peacetime training missions in order to protect their secrets. Thus, the virtual world will become an increasingly essential operational training ground for future fighter pilots.

As we built our plan for future fighter training in Canada, we envisioned as a goal a ratio of 50/50 live-to-simulated fighter training. Britain's Royal Air Force has announced recently a similar goal of 50/50 for its fighter force training. Whether 50/50 is the right ratio is still to be proven; but a definite move towards more simulation is not just simply a cost saving measure, it is actually becoming an operational imperative. It just so happens that it will also save some flying training hours. It will provide more aircraft hours for actual operations, free up pilots from support missions, and help relieve some of our past thirty years' pressures of struggling to have enough fighter pilots to do the job when required.

Since the early 1980s, we have increasingly relied on technological superiority in our quest to maintain more capable air power in the conflicts in which we have participated. As we introduce a fifth generation of fighter aircraft, similar technologies are being developed in other parts of the world and the superiority gap we have enjoyed in the last thirty years may not exist in the future. I am convinced that "training superiority" will be the edge required in future conflicts. As Commander of the RCAF, I wanted this edge to become the basis for our continued operational success, and investment in the right combination of LVC simulation is the key to this success.

-Lieutenant-General (Ret.) Yvan Blondin
Former Commander of the
Royal Canadian Air Force

Executive Summary

It is axiomatic that well-trained military forces are a foundation for military success. Incorporating new technologies is key to maintaining military superiority, but warfare has always been a contest of human wills. Technologies do not fight wars, people do – so as new technologies are developed and incorporated into US and allied forces, good training will continue to be crucial to those forces successfully employing technologies. Furthermore, in today's world of technology proliferation, purely technological advantages are fleeting at best, and historically the side that uses their technologies best usually wins.

The US therefore needs to develop alternative strategies to maintain military primacy and buttress the defenses of allies around the world, even in times of fiscal austerity. As a result, the DoD has pursued a "third offset" strategy to maintain a competitive edge in defense technologies. Since the "third offset" was first announced in 2014, a vibrant discussion has emerged in D.C. policy circles over the precise architecture of this offset, yet that architecture remains unresolved. In short, as this new strategy gels, there are still opportunities to help shape it for the future. Historically, times of austere military budgets have been times when innovative concepts have been developed, tested and implemented as military forces have simply been unable to sustain large-scale "legacy" forces or systems. So the opportunities for innovation exist even without – or perhaps especially without – large military budgets.

Live, virtual, and constructive (LVC) training that entails linking live platforms to manned simulators in virtual environments, and constructive forces in simulations should be the foundation of future military training solutions. Combining LVC capabilities is a relatively recent concept, but all the US Services, and several of our close allies, are exploring innovative ways to employ LVC to improve the effectiveness of training while controlling costs. As the US seeks to "offset" the emerging technological parity of adversaries, LVC training capabilities could be a key pillar of that strategy.

At the same time, LVC capabilities initially developed for training can also be used to support innovation. Military training, through LVC, can support experimentation. LVC can support the development and exploration of innovative tactical and operational concepts, allow the military to identify and test new technologies and platforms, and allow their end-users to be trained to a higher level of tactical and operational efficiency.

The Potomac Institute for Policy Studies believes that as LVC capabilities continue to develop, there are three major areas that require structural change in order for the military to leverage LVC's full potential.

1. **Live, Virtual, and Constructive Training should be used as in the third offset providing strategic advantage.**

2. **Standards are required to obtain the most value from Live, Virtual, and Constructive training.**

3. **Integrate current and future approaches of Live, Virtual, and Constructive training through a systems of systems acquisition approach.**

Live, Virtual, and Constructive's Role in the Third Offset Strategy

Strategists have proposed that accomplishing missions at a favorable cost exchange ratio should be a part of the third offset strategy. Therefore, improving our warfighter's training could in fact become a significant contributor to that strategy, particularly given the capabilities envisioned in LVC: reducing use, wear and tear and maintenance costs on operational equipment; enabling geographically-distributed forces to train together without having to travel to a common location (and thereby reducing "overhead" costs); and increasing the scale of exercises so that both small units and major staffs can train at the same time, and simultaneously leverage each others' capabilities to improve realism. Cost savings are only one dimension of the potential offered by LVC. By leveraging the advantages of each to offset the weaknesses of the others, combinations of L, V and C capabilities can provide improved realism relative to previous methods. Furthermore, the foundational technologies needed to do so all exist. That is not to say those technologies are as advanced as they need to be to provide high-fidelity training across the three domains, but rather that no fundamental technological breakthroughs are needed for LVC.

By being able to train together, both US and allied forces can work out differences in their SOPs, establish working relationships at the staff level, and so on – and do so at reduced cost. LVC capabilities can enable both horizontal (peer level units) and vertical (higher to lower level staffs and units) training among geographically distributed forces. Avoiding the time and cost of assembling all those forces in the same area, and all operating their operational equipment, can indeed contribute to achieving favorable cost ratios in preparation for potential future operations. Finally, by enabling "crawl" and "walk" level training to be conducted by geographically distributed units, those units can conduct "run" level training during the infrequent occasions when they do assemble for major exercises.

Common Standards for Live, Virtual, and Constructive

Having made the case that LVC can be an enabler for the Third Offset Strategy, the next logical question is "what is most needed to enable LVC?" We believe the answer to that question is to adopt a single common standard and set of specifications for LVC systems. All the Services (and our allies) currently have legacy training systems that were never designed to be integrated. Furthermore, even those systems that do follow existing standards are often not compatible because there are multiple, non-interoperable, standards. As a result, middleware is needed that can "translate" among the various systems based on the standards they use. Adding middleware increases cost, and potentially introduces processing delays or requires additional bandwidth.

The notion of common standards is not a new one, but we believe it is an issue that needs to be addressed eventually if the different DoD Services and our allies are going to be able to take full advantage of LVC capabilities. As to which standard should be adopted, that is a technical issue beyond the scope of this paper. We are aware that both US and some of our allies have been exploring the Common DataBase (CDB) standard that is part of the Open Geospatial Consortium's (OGC's) best practices specifications. Such explorations are a step in the right direction. We recommend that the US and close allies continue to explore common standards and specifications in order to promote interoperable LVC capabilities in the future. We believe that DoD and allies would be well served to explore, establish and adopt common standards and specifications for new LVC systems sooner rather than later to promote interoperability-by-design as new systems are developed in all three domains.

Live, Virtual, and Constructive Implications on Future Acquisition

The Live component of LVC implies a need to explore the ramifications of LVC on future operational systems acquisition to fully leverage the inherent capabilities of being interoperable with V and C training capabilities. Given the broad range of operational systems DoD (and our allies) employ, it is extremely difficult to make recommendations that apply across the board. But we do believe it is prudent to examine how common standards or specifications should be applied in the acquisition of (live) military systems to make sure they are interoperable with training systems.

Of course, interoperability is a 2-way street, so its impacts on acquisition need to be addressed both within the live and virtual/constructive system domains. What we recommend is that the Services should be forward thinking about the integration of training technologies along with actual live systems, so that they can move forward from the current situation in which training simulators and simulations were designed either as separate systems, or never intended to interoperate beyond the system level (e.g., a tank simulator designed to interoperate with live tanks, but not with other vehicles or simulators). We believe the primary needs for interoperability between L and V/C will be in communications and visualization components. Great strides are being made in voice recognition (and translation to digital formats) that have the potential to resolve the needs in the communication arena. So the "pacing" item for full interoperability is likely augmented or mixed reality technologies, which are still in the relatively early stages of development. But as stated above, there are no fundamental technological breakthroughs needed to enable interoperable L, V and C capabilities. The bottom line is that it is technologically conceivable, and some would argue feasible, to integrate L, V, and C, so addressing LVC capabilities and connections in new acquisition program planning – for both operational and training systems – can enable DoD and allies to leverage developing capabilities for integrated training and experimentation.

In sum, LVC is currently more of a concept than a reality, but all of the "pieces" currently exist to bring that concept to fruition. Doing so offers potentially game-changing opportunities for both US and allied forces to train together more often, more realistically, and to create larger scale training exercises at lower cost by enabling geographically distributed forces to "train at will." These same capabilities can be employed for tactical and operational innovation and experimentation, while also yielding superior training outcomes. Thus, LVC should be considered an integral component of a successful Third Offset strategy.

1. The Challenge of Maintaining 21st Century Military Supremacy

In 1965, the Vietnam War expanded over the 17th parallel into North Vietnam's panhandle and into the midlands and mountains of the Red River Delta and the Northeast. In response to the Gulf of Tonkin incident and the mortar attacks at Pleiku, the United States (US) began *Operation Flaming Dart* and the *Rolling Thunder* strategic bombing campaigns. Despite a clear American lead in hardware – advanced radars, beyond visual ranges, close-in heat seeking missiles, refuelers, heavy-bombers, and later in the war, precision guided munitions – the US failed to achieve air dominance over North Vietnam. The People's Army of Vietnam, supported by its Communist allies, fielded a formidable mixture of both sophisticated and unsophisticated air-to-air and surface-to-air weapons. By the middle of 1965, American fighters were being lost at a distressing rate of more than twelve a month, amounting to the loss of an entire squadron every 45 days. By the close of that year, the US Air Force (USAF) had lost a total of 174 aircraft, 16 pilots, and 35 aircrew members.[1]

Throughout the Vietnam War, the use of airpower was often ineffective. As Air Force Historian Brian Laslie has noted, although "poor organization, weak command and control, and lack of unity of command all contributed to aircraft losses in Vietnam…those were not as significant as [the] improper training for fighter pilots and bomber pilots."[2] Inadequate training was the largest contributing factor to USAF losses throughout the conflict. At the end of the Vietnam War, the Air Force acknowledged that they failed to accomplish their objectives, even when confronted with a country with conventionally inferior military capability.

The painful American experience in Vietnam gave birth to Red Flag – a fighter training program designed to give pilots real world experience – run by the USAF at Nellis Air Force Base in Nevada. Colonel Richard "Moody" Suter, the architect of Red Flag, recognized that superior technology alone could not guarantee victory in conflict and that USAF pilots needed real-world, high-fidelity training to fight and win in future air combat.

The lessons from Vietnam are as relevant today as they were in the mid-1960s and early – 1970s – superior technology without cutting-edge training does not secure military victory. Protracted insurgency campaigns in Iraq, Afghanistan, and now Syria have proven that a technological edge in conflict will not suffice to replicate the rapid overwhelming military success of the first Persian Gulf War.[3] Moreover, the US Department of Defense (DoD) has noted that "disruptive technologies and destructive weapons once solely possessed by advanced nations" have proliferated widely to insurgencies and terrorist groups.[4] Meanwhile, the potential for mid – and long-term technological parity has emerged between the US, China and Russia. Iran and North Korea are also expanding their precision-guided munitions stockpiles. Acknowledging that in a period of financial constraints, the US must develop alternative strategies to maintain military primacy and buttress the defenses of its allies around the world, the DoD has pursued a "third offset" strategy to maintain a competitive edge in defense technologies.[5] Yet, if the US is to leverage its technological advantages in future conflict, innovative training techniques must be utilized in order to maximize the operational benefits provided by superior hardware.

A new wave of simulation technologies promises to enable the development of the "Red Flag" of the 21st century. Live, virtual, and constructive (LVC) training that entails linking live platforms to manned simulators in virtual environments, and constructive forces in simulations should be the foundation of future military training solutions.[6] As the US seeks to "offset" the emerging technological parity of adversaries, LVC training capabilities need to be developed and leveraged as a key pillar of that strategy.

The Foundation of America's 3rd Offset Strategy

Since the end of World War II and the beginning of the Cold War, the US has confronted two periods in which it sought to reconcile the quest for greater security with sustained cuts in defense spending. During the Eisenhower years and in the in the mid-1970s, the US sought to "offset" the numerical force imbalance in favor of Warsaw Pact forces via strategies predicated on superior technology. As is the case with the

Third Offset Strategy, the First and Second offsets were intended to maintain our military superiority during lean budgetary times.

President Eisenhower's "New Look"

When Dwight D. Eisenhower assumed the Presidency in 1953, the trauma of World War II had not yet faded. Meanwhile the nation was entangled in a vicious conflict on the Korean peninsula and the Truman administration had recently ordered an increase in overall defense spending in order to meet the administration's containment objectives. Eisenhower viewed US defense spending as unsustainable and believed that the US could not afford to be bogged down in future proxy and limited wars. His campaign repeatedly emphasized that military power was not the only measure of national security and that economic vitality was the surest guarantor of US superiority over the Soviet Union. In a September 1952 public address, Eisenhower noted that "a bankrupt America is more the Soviet goal than an America conquered on the field of battle."[7] Frustrated by the Korean conflict, Eisenhower wanted to pursue a less reactive strategy – that from this point forward, the US would respond to Soviet aggression at the times and places of *its* choosing.[8]

Shortly before entering office, Eisenhower traveled to Korea with his national security advisors. On the sail home aboard the USS *Helena*, a series of conversations were held on the future of US national security policy. Two presentations helped steer the ongoing discussions: 1) Chief of the Pacific Fleet, Admiral Arthur W. Radford's argument that it was economically unsustainable and inefficient to contain the Soviet Union through a ring of distributed American forces, and 2) Secretary of State-designate John Foster Dulles' belief that America's growing nuclear stockpile was a means to deter future Soviet revisionism.[9]

Eisenhower's views became an amalgamation of the two. As Cold War historian John Lewis Gaddis noted, Eisenhower was a student of Carl von Clausewitz; "he did not doubt that the military means must be subordinated to political ends, but he thought that it ought to be possible to include nuclear weapons among those means."[10] As a result, shortly after entering office Eisenhower commissioned a senior level policy review that sought to simultaneously combine two principles: deterring future Communist aggression and enacting a cost-effective policy that would help preserve the economic health of the US nuclear weapons, both strategic and tactical, became a cornerstone of that policy.

The policy, which Eisenhower called "New Look," sought to combine the political, economic, psychological, and the military components of national power into a coherent, workable grand strategy, which is viewed in retrospect as the First Offset Strategy. It re-organized the defense establishment around nuclear weapons, cutting conventional forces. Attempting to match Soviet conventional military forces was deemed the excessive use of finite resources, whereas America's advantage in nuclear weapons could be used as a mechanism to "offset" the Soviet Army's numerical superiority.[11] In the words of John Foster Dulles' before the Council of Foreign Relations in 1954, a "deterrent of massive retaliatory power" would ensure that potential adversaries could no longer dictate the time and place of future conflict. "The way to deter aggression is for the free community to be willing and able to respond vigorously at places and with means of our choosing."[12] Eisenhower's willingness to consider the first use of nuclear weapons to mitigate strategic risk went beyond simple signaling. It was what caused Gaddis to later label him as "the most subtle and brutal nuclear strategist of the nuclear age."[13]

That being said, the "New Look" was not simply about nuclear weapons. It sought also to place greater value on the maintenance of alliances, strengthening bilateral and multilateral alliance structures while forging new ones, such as the Southeast Asia Treaty Organization and the Baghdad Pact (later the Central Treaty Organization). The US sought to assure allies of the solidity of its security commitment. The "New Look" also put greater emphasis on more surreptitious means of power – espionage, sabotage, and covert operations – in order to achieve US policy objectives at a reduced cost. As Robert Martinage notes, the Central Intelligence Agency became a favored instrument of power, toppling Communist-leaning governments in both Iran and Guatemala in 1953 and 1954, respectively.[14]

While some contemporary critics questioned some of the fundamental principles of the "New Look" strategy, history looks favorably on this period – Eisenhower was able to buttress Western deterrence without massive military expenditures. However, the strategy was not enduring – in a bipolar world in which the adversary was able to catch up technologically. In response to the "New Look" strategy, the Soviets expanded their nuclear forces while also maintaining their conventional superiority, setting the stage for Harold Brown's "Offset Strategy" of the 1970s.

Harold Brown's "Offset Strategy"

By the mid-1970s, the Soviet Union had achieved a rough nuclear parity with the United States and Warsaw Pact forces outnumbered North America Treaty Organization (NATO) forces threefold. Many in the US felt that Western deterrence was at risk. The US, still reeling from the trauma of the Vietnam War, and faced with ongoing Soviet expansionism, sought to leverage its asymmetric advantages in information communications technologies.

Then Secretary of Defense, Harold Brown, and his Undersecretary of Defense for Research and Engineering, William Perry, adopted what they termed an "offset strategy." The approach was to develop synergistic high-technology systems that could "look deep" and "shoot deep" into Warsaw Pact territory, giving US forces a qualitative edge over quantitatively superior Soviet forces.[15] As Secretary of Defense, Harold Brown explained in his 1981 report to Congress: [16]

> *Technology can be a force multiplier, a resource that can be used to help offset numerical advantages of an adversary. Superior technology is one very effective way to balance military capabilities other than matching an adversary tank-for-tank or soldier-for-soldier…*

Moreover, as Eisenhower had previously noted, attempting to achieve conventional equality would prove prohibitively expensive for the United States. The integration of high technologies into US military equipment provided a lower cost solution to Soviet military numerical superiority.

As a result, this second "offset strategy" embodied four key components: intelligence, surveillance, and reconnaissance (ISR) capabilities, providing commanders "battlefield awareness" or "situation awareness"; standoff precision strike or "smart" weapons, allowing munitions to strike targets as they are identified; stealth technologies, that would allow aircraft to evade radars; and the of use of space for ISR, communications, and precision timing and navigation. As Perry noted, taken together, these systems came to represent a "system of systems."[17] Most of the core enabling technologies for these systems were developed by the late 1960s and early 1970s. By the mid – to late-1970s, the Defense Advanced Research Projects Agency (DARPA) began to take these core enabling technologies, and combine them into proof of concept systems such as the F-117A stealth aircraft; the Integrated Target Acquisition and Strike (ITAS) concept for attacking armor deep within enemy territory, via airborne reconnaissance, long-range missiles, and terminally guided munitions, which later became the "ASSAULT BREAKER" program; the integration of ISR subsystems; and new weapon delivery programs, such as remotely piloted vehicles (RPVs).[18]

While conceived in the 1970s, most of these systems did not reach operational maturity until the mid – to late-1980s, and in some cases the early-1990s. The dissolution of the Soviet Union in 1991 ensured that the United States never had to employ these systems in combat against Warsaw Pact forces, but we did employ them at a large scale for the first time against Iraq.

The 1991 Persian Gulf War, or *Operation Desert Storm*, provided the first operational demonstration of Brown's 1970s "offset" strategy. Indeed, coalition forces employed most of the technologically advanced military systems that had been in development in the 1970s and 1980s, including, satellite communications and reconnaissance, direct-attack and standoff precision-guided munitions (such as the Paveway III laser-guided bombs and the Tomahawk Land Attack Missile or TLAM), and the radar evading aircraft, the F-117. The 500,000-man strong, Soviet modeled and equipped Iraqi Army was little match for the US and coalition forces' superior precision firepower.

For many, the triumph of this operation suggested that countries which successfully leveraged high-technology systems would rapidly acquire overwhelming military superiority. However, despite the swift victory achieved in the Gulf War, others have repeatedly cautioned that technology is not a panacea. Technology alone is insufficient to obtain battlefield superiority; rather it is the manner in which a country embeds technologies within a larger military strategy that helps to ensure victory.[19] To more sceptically minded strategists and academics, the Gulf War was only partially successful at translating technologically enabled concepts into battlefield victory.[20]

The Challenges of the 21st Century Operating and Strategic Environment

Today the US and its allies find itself facing an increasingly complex security environment.[21] The unipolar moment of the post-Cold War has collapsed, giving rise to an operational environment characterized by multiple increasingly revisionist and expansionist competitors and an extremist proto-state that has exported its terrorist philosophy abroad. Secretary of Defense, Ash Carter, has characterized this as "four countries and a condition" – Russia, China, North Korea, Iran, and the Islamic State of Iraq and the Levant (ISIS).[22]

In the Middle East, the sovereign border between Syria and Iraq has largely been erased by ISIS – a totalitarian entity that has sought to impose an Islamic-extremist form of governance on swaths of the Levant region. While ISIS is beginning to lose some territorial control as a result of US-led coalition airstrikes, their cancerous ideology has metastasized around the globe, inspiring terrorist attacks from San Bernardino, to Ottawa, Paris, Ankara, and Dhaka. Meanwhile, the Sahel has emerged as a second major front in the global war against terrorism, as Boko Haram, ISIS, and al-Qaeda in the Maghreb, along with other Saheli-based terrorist groups, gain a larger toe-hold in the region. At the same time, an Iranian-dominated "Shia Crescent" is emerging in the region, as Shia militant groups increasingly fill the vacuum created by the fragmentation of Syria and Iraq. Iran and its allies have sought to prop up Bashar al-Assad in Syria and supported violent proxies in Yemen. [23] Perhaps more concerning, the Deputy Commander of the Islamic Revolutionary Guards has reiterated Iran's longstanding threat to close the Strait of Hormuz – a key maritime chokepoint for the global economy – to any "threatening" ships, in a clear signal to US naval vessels.[24]

In East Asia, North Korea's nuclear and ballistic weapons programs continue to pose a threat to US and allies' security. In January 2016, North Korea conducted what it claimed was a successful test of a "hydrogen bomb." North Korea's stockpile of ballistic missiles – both close range and intercontinental – continues to expand. What's more, North Korea has become particularly skilled at using offensive cyber operations for influence and sabotage. Pyongyang has thus been linked to the 2014 Sony Pictures Entertainment hack and the Korea Hydro and Nuclear Power (KHNP) plant.[25]

China, under the leadership of President Xi Jinping, has placed a renewed emphasis on military power. The Chinese have modernized their nuclear weapons force, ensuring the viability of their second strike capability by upgrading their silo-based system and integrating more survivable road-mobile systems.[26] Likewise, the government has heavily invested in systems geared towards anti-access and area denial capabilities. These systems not only include anti-ship ballistic missiles and cruise missiles – such as the much-discussed DF 21-D anti-ship ballistic missile – but also more asymmetric methods such as offensive cyber, electronic, and information operations.[27] Indeed, in 1999, People's Liberation Army (PLA) colonels Qiao Ling and Wang Xiangsui published a seminal work entitled *Unrestricted Warfare,* which argued that modern warfare should transcend traditional military hardware to include information, economic, and psychological operations.[28]

Likewise, a revanchist Russia continues to exert pressure on its neighbors. Using a combination of nuclear-tinged coercion, propaganda, and strategic deception, Russia has sought to sow instability abroad.[29] President Vladimir Putin has overseen an impressive overhaul of Russia's armed forces. The Kremlin has actively updated the three legs of the strategic triad and modernized its conventional force structure, with the goal of updating at least 70% percent of the Army's equipment by 2020.[30]

Moreover, both China and Russia have become increasingly revisionist and assertive towards their neighbors. Indeed, from Ukraine to the South China Sea, Moscow and Beijing have been attempting to resurrect age-old spheres of influence and challenge the existing global order. They have manifested a predilection for "gray zone" approaches – testing US security commitments and platforms through "salami slicing" or probing tactics that do not in and of themselves amount to a *casus belli*, but nevertheless threaten to create a *faits accomplis*.[31] The development of Beijing and Moscow's strategic and conventional weapons systems, and their irredentist strategic behavior, has caused some to label the emerging threat environment as one characterized by the materialization of "great power competition [on a level] that we haven't seen since 1989."[32]

It is within this context – and during an era marked by fiscal austerity – that the US has sought to adopt a "third offset" strategy. Unlike the first two offset strategies, no single technology or set of technologies characterizes the third offset. In fact, exactly what the third offset is has been somewhat elusive, but we are confident that technology alone will not solve the complex strategic and operational problems of the 21st century.[33] Any long-term strategy to help stabilize the Middle East – one day devoid of ISIS and other radical groups – requires more than an antiseptic approach to warfare; it requires human interaction and involvement on the ground, which inevitably requires well-trained soldiers.

Moreover, as China and Russia continue to pursue programs of rapid military modernization, and Iran and North Korea enlarge their stockpiles of precision guided munitions, the US and allies will need to develop alternative strategies to project power and maintain military supremacy.[34] Officials at the Pentagon have noted that the US and coalition forces face the real possibility that in the near – to mid-future they may find "themselves facing an arsenal of advanced, disruptive technologies that could turn [US and coalition] previous technological advantage[s] on its head."[35] Deputy Secretary of Defense Bob Work has advocated the transition from one new technological regime to another in order to maintain superiority – a "third offset." This must be accompanied, he notes, by "innovative thinking, the development of new operational concepts, new ways of organizing, and long-term strategies."[36] In this report, we argue that training that leverages the capabilities offered by LVC can be a significant enabler of the innovative approach Deputy Secretary Work requires.

The Third Offset Strategy and Live, Virtual, and Constructive

Since the "third offset" was first announced in 2014, a vibrant discussion has emerged in Washington, DC policy circles over the precise architecture of the "third offset," yet that architecture remains unresolved. Robert Martinage of the *Center for Strategic and Budgetary Assessments* has noted that the prevailing approach to US and coalition warfighting since *Desert Storm* has been predicated on the ability for large concentrations of combat forces to project power from safe havens prior to the start of a high-tempo, combined arms campaign. This, he notes, has become increasingly untenable.[37] The "third offset" strategy, he argues, should exploit "enduring sources of US advantage" to maintain a forward presence, while projecting power against adversaries armed with anti-access/area-denial (A2/AD) capabilities and expanding precision guided munition weapons arsenals.[38] Shawn Brimley and Loren DeJonge Schulman of the Center for New America Security have largely echoed such sentiments – the third offset strategy should ensure US ability to operate in an era marked by the proliferation of precision.[39]

In order to meet 21st century threats, Brimley and DeJonge argue for continued investment in undersea platforms, particularly unmanned underwater vehicles (UUVs), and comparable investments in emergent capabilities for ground forces, such as the DARPA's EXACTO guided 50-caliber bullet.[40] Likewise, Martinage advocates for the adoption of UUVs; "seabed payload pods" that could hide UUVs; electromagnetic rail guns; increased coverage of undersea sensors; and counter-sensor weapons, such as directed energy systems; among many other technologies.[41]

While technology should be a key aspect of the "third offset" strategy, technology is not an end in and of itself. Steven Biddle, a preeminent theorist of military strategy, has noted that "the defense debate is increasingly focused on technology; most assume that in the information age, superior technology wins wars, fueling growing pressure to speed modernization by spending less on training and readiness."[42] History shows that is not the case, and modern history has demonstrated that technology advantages are fleeting – and are becoming more fleeting. Furthermore, technology alone does not provide capability. Ultimately, combat effectiveness results from a combination of technology, training and a range of materiel and logistics factors that are often combined into the term "readiness."[43]

We argue that in order to meet the third offset strategy's innovation challenge, training enabled by combinations of LVC capabilities can and should be a key part of that strategy. We will also argue that LVC capabilities can enable US forces and coalition partners to train together more often, and more affordably, for operations in increasingly contested environments.

The Rationale for Live, Virtual, and Constructive in the Third Offset

A common mantra within the US armed forces, and other militaries, has been to "train as you fight." The hemorrhaging of fighter aircraft through the latter part of the Vietnam War gave rise to "Red Flag" – a fighter training program designed to give pilots real world experience. However, the dogfights and tight aerial maneuvers that characterized air combat in the 20th century, have given way to the contested, beyond visual range environments of the 21st. The Army, Air Force, Navy and Marine Corps need new operational concepts, and new training techniques, to fight and win in these increasingly complex environments. While the end goal – realism in training – remains the same, the means to achieve that end are different. A high fidelity A2/AD training environment – which successfully incorporates both "traditional" kinetic as well as non-kinetic effects such as those created by cyber and electronic operations – cannot be created solely in a live training environment.

LVC provides the means to achieve that realistic training end. By combining live platforms with virtual simulators and simulations providing constructive forces, the military can train for larger, more diverse operational scenarios that involve cyber-attacks, electromagnetic spectrum warfare, saturation attacks of precision guided munitions, and cross-domain lines of operation. Testifying before the House Armed Services Committee on the Air Force's FY2015 science and technology budget, Air Force Deputy Assistant Secretary, David Walker, noted that "the training need for LVC is real…in particular realistic training for anti-access/area-denial environments is not available." Walker went on to explain that LVC training "can provide greater focused training for our warfighters across a range of operational domains such as tactical air, special operations, cyber, ISR, and [command and control]."[44] Furthermore, live training environments will not be conducive to the training needs of many 5th generation platforms, such as the F-35 Joint Strike Fighter – their capabilities are more sophisticated than USAF's Red Flag's capacity to test them. Moreover, the spatial limits of live training ranges, when combined with the threat of potentially revealing the unique warfighting attributes of 5th generation platforms in a live training environment, means that a lot of 5th generation fighter training may be better conducted in the virtual domain.

Finally, as the US and allies grapple with a period of fiscal austerity, LVC provides the potential for substantial defense savings in the long run. The increased use of virtual and constructive training platforms could lower the maintenance costs on live platforms, avoid costly trainee errors that break equipment, and shrink the transportation and logistics costs associated with complex live cross-domain and coalition exercises. Moreover, the cost differentials between an hour of live flying versus an hour in a simulator are estimated to be significantly less; with an hour of live F-16 bloc training valued at $7,500 in comparison to $900 for an hour of simulation-based training.[45]

In sum, as the US seeks to develop another offset strategy to counter the emerging capabilities of adversaries, LVC training should be leveraged as a key pillar of that strategy. As Rear Admiral Michal Manazir, Deputy Chief of Naval Operations for Warfare Systems has noted, "training for expanded battlespace is the key to success…[and] modeling, analytics, and simulation is the coin of the realm as we go forward."[46] Though this remark was addressing the Pacific Theater – the largest theater for any of our combatant commanders – the ability to expand the training battlespace is equally important for overcoming adversaries in any of the "four countries and a condition" or, for that matter, future emergent threats. The only affordable way to accomplish that kind of training is with new LVC capabilities.

2. Imagining the Future of Military Training and Experimentation for Next Generation Warfare: The Role of Live, Virtual, Constructive

In this section we introduce some key concepts, provide an overview of current training methods, and briefly highlight why they are insufficient to meet the training and experimentation needs of the future. We then explore LVC – including the benefits of combining LVC for future individual, team, platform, unit, and joint training. We assess how LVC can be utilized by the military to train for future operational scenarios. Moreover, LVC's role in strategy development and innovation is analyzed. Finally, we investigate how – as the geopolitical and technological landscape undergoes massive shifts – LVC can be used by the military to train for black swan scenarios (i.e., those that deviate well beyond our expectations and/or that pose a situation we have been unable to predict).

The US military Services' vision for future training is clear. Each of the Services describe their preferences – in varying levels of detail – in briefings, concepts, and news media articles. One of many examples is that in 2014, the Army developed a new vision of next generation simulation called the Future Holistic Training Environment (FHTE) Live Synthetic or, simply, Live Synthetic[1] describing an ideal future in training exercise.[2]

This is followed by an explanation of why the Army believes this is not a pipe dream. The article describes a future application of LVC capabilities to establish more realistic training systems, and to enable geographically distributed forces to train together seamlessly and frequently.[3] All the Services are exploring LVC capabilities for a variety of reasons. Here, we will combine descriptions of LVC capabilities including some viewpoints on the future of military training – and experimentation – and will explain our rationale for why we believe this future is achievable.

Definitions

Let's start by defining and describing the terms "Live," "Virtual," and "Constructive" as applied to military training. "Live" training means real people training on real systems.[4] Live is the "traditional" venue for training, and the one still preferred by many military commanders and trainers. An example of Live training is a dismounted patrol, moving through real terrain, observing events and conditions with their own eyes and ears, and reporting to their higher headquarters using genuine radios. The general opinion is that with live training, you are actually doing your mission with your actual equipment, so this type of training is "best" because it is the most realistic.

On the other hand, experienced military personnel often use the aphorism: "anything short of actual combat is simulation." There is truth in this statement. Considering the example of the patrol, if that patrol is part of a force-on-force exercise, in which the "enemy" is also live people using their equipment, then when opposing forces meet, they are not firing live ammunition at each other for obvious reasons. At the same time, if the patrol is part of a live-fire exercise, then when they encounter "enemy forces" those are *not* going to be living, adaptive, reactive people. At best, the enemy may be robotic or remote csontrolled targets that are at least mobile, but often times live-fire targets are piles of tires or the hulks of old military vehicles that do not move or react at all.

The point is that even in "Live" training there are simulated elements. Probably the most prevalent example of "live simulations" is weapons effects training systems used to inject an element of realism into force-on-force exercises.[5] These may include both actual low-powered projectiles such as Special Effects Small Arms Munitions (SESAMs), sometimes called simunitions, which replace bullets with wax pellets that have various colors for marking which side shot the rounds. Basically, SESAMs are accelerated versions of paintballs, and the two share many of the same limitations. To avoid injuring trainees, SESAMs are sufficiently low-powered that they have relatively short range (50 meters is long shot with SESAMs), and ballistics that are very different from live rounds – for example, beyond 20-25 m, getting a hit with SESAMs is as much luck as good aim because the light-weight projectiles quickly lose their velocity and deviate from their aim point by wind or simple air resistance.

Another form of weapons simulation that is widely used is laser-based systems such as the Multiple Integrated Laser Engagement System (MILES) or its follow on, the Instrumented Tactical Engagement Simulation System (I-TESS). These systems increase range dramatically by using lasers, but lasers are also ballistically different than live ammunition. Furthermore, if a soldier is missing the target with a laser-based system, he/she cannot see where the misses are hitting, so cannot effectively correct aim. The bottom line is that "Live" is frequently preferred because it appears to have the highest form of realism – but even live training has shortcomings.

"Virtual" training means real people using simulated systems.[6] For example, a pilot in a flight simulator training for emergency procedures is conducting virtual training. With live aircraft, you only get to really foul things up once, and the consequences of so doing are loss of an expensive aircraft, or possibly the pilot's life. So the aviation community was arguably the most receptive to virtual training because of the safety of flight considerations associated with operating live aircraft, particularly in dangerous situations such as engine flame-outs.

So the aviators may have been first, but other communities have also embraced the advantages of virtual simulators for combat vehicles, convoys, fire support training, missile and naval gunnery engagements, and other areas. One of the advantages seen virtually across the board is the cost savings associated with operating virtual simulators, with lower system operation and maintenance (O&M) costs, and also enabling users to avoiding the cost of live ordnance.[7] Even for unguided mortar and artillery, and "dumb" bombs, the cost of live ordnance adds up quickly, and in general for explosive ordnance there are restricted impact areas where it can be employed. For these reasons, virtual simulators are increasingly being developed and used even in training areas where safety considerations are not the driving factors. The Services are seeing that the development costs of simulators can be relatively quickly offset by the cost avoidance for live equipment O&M, reduced wear and tear on combat gear, and in particular live ordnance cost savings. As a result, simulators are often the only way some get to launch live ordnance.[8] For example, the Marine Corps recently developed an experimental "squad fires" training program to teach their squad leaders to employ Type II.[*] They used a simulation from their Deployable Virtual Training Environment (DVTE) to support this training because they simply could not afford to have every infantry squad leader controlling live ordnance.[9]

"Constructive" training means simulated people using simulated systems. Traditionally, constructive simulations were developed to reduce the number of people and equipment involved in staff training, while providing a more dynamic environment than Master Scenario Events List (MSEL) driven Command Post Exercises (CPXs).[10] MSELs and CPXs are still used for military Commanders and Staff to work through procedural issues, but constructive simulations can provide a much richer and less predictable (depending on the capabilities of those operating the simulated forces) environment for "graduate level" Staff Exercises (STAFFEXs).

Sometimes, constructive training simulations are derivatives of the large analytic or combat models used to address budgetary issues such as non-nuclear ordnance requirements or other formal requirements trade-space issues. Because these models and their results can be highly classified, training versions of the same basic simulations that change weapons systems performance and effectiveness "just enough" to lower the classification can be very useful for training. For training, the question of who might "win" a particular engagement is generally much less important for commanders and staffs than the problem-solving, decision making and coordination objectives. Oftentimes, the training simulations have additional features included that allow better interaction between commanders and staffs that combat models often do not include because they are intended to calculate physics-based trade-offs.

* Type II CAS is used when a trained Joint Tactical Air Controller (JTAC) cannot observe the target. So the JTAC manages the engagement, but an observer (squad leaders in this case) conducts the pilot talk-on, calls for the mark (if used), and adjusts ordnance impact locations if necessary for subsequent passes of the aircraft on the target.

Constructive training simulations can be developed at relatively low cost by "tweaking" combat models originally developed for analytic purposes, and then adding training-specific features, rather than developing entire simulations from "scratch."[11]

Combining Live, Virtual, and Constructive: Live, Virtual, and Constructive Capabilities

The definitions and descriptions above are all based on traditional, single uses of L, V, and C training capabilities. The Services have been using them for years, and even sequencing them (e.g., using virtual simulators to conduct procedural training for small units, and constructive simulations to train command and staff actions, before putting all the elements together in a large-scale exercise). That being the case, what's the point of *combining* them into "LVC" as opposed to traditional single uses? Perhaps more important, what can the Services accomplish if they do combine them? The short answer is that L, V, and C all have unique strengths and weaknesses, and combined properly their various strengths can offset the weaknesses of other capabilities. Furthermore, combining L, V and C capabilities via network connections can offer additional opportunities to scale exercises without requiring large numbers of people to all travel to a common location. The fact that all the Services are exploring LVC is an indicator that they believe there are benefits to so doing, and they are expending resources to do so even in an era of shrinking budgets. In this section, we explore those strengths and weaknesses, and provide some examples of how combining them can produce previously unrealized benefits.

Individual Benefits of Live, Virtual, and Constructive

As we have stated, live training has traditionally been considered the "gold standard" of realism and useful training experiences.[12] We also pointed out some of its shortcomings, mainly having to do with weapons effects – we cannot shoot/launch/drop real ordnance at live opposing forces in force-on-force exercises, and live fire training against non-live targets means that the targets do not act and react realistically.

Another downside of live training is that it is resource intensive, particularly for training forces that are geographically distributed.[13] Furthermore, even forces that are co-located frequently must travel to live training areas to have sufficient maneuver room. Finally, the larger the scale of training exercises, the fewer opportunities there are to participate in them. For example, the Army's National Training Center (NTC) at Fort Irwin is viewed as the exemplar of force-on-force maneuver training,[14] the Marine Corps Air Ground Combat Center (MCAGCC) at 29 Palms is viewed as their premier live-fire training venue, the Navy's Top Gun and Air Force's Red Flag are their best pilot combat training centers.[15] As a result, those training areas and schools are scheduled months or years in advance, and many individuals and units only get to participate in such foremost training every year or so at best. So the opportunities for the most realistic live training opportunities are few and far between.

Also as noted above, virtual simulators provide opportunities to train for dangerous or unsafe activities, and to reduce the cost and wear and tear on actual systems. Done properly, virtual training can be very realistic. Even so, trainees know when they are in simulators that there is a "reset button" if they do err, so even though the experience can be very immersive and realistic, the "pucker factor" of fully live operation of an aircraft, tank or ship's combat system just is not there in a simulator. And for dismounted troops, the available virtual systems (such as the Virtual Battle Space (VBS) systems the Army and Marines use, which are adapted from video game technologies) cannot replicate the heat, sweat and fatigue of slogging heavy burdens long distances and then engaging in a firefight.

On the other hand, with virtual simulators, trainees can build the "muscle memory" of repetitive procedural actions, confirm-by-doing operational and coordination procedures, and take advantage of that reset button to quickly reset and redo training exercises if they do mess up. So virtual simulators have in the past been used to practice for the relatively fewer live opportunities: in short, simulators can be used to conduct "crawl" and "walk" level training so that when they do get live opportunities, our servicemen and servicewomen are ready to "run" during those limited opportunities. Having said that, this does not yet make the case for LVC combinations, but rather for using V (and C, see below) in sequence with L. We return to this topic after we discuss constructive simulations.

Constructive simulators do for staffs and commanders what simulators do for individuals and vehicle crews. In these simulations, at relatively low cost large numbers of forces can be replicated by a relatively small number of simulation operators (often called "pucksters" because in some of the early simulations they used mouse-like devices called pucks to control the constructive forces' actions) to stimulate commanders and their staffs to respond and act. Furthermore, with sufficient experience and imagination, the pucksters can provide varying and challenging situations for commanders and staffs to act on.

But the fact remains that constructive forces have rote/pre-programmed behaviors, particularly for their activities at the tactical level. If they did not, then it would take a puckster to play every individual, which would defeat the purpose of having constructive simulations in the first place. As a result, the actions of constructive forces, even if "brilliant" at the operational level due to the pucksters' skills, are predictable at the tactical level. Furthermore, in the constructive simulations, everything works as intended – unintended consequences and unforeseen circumstances rarely arise in constructive simulations, and when they do, the trainees (knowing they were induced by pucksters) often argue the results are unrealistic (which is generally true – when pucksters do introduce unanticipated problems, they almost always do so in critical areas in order to stimulate responses that support training objectives). So constructive simulation based training tends to become predictable after a few repetitions. As Murphy's corollary of combat puts it: "professional warriors are predictable, but battlefields are full of amateurs."[16] In short, the activities of constructive forces do not provide the range of realistic adaptability that is key to modern warfare.

Benefits of Live, Virtual, and Constructive

So how can the strengths of each environment: L, V, and C, be combined into LVC to offset their individual weaknesses? We make the claim that combinations done properly can introduce synergies by leveraging the unique aspects of each environment to offset some of the weaknesses of others, but other than this bold (and thus far unsupported) assertion, what do we mean? To answer this question, let's start with the elephant in the room: the cost of training. That cost can be measured in dollars and in time. As briefly described in the Army's Live Synthetic vision, combining LVC capabilities can enable geographically distributed forces to train together.[17] As a result, they do not all have to travel to the same location in order to do so. This can dramatically reduce the cost of training, and also reduce the time required to conduct that training.

Let's explore that from the perspective of current training at the NTC or MCAGCC, as two examples. Both have training equipment, including major end items such as vehicles, and logistics support for exercise equipment, so that the unit to be trained does not have to transport all its equipment, support and supplies to the training center (thus reducing the transportation cost). But the unit does have to draw (take custody of) that equipment from the training pool, check it out to make sure it is functional, and put it together with other, smaller items they have brought with them. Doing this takes time and, as most who have trained at one of these centers of excellence will tell you, *because* that equipment is there for use by all, it is owned by none and therefore tends to be in less than ideal condition. In part, that situation occurs because training pool equipment gets used a lot. But the reality of human nature is that soldiers or Marines know they are only "renting" that equipment for use during their training. Do you take the same care with a rental car as with your own car? Perhaps not, and the same is true of equipment drawn from a training center for use during an exercise.

The point is not to criticize common training equipment pools, but simply to call attention to the reality: the cost of not transporting their own equipment to the training center has other consequences, meaning a unit has to allow the time to draw the equipment, assemble it, check it out, learn any differences in types or models from their primary equipment, and so forth. In short, the time and effort to conduct all these functions offsets some of the cost avoidance advantages of not transporting their equipment.

NTC and MCAGCC training exercises are not the only examples. The Air Force Red Flag exercises or the Navy's Rim of the Pacific (RIMPAC) are other major exercises. Beyond the cost of operating military aircraft (generally several thousand dollars per flight hour),[18] the basic problem for aerial and naval exercises is scale within the available training areas: the limitations on air space reserved for training limits the scale at which aerial combat training can be realistically accomplished, and naval maneuver areas[†] near land masses of any significance tend to be very restricted. High-performance aircraft can travel great distances very quickly, which means that only a relatively few can be in the air at any given time.

On the other hand, some of the major exercises conducted in Combatant Commander (COCOM) areas – such as RIMPAC exercises – have purposes other than pure training.[19] Many such exercises are intended to demonstrate our capabilities to allies and adversaries as well as provide training opportunities, which means that the training planners have to keep those potentially competing objectives in mind. With reference to cost, the hourly flight costs of military aircraft are small in comparison to ship steaming days. So while one might opine that the oceans are large, the Navy cannot afford to have all its ships steaming constantly – in short, opportunities for training while in port are important to the Navy, too.

If LVC capabilities enable units to train at their home stations or home ports, connecting to other units elsewhere, then LVC can offset the disadvantages of having to transport and assemble combat formations at major training centers, can enable greater scaling by "stitching together" smaller scale, geographically distributed forces, can focus primarily on the training objectives of individual and collective units, and can enable training regardless of whether ships are steaming or in port. In short, LVC, *if successful*, can enable units to remain and train at their home station, but to "virtually assemble" into larger formations more frequently than the limited opportunities to engage in those premier training events at NTC, MCAGCC, Red Flag, RIMPAC, and other exercises. We'll address the technology aspects of that "if successful" qualifier in the next section. But before we do that, let's briefly summarize the advantages of geographically distributed, LVC enabled training, and levels from individual through large-scale formations:

1. From individual to small team level: this includes individual soldiers, sailors, airmen and Marines along with collective small teams such as aircrews, vehicle crews, infantry fire teams, and specialized individual and small team functional specialists and organizations such as Joint Tactical Air Controllers (JTACs) or Fire Support Teams (FISTs). Both live and virtual training can enable practicing procedures (e.g., communications or calls for fire), repetition to develop "muscle memory" needed for common skills, and coordinated team activities. Particularly if simulators can be tied together, then a pilot may be flying a virtual aircraft at Nellis Air Force Base, NV, supporting a JTAC located at Camp Pendleton, CA who is providing supporting fires for an Army squad maneuvering within VBS at Ft Hood, TX. That JTAC may be adjusting fire from a mark provided by a Navy destroyer (DDG) located at a pier in San Diego. This can increase training opportunities, build teamwork between geographically distributed organizations, and reduce the overhead and O&M cost of training.
2. From small team to "teams of teams" (units) level, which means tactical level units such as an Army platoon, a Marine company, an Air Force squadron or flight of F35s, or a Navy individual platform or small surface action group of two DDGs and a cruiser. These small units may be maneuvering, providing supporting missile strikes, or working on building common standing operating procedures (SOPs) for tactical level combined arms task forces, and of

† So why can't the Navy just go to open ocean areas to train? They sometimes do, but the last major ship vs ship battle was at Jutland in 1918. The Navy's modern missions generally involve operating near strategically significant land masses, and those areas tend to have high concentrations of commercial ship traffic so the available maneuver areas are indeed restricted.

course may include "all of the above" as well as other options. At the low tactical level, Joint forces are frequently "globally sourced" from whichever tactical formations are available to deploy to an emerging crisis or contingency in a COCOM's area of operation.[20] By providing connectivity to these units engaged in live or virtual training, tactical units can practice command and control (C2) or communications connections and processes, familiarize each other with their SOPs and practices, and get to know each others' tendencies through repeated interactions prior to deployment, or even during movement to the theater. Even though unanticipated contingencies may require deployment of whoever happens to be available, the various COCOMs generally have forces allocated to them in an ordered way. Knowing who is on "their team," low-cost team of teams exercises can be scheduled at various unit's home stations if the L and V systems and connectivities are available.

3. From units to formations and task forces (multiple units) levels. This is the arena where there are opportunities for scaling up by mixing L and V with C. L and V units provide improved stimuli for staffs by having live forces providing reports and other inputs, to include introducing believable "things going wrong" (because they really did) as conditions change, while fleshing out the task force with constructive forces so the staff must manage the entire battlespace. Commanders and staffs engaged in exercises with even a few live and virtual forces have reported that the live players (even those in simulators) offer more realistic inputs and reactions because they are actually conducting their missions (as opposed to pucksters, many with extensive military experience, having to "remember" mission experiences while controlling multiple constructive elements). And having additional constructive forces to flesh out the exercise to a appropriate scale tends to overcome the tendency of commanders or staffs to micromanage the few "live humans" they have access to, while enabling those unpredictable people and their actions to introduce the "fog of war" that is frequently not available in purely constructive training exercises. The result is a larger-scale exercise with a fewer resources, the ability for participants at all levels to train simultaneously, and enabling the lower echelon to access higher-level functions (such as Fire Support Coordination Centers) they might not have in separate, smaller-scale exercises.

Of course, all these possibilities are moot if the various L, V, and C capabilities cannot be tied together successfully. In Section 3 of this report, we explore some of the specific technical challenges, and opportunities, the Services are experiencing now. But prior to getting into the here and now, we propose in the segment below that though there are, and probably always will be, technical challenges, the foundational technologies to enable L, V, and C to be melded into integrated, interoperable LVC capabilities are all available. In short, there are certainly developmental and engineering challenges, but no "breakthroughs" that are preventing LVC from becoming a reality for Service and Joint training.

Live, Virtual, and Constructive Technologies

As stated in the paragraph above, the idea of this particular part of the report is somewhat in opposition to the technology discourse in Section 3. In Section 3, we discuss some of the current technology challenges, and consequently the opportunities for overcoming them. In the current section, which is more about imagining the future of LVC, we point out that with recent developments, there are no fundamental technology breakthroughs needed to enable fully integrated, interoperable LVC capabilities. So with a view toward the future, let's explore why we make such a claim.

We begin this discussion with a relatively low-risk claim: integrating V and C capabilities is an engineering challenge. In Section 3, we delve into the current nature of this challenge given that the Services all have existing, or "legacy," virtual simulators and constructive simulations that were not designed to work together, and that were designed to meet different data transfer standards. Therefore, the current situation does have significant challenges to the Services desires to federate, if not integrate, their existing systems.[‡] We do not mean to minimize that challenge here; instead, we point out that there are few developers who, presented with a challenge to design a new generation of virtual and constructive training systems, would propose that there are any significant technical reasons why that cannot be accomplished (cost issues, however, can significantly change that response). In short, there are *transition* challenges, not fundamental *technology* challenges, to integrating V and C capabilities.

In fact, it appears that the Army has recognized this is the case, which may have triggered their new FHTE/Live Synthetic concept. The underpinning hypothesis of Live Synthetic appears to be that in the long run, rather than continuing to pour resources into existing sims (an abbreviated term we use to mean both simulators and simulations) that were never designed to work together, they may be better off to just start over and design them that way in the first place. Furthermore, a recent Air Force briefing on LVC proposes an Air Force "LVC Chassis" that will enable them to build onto their existing simulators to (among other things) scale up to larger aerial forces by connecting available live air space with virtual and constructive capabilities. The briefing indicates that it is the Live aspect of this proposal that is the most challenging (we agree – more on the Live aspects, below).

So, the Army and Air Force appear to agree with the assertion that integrating V and C is an engineering challenge. Currently, the Marine Corps is watching carefully what the Army is doing, while continuing to focus on federating their existing sims (at least some of them). This is not surprising; the Marine Corps frequently lets the (in their opinion) better-resourced Army pioneer such efforts, and then joins the Army when it appears they will be successful. Certainly the Army and Marine Corps have been and are continuing to discuss areas where their training needs overlap. So it would not be surprising at all to see the Marines join an Army purchase of next generation sims once the Army has progressed from concept to a new LVC architecture and family of sim designs.

The Navy has not been as vocal as the other Services on LVC capabilities. Certainly they are paying attention to them, but thus far, most of their use of the term LVC has been focused mainly on the aviation community, which fundamentally is in the same situation as Air Force aviation: the need for more airspace (and ability to track activities/conduct engagements in that air space, not just fly around) and scaling to larger force levels. The Navy also has ties to the Marine Corps, and the Marine Corps aviation community's Aviation Distributed Virtual Training Environment (ADVTE) is progressing in development; in fact, Navy simulators can join ADVTE.[21] So the Navy aviation community's approach is currently similar to, and in fact connected with, Marine aviation.

As we'll point out in the current situation discussion in Section 3, aviation is only one of five major "tribes" in the Navy. But that does not mean the other tribes are not paying at to LVC. They often discuss the ability to network training systems and devices, and in fact the Navy is already advancing in building the underpinning network connectivity, called the Navy Continuous Training Environment (NCTE) – so well along that the Marines want to leverage that network for their own training sims.[22] NCTE is designed to enable geographically distributed Naval commands to network training capabilities, and the Navy Warfare Development Command (NWDC), which is co-located with the Navy's well-known, world class wargaming capability in Newport, RI, is responsible for developing concepts, doctrine, and innovative capabilities.[23] So the Navy may not be waving the LVC "banner" around, but that does not mean they are not well invested in developing LVC capabilities. We'll discuss their rationale in Section 3, but the short version is that the Na-

‡ We use the terms federate, integrate and interoperate in various places throughout this report. Different organizations use these terms to mean different things, so let's define our meaning, which we use consistently throughout. "Federate" means two or more systems are connected through middleware such as a bridge or translator program. The middleware is needed to enable systems that were not originally designed to work together in order to do so. "Integrate" means two or more systems can connect and operate without the need for separate middleware between them. "Interoperate" is a more general term meaning two or more systems are able to operate together at some level, whether requiring middleware or not.

vy's greater challenge is training a wide variety of military occupational specialties (MOSs) and ratings to operate ships' systems in a realm where even different ships of the same class have differing systems. So they are interested in LVC, but the Navy's elephant in the room is focused on leveraging individual distributed learning, on ship-level simulation support (i.e., being able to stimulate all of a ships' combat systems individually toward a common end – "fighting the ship"), and on individual refresher training for those in shore billets (again, focused on individual distributed learning).

The bottom line is that all the Services are exploring ways to better interoperate V and C training capabilities, and there are no fundamental technology breakthroughs needed to do so. The question is mainly should they skip federating (or integrating) their existing sims or simply design the next generation to do so.

And that leads to what many consider to be the biggest remaining challenge: integrating V and C into L. Note the way that is phrased: getting V and C into L. The challenge is the directionality implied by that statement: "into" L. For years, the Services have been able to inject L into V and C by means of their various instrumentation systems, which can record and transmit position location information (PLI), health status (entities that are "alive" or "dead" based on simulated engagements), and where engagements are taking place – down to individual soldier/Marine/vehicle/aircraft/ship's system engagements. We have already mentioned the MILES[24] and I-TESS[25] simulators that the Army and Marine Corps have used (I-TESS is the more modern version that is replacing MILES). Those systems allow "scoring" of weapons shots on targets, and provide feedback to the live participants if they are hit (or have a near miss), so from that perspective simulated effects are being incorporated into live training.

The problem is that those effects are not presented to the live participants realistically. A near miss is indicated by a sound, not a soldier seeing a bullet splash near his/her position. A kill is indicated by a Marine's vest signaling him/her or by a flashing light on a vehicle. If simulated artillery or mortar rounds are landing, the first time the live participants can recognize it is when vests start beeping and lights start flashing, or when an observer controller tells them they are receiving "incoming." So at present, *realistically* introducing the effects of a virtual aircraft dropping bombs on a target, or a constructive ship firing a naval gunfire support mission, to live exercise participants has been sorely lacking.

Until recently, that is. The brief Army vision presented at the opening of this section mentions "Soldiers see the visual recreations … in real-time through special glasses that allow them to see the real world around them, while simultaneously viewing the simulations." Those "special glasses" are not yet available, and certainly the computing power to allow a large number of soldiers to each see virtual and constructive injects from their own, individual perspectives, are also not available. But, the Marine Corps recently transitioned an Office of Naval Research (ONR) project that does just those things, only to a limited degree. The system is called Augmented Immersive Team Trainer (AITT), and it is an example of a first-generation Augmented Reality (AR)[§] system that allows virtual and constructive effects to be injected into live training.[26] What it allows Marines to do is see virtual effects from mortars, artillery and aircraft on the live battlespace. In short, AITT uses a helmet-mounted camera to overlay the "live world" and virtual effects onto the same view. At present, that view is camera-based, and has not reached the see-through "special glasses" stage, though ONR continues to work on the see-through viewer (to date, the issue with the see-through viewer is that the virtual objects appear to "jitter" relative to the live view as the wearer moves his/her head around).

Obviously, the technology is not "there" yet, but AITT demonstrated that it is technically feasible to inject virtual (or constructive) objects into a live environment in a way that is realistic to a dismounted, mobile observer in that live environment. To scale this technology to a much greater number of effects (e.g., individ-

§ As we note in Section 3, we are not going to join the technical debate over whether the correct term is AR, MR (mixed reality), or the two are synonymous. We choose the term AR, and what we mean by it is the ability to realistically inject entities and effects from virtual or constructive sims into live environments.

ual bullet splashes from a machinegun) and a larger number of participants, each with individual viewpoints, remains a challenge. And getting the virtual objects to register properly (and stably) on see-through viewers is another challenge. But that challenge may not be too far from solution – the DARPA Ultra-Vis program has already (in 2014) demonstrated the ability to overlay tactical icons onto a see-through display.[27] Tactical icons are much simpler than virtual weapons effects, but again, the foundational technology exists.

So all the technology challenges have not been fully resolved, and one can certainly say the processing power needed to do all this in a man-wearable configuration remains a technology challenge. But we claim that these are issues of scale, not basic, foundational technology. As a result, we assert that the basic technologies to enable the "free exchange" of information and images between live, virtual and constructive systems to enable full, two-way communication between all elements of LVC exist, at least in first generation formats. The future envisioned in the Army Live Synthetic concept is not something that we can just buy today, but all the building blocks needed to make it happen have been demonstrated – the Army's vision is not, as the article from which it is quoted asked, a "pipe dream."

In sum, what may appear to be speculative examples in the "Combining L, V, and C" segment above are technologically feasible. Geographically distributed forces can train together more realistically (e.g., an infantry battalion at Camp Pendleton can train with its aviation support unit in Yuma without either having to move to the other's location). Consequently, the administrative and logistics costs to gather units for large scale training can be avoided during the "crawl-/walk-" level workups, and the relatively fewer live opportunities can be leveraged for run-level training when they are available. Thus, the Services and the Joint Forces can achieve training goals with fewer resource expenditures. And the rare large-scale training opportunities are not spent working on "basics" because the participating units have already drilled in basics, and basic teamwork, before assembling for the major exercise.

Live, Virtual, and Constructive's Future: Enabling Training Exercises and Experimentation

In the second paragraph of the Introduction to this section, we dangled the term "experimentation" before the reader – and have not said anything about it since. So let's return to the topic of experimentation, and the relationship of military experimentation to training.[28] To some degree, all the Services experiment, whether it is with entirely new warfighting concepts, with new tactics/techniques/procedures (TTPs), with new technologies, or simply with new ways of employing existing capabilities. In short, they do "all of the above" at some point or other – and, as we'll explain, the difference between training and experimentation is the overall goal. That's a pretty bold assertion. Our point is that the Services use the same approaches, the same support equipment (e.g., instrumentation), and the same kinds of people, to conduct military experimentation as they to do conduct training. In fact, training is a key process in preparation to conduct experimentation.

The difference between training and experimentation is not the underpinnings or approaches, it's the goal of the event, so let's discuss goals. Military training exercises are designed to test how well an individual or organization has learned to execute existing tasks, to established standards, in specified conditions. Military experiments are designed to test whether and how well a new concept, TTP, technology, or employment method works. In order to conduct a military experiment, the experimental units in fact train to execute the new experimental topic, in the same way that they "train to standard" for existing capabilities. The methods, and the steps involved in the process, are the same – only the overall goal is different. In experiments, after action commentaries from units designated for experimentation frequently note that going through the experimentation process provided some of the best training the unit has received.[29] In both cases, the forces train in preparation for the "test," whether it is of their ability to absorb the training to standard or of the experimental concept's ability to improve capability. So in both cases, the same LVC capabilities can be employed because the process is fundamentally the same.

In sum, military training and experimentation are approached methodologically as two sides of the same coin, and as the Services develop LVC training capabilities, those capabilities can be used for experimentation, too. We'll first describe how experimentation organizations can leverage LVC capabilities, then end this section with brief illustrative examples of future LVC applications to both training and experimentation. The illustrations are not intended to in any way compete with the various Service visions for LVC (in fact the are intended to complement them), but rather than describe "the end," they will lay out examples of how structured methods (the *Ways*, using the military strategy model) for employing LVC capabilities (the *Means*) can help the Services achieve the desired *Ends* they envision for both training and experimentation, even in budget-constrained times.

Experimentation

Let's start the discussion of experimentation with a brief overview of how the Services approach military experimentation, because they do not use the traditional, laboratory science model.[30] Certainly they attempt to apply the scientific method where they can, but basic laboratory procedures such as controlling all variables but one simply are not practical in military experiments. Warfare is fundamentally a contest of human wills, and is therefore "messy" business in which illogical, irrational behaviors routinely occur, and military experiments must balance the desire for complete, scientific control with the realities of experimentation that is useful for updating military concepts, operations and tactics.[31] So they cannot apply the full scientific method, but they do all take a structured approach to designing and conducting experiments to be able to gain unbiased, if not fully objective in the literal scientific sense, results. Which, in fact, is exactly what they do in their training exercise designs: attempt to gain unbiased, reliable results without so over-controlling the exercise that the human element that is crucial to military effectiveness is eliminated.

In military experimentation, the Services all generally conduct three different levels of experimentation. They refer to them by different labels, but at their core they conduct experiments to address single factors (very close to laboratory science, but in changing, often unpredictable conditions, such as weather), experiments to address limited combinations of small numbers of factors, and experiments to address major new concepts. To avoid confusion in distinguishing these categories, we will refer to these them as limited technical assessments (LTAs), limited objective experiments (LOEs), and advanced warfighting experiments (AWE), respectively (though the Navy refers to AWEs as fleet battle experiments, or FBEs). These are summarized below:

1. LTAs address a single factor, such as a new technology or a new tactic. So on the surface, these may seem to be very close to laboratory science experiments, but even with single factors there are usually multiple uncontrolled (or independent) variables. These can include variations in terrain, weather, or even people's and teams' personalities in applying the new technology or tactic. Furthermore, even though "single factor" is the key at this level, if that factor is a new technology they have to have at least a concept for employing it (i.e., a new tactic). If that factor is a new tactic, then there are often organizational or training changes (or other elements) that change along with experimenting with the new tactic. The point is that LTAs are the smallest in scale, and are an initial assessment of a new thing or a new idea. Procedurally, preparing for and conducting LTAs is very similar to individual or small team training (and almost always directly involves such training).
2. LOEs address a small, or limited, number of factors. Normally, LOEs are conducted at the low tactical level, and involve relatively small "teams of teams" such as an infantry platoon, a single ship, or a flight of aircraft (with the number in the flight varying as needed to address the objectives of the LOE). LOEs by design incorporate multiple factors – they are intended to address elements of a new warfighting concept, which may include technologies as well as new TTPs for employing them, so they can later assemble these elements into a greater whole. They are often conducted as preparatory events to experiment with piece-

parts of new concepts before proceeding to AWEs (or FBEs). Procedurally, preparing for and conducting LOEs is very similar to unit-level training, to include tactical task-force level combined arms training.

3. AWEs are major experiments, formerly conducted at a grand scale but seen only infrequently in modern times. It was not unusual in the 1990s, considered by many the peak of modern experimentation, to see Army Brigade Combat Teams, Marine Regiments, Navy Fleets, and/or Air Force Wings involved in AWE level experiments. But these grand scale experiments have virtually disappeared. Even between the two World Wars, large-scale experiments were conducted (the Navy's Fleet Experiments, the Marine Corps' Amphibious Doctrine and Culebra experiments, the Army's Louisiana Maneuvers – which included the Air Force, which was the Army Air Corps at the time), and these experiments were crucial to our success in World War II.

In recent times, however, grand-scale AWEs seem absent from the stage. Why? We believe it is because they are resource intensive, and therefore expensive. Some may argue that large-scale experiments have not been conducted recently because our forces have been engaged in two "real-world" theaters in Iraq and Afghanistan. That is true, but it is also true that it has been two to three years since major combat operations in either of those theaters have been ongoing. So again, why haven't AWE-level experiments been reinvigorated? We believe the cost is the reason. And cost constraints cross the boundaries between experimentation and training.

Live, Virtual, and Constructive in Experimentation

By the way, previous experiments, including AWEs, have included L, V and C capabilities. For example, the first AWEs conducted in the 1990s, which were the Army's Force XXI[32] and the Marine Corps' Hunter Warrior AWEs[33] (conducted simultaneously with the Navy's FBE 1), *all* used simulations to adjudicate the effects of indirect fires. Each of the Services used different simulations but all of them used those simulations to determine how well future fire support capabilities could support and enable tactical engagements. Furthermore, the Army and Marine Corps AWEs also used information from live forces to support their constructive simulations' adjudications of indirect fires. The Marine Corps used the DARPA-developed Semi-Automated Forces (SAF) for mortars, artillery, naval gunfire and air-delivered ordnance; and the Army used the MILES (then state of the art) mortar and artillery simulations; to adjudicate the indirect fires. To enable those simulations to perform their adjudications, they used instrumentation to incorporate PLI on where the live forces were actually located, and either automatically (Army) or manually injected (Marine Corps) indirect fires results into the experiments' live forces. So the use of simulations in support of live experiments is not new.

Furthermore, Constructive simulations and Virtual simulators have been used in previous experiments to expand the scale of AWEs. For example, during the Marine Corps Urban Warrior experiment during the late 1990s, Constructive entities were injected via the Joint Conflict and Tactical Simulation[34] (JCATS, a derivative of the JANUS entity-level simulation) to expand the scale of play for the Special Purpose Marine Air Ground Task Force – Experimental (SPMAGTF-X) that was involved in the AWE, so the SPMAGTF-X Commander and staff could address experimentation objectives beyond the relatively small-scale urban warfare live experiments (which were at times being conducted in single buildings). But Constructive and Virtual elements have, to date, been either physically or temporally separated from Live participants in experimentation, often due to safety concerns.

As we discuss in association with training, there are legitimate concerns about making sure that a Live aircraft does not execute an unsafe (and potentially fatal) maneuver based on the actions of a Virtual or Constructive missile. But that is not really the point. The point is that Live, Virtual and Constructive capabilities initially developed for training have already been incorporated into large-scale experiments. In general, these incorporations have to date separated Constructive (expand scale) and Virtual (avoid unsafe interactions) from Live participants.

Live, Virtual, and Constructive in Experimentation (and Training)

So the notion of L, V, and C, all used to support experimentation – as well as training – is not a new idea. What is new is the idea of using them in conjunction with each other, and in a federated or, even better integrated, way that can enable cost-constrained military organizations to envision, develop and conduct large-scale experiments (AWEs and FBEs) without needing to put *all* those forces in the field, in the air, or at sea. Reducing cost is not unique to experimentation. For example, the Navy and Marine Corps have been conducting the Bold Alligator series of exercises to "get back to their amphibious roots."[35] After the initial exercise, the Bold Alligator series has been largely CPXs with constructive forces. Again, at least one of the driving reasons for this situation is to control cost.

The old aphorism "the pendulum never stops in the middle" appears to be at work in both the training and exercise realms. In the last two to three years, our forces have gone from real-world operations in two theaters to budget constraints that, if not yet fully realized, at least appear reminiscent of the 1970s. As a result, our Services (and the Joint forces associated with assembling Service elements into Joint Task Forces to respond to contemporary requirements) have been whipsawed between the "horn of plenty" mentality of ongoing warfare and the current, seemingly draconian, budget cuts. And though this situation may be "new to you" to the current generation, those in uniform during the 1970s remember the shortages and difficulties of conducting training in constrained times.

But those who remember the 1970s also know that there was no Internet (although the ARPANET[36] that was the forerunner of the Internet came about in the mid 1970s, it was not available to anyone below strategic command levels), there were no computer networks (computers were, at the time, very powerful calculators located in their own buildings, not handheld communication devices), and there was no such thing as Live, Virtual and Constructive to support training or experimentation.

So the question becomes, how can our Services (and Joint organization) leverage the capabilities that are available in the modern age to get back to the experimentation – and training associated with successful experimental concepts – that enabled our forces to win World War II? We believe the answer to that question involves both experimentation and training with LVC capabilities. In the next section, we provide two illustrative examples that both outline how the Services might get from today's situation of L, V and C capabilities never designed or intended to work together, to a future that involves fully federated or integrated LVC capabilities. In the process, we describe how these capabilities can support both military training and experimentation.

Illustrative Examples

In this final part of Section 2, we describe two imaginary future examples that both may support and enable future training and experimentation. Crystal balls are notoriously unreliable, so we are not going to claim prescience for either of these illustrative examples. Instead, we attempt to address the two most likely "boundary" options: 1) either develop ways to federate/integrate/interoperate what the Services already have, or 2) continue to use those sims separately (as they were designed) and start over with a new generation of sims designed to be integrated from the beginning. We explore the ramifications of both examples.

In the first example, we take a "low road" approach of federating existing simulations and simulators with live training systems. In this example, we assume the Marine Corps and Navy are correct in their apparent current approaches of federating and, where possible integrating, existing sims. We explore what would need to happen in order for this incremental vision to occur, and the implications of this vision.

In the second example, we assume that federating existing sims turned out to be an exercise in futility, and explore the possibilities of next-generation LVC training capabilities that are designed from the beginning to be integrated. Rather than repeating the entire illustration, we examine how that approach, which the Army and perhaps the Air Force seem to be exploring, differs from the first example. Either approach may turn out to be that which enables the next generation, and whichever approach "wins out" can apply to all the Services. But we focus on Navy/Marine Corps for the first example, and

Army/Air Force for the second, purely because we believe the respective Services are most likely to attempt to implement those examples.

Example 1: Incremental Development

After several years of diligent development, supported by several ONR Future Naval Capabilities to "leap generations" for the capabilities offered by two technologies, the Navy-Marine Team has developed a fully federated set of simulations addressing aviation, ground and ship-based simulations. The first technology enables L, V and C forces and sims to work together realistically. Though the hoped-for universal bridge or universal translator never fully came to fruition, ONR was able to develop a much-simplified coding approach that contains a core that addresses the processing and synchronization needed to address the "fair fight" issue, along with simplified special codes that address the data input and output for each individual sim. The core capability simply delays the adjudication of weapons firings between sims a few milliseconds – unnoticeable by the human operators, but long enough to ensure that the location and timing of both firing platforms and targets are consistent in all the sims involved in a particular firefight or engagement. This breakthrough was able to resolve approximately 80 percent of the coding requirements to successfully federate multiple sims. The other 20 percent constitutes custom code written for each sim to address its particular standards (e.g., DIS or HLA) and translate data coming in from other sims into the formats and data rates that sims can accept – the "hard problem" in this arena was throttling down high-volume data from high-resolution sims to levels that sims with lesser processing capabilities could handle. In short, these developments enabled the fair fight and data exchange issues between existing V simulators and C simulations to be resolved affordably.

Interestingly, this same basic approach was used to resolve the problem of effectively stimulating the myriad ships' combat systems, including the varying mods of the same system on different ships, for relatively low total cost. As a result, the Navy, though still focused on individual distributed learning as the technology that could resolve their most pressing training problems, was able to develop an exercise design and control tool that enabled full and consistent stimulation of onboard combat systems for any and all of their individual ships. Full stimulation means that all the ships' sensors, weapons and systems are included; consistent means that a ship's radar and EO/IR sensors, for example, are receiving consistent contacts and tracks based on their capabilities. So all the exercise designer needed to do was use this tool to lay out what sorts of events the ship needs to encounter to complete their training objectives. During the exercise (or experiment), the corresponding exercise control capability realistically presents and portrays those events either via constructive injects or by connecting to virtual simulators that are properly positioned.

The second technology development was a 100-fold increase in the processing capabilities of mobile AR headsets for dismounted Marines and Sailors, along with solving the see-through display jitter issue. Though there remain limitations in how many players can simultaneously view the injects from V and C systems, the Marines have been able to conduct platoon and company-level force-on-force exercises in which the live players can see, from their individual perspectives, both V and C systems and weapons effects that are within their fields of view. For weapons effects, even with the massive processing upgrades, individual rounds impact splashes still cannot all be shown. As a result, weapons-firing simulations such as I-TESS2 now group individual rounds from automatic weapons so the location of their impacts can be seen on the see-through headsets. The solution is not perfect, but it is sufficient to allow gunners to adjust their aimpoints realistically if they need to do so, and to allow those being fired upon to see how close the rounds are impacting to them and act accordingly. In solving the processing power – which included battery life – for AR headsets designed for dismounts, AR displays for aircraft cockpits and vehicle windshields or viewers were relatively easy – these platforms have much greater capacity for both power and computing/processing systems, so virtually all platforms can now display virtual and constructive injects.

One of the last remaining problems for mixing V and C with L was the aircraft flight safety concerns. This problem was resolved by marking V and C injects such as other aircraft or missiles with a color-coded "halo" around them so the aircrew can easily distinguish between live and non-live systems. Virtual missiles can still "shoot them down" (i.e., they can be assessed as damaged or destroyed during the conduct of the exercise), but the pilots can quickly and easily distinguish actual and virtual hazards. In addition to the color-coding, all pilots are trained in simulators for such situations and must prove they can distinguish and react properly to actual and virtual hazards before flying live aircraft in an LVC exercise. As a result, the color-coding reduces the realism somewhat because the pilots can immediately distinguish between live and non-live, but that disadvantage is viewed as being more than offset by the safety of flight advantages.

As a result of these upgrades, the recently established "Naval LVC Federation," supported by the now-complete NCTE, has been used to support both training and experimentation to address near-peer anti-access/area-denial (A2/AD) and expeditionary (amphibious) power projection operating concepts. With the federated sims, the Naval Services embarked on a cyclic process of training – experimentation – training to develop and test modern A2/AD and amphibious power projection options. Initial exercises in the Bold Alligator series of the 2010s indicated a need to modernize command and control, organizations, and tactics to conduct amphibious operations in the future environment. Furthermore, the Navy's A2/AD experiences within Joint Force Command and Staff exercises were indicating that a sequential approach of first defeating the A2/AD capabilities, then fully establishing air and sea superiority before attempting to project amphibious power, was simply not a viable way to operate. In short, the traditional conditions for enabling amphibious operations would never be met, but amphibious capabilities were needed to help defeat the A2/AD. Thus, a new Naval concept was developed that called for creating "holes" in the A2/AD umbrella, inserting small amphibious forces into enemy's rear areas, and eventually by maneuver and continued Naval strike operations, the combination would unhinge the enemy's cohesion – at that point, the enemy's centralized architecture upon which his A2/AD capabilities were founded, would crumble. That was the theory, at least. What the Naval Services needed was experiments to confirm or deny the theory.

But these new concepts could not be tested in single steps. As smaller forces would conduct training using LVC capabilities to increase the realism of tactical level engagements, they discovered that with modern technologies, we could not conduct certain operations has we had done before. Thus, the training results led to experimentation in developing new TTPs and incorporating new technologies at small unit levels. The Navy and Marine Corps separately tested these experimental capabilities individually (in LTAs), then combining related capabilities into relatively small scale LOEs. As new TTP and technology combination that provided improved capabilities were developed, they were "spun off" into training cycles. Furthermore, the results of both experiments and exercises were documented and analyzed to update the algorithms in constructive simulations (improving tactical behaviors) and to incorporate upgrades that properly portrayed the effects of new TTPs and technologies in virtual simulators.

Thus, in addition to the training – experimentation – training cycle, a form of symbiosis developed between the L forces and VC sims. New TTPs and technologies were tested at small unit levels live, and the results of live tests were then used to update the V and C sims. As a result, as new V and C capabilities were developed, initially at small unit levels in live LTAs and LOEs, the sims would be updated to replicate those results realistically. Then, tying the updated V and C sims back into live exercises and experiments enabled the Navy-Marine Team to "bootstrap" up to larger and larger force levels leveraging all LVC capabilities. Also at these larger levels, the Team was able to incorporate new ways of using prepositioning ships and "connectors" to reinforce the aging and dwindling amphibious warship fleet.

Eventually, by this small unit – larger unit – even larger unit bootstrap method, the Navy and Marine Corps were able to re-establish the capability to conduct LVC-enabled operational level AWEs and FBEs to experiment with new

Naval operational capabilities – without having to field fleets of ships and regiments of Marines as was done in the mainly live AWEs and FBEs of the 90s. Furthermore, because training and experimentation could be conducted using the same sim systems, the time from successful experiment to incorporation into formal training programs was greatly reduced. In sum, there remain a few challenges, and certainly there are gaps in availability of some types of sims, but the Navy-Marine Team has been able to make great progress in both training and experimentation, both in returning to the days of major experiments to address new warfighting concepts and capabilities, and also by incorporating experimentation successes into the training programs of instruction.

Finally, the Naval LVC Federation enables lower-cost assemblages of a wide variety of forces and scenarios, all networked at their own home stations. Thus, the relatively few large-scale exercise opportunities can focus on providing the most pressing training requirements for near-term deployments. Then, LVC excursions can be used to explore unexpected, "Black Swan" scenarios that addressed unanticipated variations from the existing standard training. These Black Swan explorations often start with simple wargames that can indicate which are the most challenging scenarios, and then LVC exercises can be designed to construct and play those scenarios out in more detail. So, being able to reduce the cost of such excursions can both preserve limited high-end training opportunities and simultaneously enable exploration of unexpected cases.

Example 2: Next-Generation Live, Virtual, and Constructive Architecture

Meanwhile, the Army and Air Force took a step back from a series of legacy sims that were never designed to operate together, and designed a new LVC architecture from the ground up. As a result, they, too, have been able to reinvigorate a program of training – experimentation – training, but were able to scale up much more quickly. Rather than repeating a slightly altered version of Example 1 – because the outcome is the same, but we are merely reaching it a different way – in this section we discuss how this approach might be different than the incremental approach.

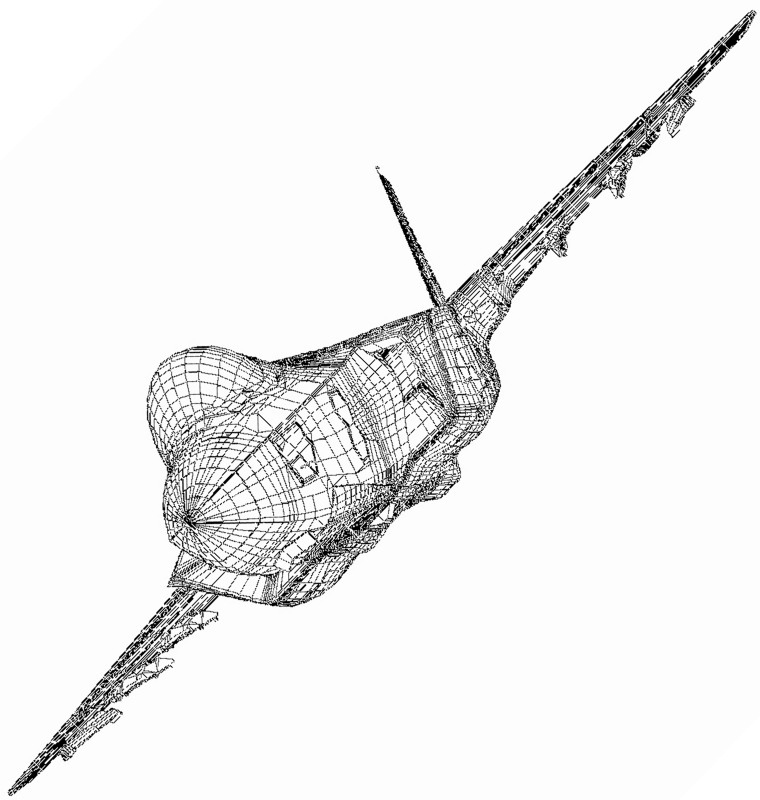
The most obvious difference is plausibility. To make the LVC federation in the above example work, we had to assume that an affordable method of federating sims would be developed, and also that that method would enable the proper throttling and volume transmission of data in such a way that humans would not notice the delay. While doing so is technically feasible, do so in a way that is *affordable* has been, to date, an elusive goal. It seems much more credible to posit a new architecture that includes new sims (even if they simply replicate the capabilities of existing sims) that are *designed up front* to be integrated and interoperable. The Army and Air Force can control that architecture from inception, which is more likely to result in a usefully integrated set of sims than hoping someone solves the universal bridge/translator problem, and does so affordably.

On the other hand, ensuring that the integrating architecture does what the two Services want it to do means they will need to expend the effort to take into account all the potential sim requirements, as well as requirements to be able to interoperate with existing and planned C2 systems, and make places for them in the architecture. That is a non-trivial task, particularly as the commercial gaming industry is constantly developing new game engines the military would like to be able to adapt to their own use. Many of the new engines claim to be "open source," but that term can have a variety of definitions, and few of them are fully or truly open. In short, game engine developers invest large amounts of money into developing engines that are better than their competition, and they do not simply want to give their proprietary intellectual property (IP) away. So in designing the integrating architecture, the Army and Air Force would need to ensure the architecture can handle changes and upgrades in a structured fashion. Even so, this seems more plausible than hoping to solve what has for years been a "wicked hard" problem (the affordable universal bridge).

The second difference from the first example is that the Army and Air Force would have opportunities to "plug holes" in existing sim capabilities in a from-scratch design. And they could do so sequentially, as constrained budgets allow, by ensuring their architecture has "hooks" in place to plug in new sim capabilities as they are developed. Then, they could prioritize which sims are developed first, and develop others as budgets allow. In our Naval example above, we not only assumed the universal bridge problem away, we glossed over areas in which the Naval Services do not have sims they might need to address future training and experimentation requirements. And for the Navy, we also assumed they would have an exercise design/control tool that could coordinate all the ships' combat systems for every ship, to include handling all the variations in different ships. There are combat systems for which the Navy currently does not have adequate simulators/stimulators (e.g., their 5" guns, of which the Navy has over 100, and that are currently roughly evenly split between two different mods). While exercise design and control are not as technically difficult as the universal bridge (and there are already several such tools in existence), our assumption that such tools would be able to handle the wide variety of requirements in the Navy (and that the Navy would be able to develop and field adequate sims for all their combat systems) was pretty "bold" at best.

So the bottom line is that designing an architecture that is purpose built and optimized for integrating a new set of sims, and then designing the sims to fit into that architecture, is more likely to be a viable approach. Whichever version provides the eventual solution, there are currently efforts that are reflective of both examples. The Marine Corps is currently working to federate existing sims, and the Army is currently trying to develop a new approach to Live Synthetic architecture. The Air Force is looking to scale to larger exercises, but they already have a lot of simulators that do interoperate – so they may end up with a mix of both. The Navy aviation community is in the same boat (no pun intended) as the Air Force, but the other Navy "tribes" are exploring a variety of solutions.

Which approach will end up "winning" and become the future LVC architecture? No one knows at this point. We predict it will probably be somewhere in between the two extremes, but that is speculation. The fact that the Services are exploring the possibilities – and that they are not all exploring the same possibilities – means that there will be opportunities to provide solutions in a wide variety of arenas. In the next section, we explore the current state of LVC in the various Services in more detail, and we catalog some of the challenges and opportunities.



3. Where is the US Military Today in Training and Education?

In this section we provide a high-level overview of the current state of training within the various US Military Services. First it is important to consider a few caveats to frame this description.

1. Even a high-level overview of training across all the Services, throughout all their various functions, would be a voluminous undertaking – well beyond the scope of this paper. As a result, we focus on the "mainstream" of training for the Services.
2. All the Services have supply, service, maintenance, administrative and other supporting functions, and many do use simulations (e.g., in the maintenance arena, computer-based multimedia and even virtual reality headsets are being used to demonstrate maintenance procedures; various electronic media are beginning to replace the old-style, paper-based maintenance manuals). But most of these personnel are working at their actual jobs daily – they just (for the most part) are not in an active combat zone.
3. We do not address Special Operations Command (SOCOM).[1] Though the special operators do their own individual and team/collective training, often outside their parent Services, they are not a "Service," per se. Furthermore, because of their high-risk/important missions and small size, they tend to be given the resources to do training the way they prefer. This doesn't mean they don't use simulations, nor does it mean to imply that SOCOM would never be an LVC "customer." Rather, in our opinion SOCOM is less likely to drive LVC requirements at the level of the various Services. SOCOM is likely, however, to continue their pattern of leveraging the Services' training capabilities, including LVC, where it makes sense to do so.
4. Finally, we have not overtly addressed education, and have referred to training capabilities almost exclusively below. The reason is in our experience, the Services do not develop virtual or constructive simulations specifically and only for use in their basic training or schoolhouses (the word commonly used to collectively describe the multi-faceted military education system). The schoolhouses *do* use simulations and simulators (e.g., both the Army and Marines have and use Virtual Battle Simulation [VBS] – their "first-person shooter" – computer game in schoolhouses), but they use those that were developed for training.[2]

Training Differences and Similarities Among the Services

The Army, Marine Corps, Navy, and Air Force have both different and similar training needs/challenges. Each Service conducts live training, and uses simulators and simulations for various training needs. As well, all have at least explored linking simulations together (as a general rule, explorations to link computer-based simulations and simulators have been the focus of most of this effort). And every Service has "injected" simulation results into live training[3] (a simple example is using a computer simulation to "score" weapons effects in force-on-force training where live ammunition is not used). They are all, however, exploring and actively developing LVC training capabilities. We will begin by briefly overviewing the various Services' needs and challenges, and then addressing their current approaches to LVC.

Army

The Army has been exploring LVC capabilities for years, for both the ground and aviation (rotary-wing/helicopters) communities. The Army already has both ground (e.g., tanks, Stryker vehicles)[4] and aviation (e.g., Apache, CH-60)[5] simulators for individual vehicle and air crew training. In addition, they have several simulations designed for both small team and larger unit training. Many of these simulations and simulators are "non-standard," which means they were not originally developed as part of an overall training architecture. Instead, they were designed as "one-off" applications for a specific purpose. As a result, in general, the Army's simulators were not specifically designed to be compatible, much less interoperable.

The Army has until recently been attempting to at least federate, if not integrate, their various simulators and simulations. In this context, the term "federate" means that the architecture and "middleware" are in place to allow different simulations/simulators ("sims") to exchange data and to address "fair fight" issues. There are already two established "standards" called Distributed Interactive Simulation (DIS)[6] and High-Level Architecture (HLA).[7] DIS has been in use longer, and the models and simulations using DIS broadcast and receive Protocol Data Units (PDUs) over a common network. HLA was developed using an object-oriented approach that enables models and sims to publish and subscribe to various objects and interactions. Both DIS and HLA have their proponents and detractors. The point is that these standards are different, and if simulation A uses DIS and simulator B uses HLA, the two are not compatible so some sort of "translator" or "bridge" is needed between them.

The "fair fight" issue goes beyond the seemingly simple issue of being able to exchange data, to addressing the issues of two separate sims' objects and effects being synchronized in both space and time. For example, if a tank in simulation A is shooting at a helicopter in simulator B – and vice versa – fair fight addresses whether or not the helicopter avatar in simulation A is at the same place at the same time as the "real" (actually, in this case virtual) helicopter in simulator B.[8] In short, the fair fight stipulation tries to ensure that the two sims can interact fairly – that is, the tank is not shooting at where the helicopter was a few seconds ago, or shooting at a helicopter avatar that is in a different location than the virtual helicopter in the simulator at a give time.

Given the different standards and fair fight issues, federating different sims is difficult. And the more middleware is introduced to, for example, translate from DIS to HLA, the more likely there will be transmission time lags due to processing or bandwidth, thus introducing fair fight problems. As a result, the Army recently decided to take a step back from "doggedly" trying to federate its different non-standard sims. Recently, the Army introduced the FHTE Live Synthetic concept to describe its design for the "next generation" of simulation.[9] Note that in this sense, when the Army says "simulation" they are referring to the axiom "everything short of actual combat is a simulation." The Army's vision for FHTE does include LVC training capabilities, all integrated by design, rather than by attempting to "band-aid" together existing trainers.

At the time of this report, FHTE (or "FHTE Live Synthetic," as some call it) is a concept. The Army is focused on documenting the requirements, not the solutions, for FHTE. Within that realm, the Army uses the term LVC-G to identify the four types of simulations they are seeking as part of the integrated FHTE approach:

1. Live Simulation is real people operating real systems, as has always been the case.[10] But those systems may have simulated augmentation, such as the various forms of "laser tag" that have been around for decades: MILES, I-TESS or One TESS (ironically, the widely familiar laser tag game systems are in fact commercial adaptations of the original MILES gear). The Army is also discussing introduction of other simulated effects, such as sounds and smells, via simulation.[11]
2. Virtual Simulation is real people operating simulated systems.[12] The familiar aircraft and ground vehicle simulators are classis examples of virtual simulations.
3. Constructive Simulation is simulated people operating simulated equipment in a simulated environment. Computer-based training simulations such as Semi-Automated Forces (SAF) are examples of constructive simulations the Army uses.[13] The Army is indicating that these systems must realistically inject constructive entities and effects into live and virtual simulations.
4. Gaming Simulation is similar to video games, but with a huge difference: video games are intended to entertain; training games are intended to realistically train.[14] Though both may use similar software (such as game engines), the requirements for training games are very different than those of entertainment-oriented video games. For example, video games often restrict the player to specific corridors, and the "bad guys" are frequently in the same

> places every time a player runs the game. That is not how the real world, or real enemies, work. So, the Army is seeking to describe their requirements for game-type simulations that are useful for training.

The nature of FHTE, including whether and how well the Army will be able to develop a "whole new generation" of training sims in a budget-constrained environment, remains to be seen.[15] The key take away from this brief description is that the Army has experienced the myriad difficulties of trying to federate sims that were never designed to be federated, and is taking a fresh view: rather than trying to "glue them all together," the Army is carefully and seriously considering doing what they can with their current sims until they can design the next generation, fully integrated training architecture and associated applications throughout the LVC-G environments.

Marine Corps

The Marine Corps LVC challenges on the ground side are very similar to the Army; in many cases, the Army and Marine Corps use the same sims. But the Marines have a much more extensive aviation capabilities, including not only rotary-wing (to include different aircraft type/model/series [T/M/S] across the board) but also fixed-wing aviation.[16] In addition, the Marines are part of the Department of the Navy (DoN), so they must be able to operate with their Navy counterparts. In order to operate effectively with the Navy, they need to be able to train with the Navy. We'll address each of these areas in turn.

The Marines are in a similar situation as the Army when it comes to ground sims. Both the Army and Marines currently have Virtual Battle Simulation (VBS) as their "first-person shooter" simulation – and, the Marine Corps recently upgraded to VBS3, which is the same version the Army is currently using.[17] Though their databases differ, the simulation itself is the same. Similarly, the Army and Marine Corps both use the same M1A1/2 tank simulators. On the other hand, the Marines in some cases use purpose-built sims that differ from their Army counterparts. For example, the Marines use the Marine Air Ground Task Force (MAGTF)[18] Tactical Warfare Simulation[19] for their "battle staff" training because MAGTFs are significantly different from Army counterparts: Division or Brigade Combat Team (BCT) staffs.

So the Marine Corps is facing the same challenges as the Army in terms of federating different sims that use different standards, and have the same fair fight issues. In fact, during Marine Corps Large Scale Exercise 2014 (LSE 14), the First Marine Expeditionary Force (I MEF) established a federation of both ground and aviation sims to evaluate how well it would work and identify issues that needed to be overcome.[20] What they confirmed during LSE 14 is that it is one thing for sims to "talk" to each other, and another thing entirely to "play well" together. What the Marines are doing is incorporating the lessons from LSE 14 (and other events) into their Live, Virtual Constructive Training Environment (LVC-TE¶). So the Marines have not yet stepped back from trying to federate their existing non-standard sims, and indeed are trying to federate both ground and aviation sims – in selected places, at selected times.

The Marine Corps Aviation community currently outpaces their ground brethren. Marine aviators have utilized aviation simulators for years, mainly because in aviation, you may only get a single chance to screw up. So for safety reasons, the aviation community has embraced sims during times when the ground community wanted to focus on live training as the "gold standard" for training exercises. Without safety considerations driving them to sims, the ground community was able to hold onto the desire for live training much longer – especially during the past decade plus when the Marine Corps was effectively at war in Iraq and/or Afghanistan.

The aviation community's LVC capabilities (mainly V and C) have been federated, and in some cases fully integrated, into the Aviation Distributed Virtual Training Environment (ADVTE). ADVTE is an "environment" that includes a persistent, classified distributed network

¶ The Marines are currently considering "rebranding" LVC-TE into a different name, possibly the Marine Corps Training Environment. But as of this writing, no final decision has been made on the name change. Whether the name changes or not, the approach is the same.

backbone into which aviation sims can plug in and plug out as needed to accomplish their training needs.[21] ADVTE allows geographically distributed aviation Marines to train together; the environment can accommodate virtually all their existing aircraft simulators, to include some unmanned aerial systems (UASs), as well as their command and control, air traffic control, and other sims. Whether and how the F-35 simulator (which, fully functional, operates at a higher classification than ADVTE) will be incorporated remains to be seen.[22] Furthermore, though ADVTE was incorporated into LSE 14, the different classification levels of ground and aviation systems proved problematic. Even though there are "guard translator" systems such as Radiant Mercury that can enable traffic between classified and unclassified systems, these are generally rather restrictive and slow.[23] As a result, there were numerous fair fight disconnects between ground and air sims both in time and space.

Even so, the Marine Corps currently intends to federate selected ground sims with ADVTE, deal with the standards, fair fight, and classification issues, and do so in a measured, phased program. As of this writing, the Marine Corps Training and Education Capabilities Division (TECD) and Program Manager, Training Systems (PM TRASYS)[24] are working on an LVC-TE Capabilities Development Document (CDD) that lays out a phased way ahead. They are working closely with the Deputy Commandant for Aviation (D/C Aviation) to make sure that the ground side is coordinated with the aviation community's training systems. In fact, TECD is currently drafting a Ground Training Systems Master Plan that mirrors its aviation counterpart.[25]

The Marines understand, as does the Army, the challenges in federating sims that were not designed to be federated, but the Marines are still trying to overcome those difficulties. Having said that, traditionally the Marines frequently watch what the Army is doing, let the Army deal with the development issues, and then "jump on the bandwagon" if it looks like the Army is succeeding. And the Army and Marines are both talking to each other now, both formally and informally, about the way ahead for training sims. So if they Army somehow manages a breakthrough in integrated next generation sims, expect the Marines to evaluate that and join the Army if it makes sense for them to do so.

With regard to integration with Navy, Marines (often called "soldiers of the sea") are part of the DoN and are a Naval Service. So one might expect the Navy and Marines to be closely coordinated in LVC training capabilities, right? Wrong. Recognize that, particularly on the ground side, the advent of training sims has occurred mainly in the past two decades – when the Marines were focused on fighting in two land-locked theaters (Iraq and Afghanistan). So Marine and Navy training sims were not developed together (see more on Naval aviation, below). Fundamentally, aviation sims are compatible, interoperable and often the same at the individual aircraft level, but not at the organizational level. As a result, Marine and Navy LVC capabilities are, in general, not integrated/interoperable, federated or, in most cases, even compatible.

In recent times, the Navy and Marine Corps have been attempting to get back to their "amphibious roots" via the Bold Alligator series of exercises.[26] Even so, they still have a lot of work left to accomplish just to figure out how to operate together in the modern era, much less how to incorporate their individual Service LVC capabilities, and even less so identifying needs for or solutions to a Naval LVC capability for Navy/Marine Corps amphibious/expeditionary training. At the deployed Expeditionary Strike Group (ESG)/Amphibious Ready Group (ARG)/Marine Expeditionary Unit (MEU) Special Operations Capable (SOC) level, the Navy/Marine team routinely operates extremely well together. The Navy and Marine Corps have been building and deploying these teams for decades, and they have a well-developed model that works successfully. What it involves is the two "Sister Services" first working up individually, and then together, in a series of almost exclusively live exercises, supplemented by STAFFEXs and CPXs that are driven by manual (not computer-based or automated simulation) mechanisms. ESG/ARG MEU(SOC) deployments are a bread and butter item for the Navy and Marines, and they work well, but they put a lot of resources into making sure they are ready for deployment, and few of those resources are related to LVC (though the individual units and components may use LVC capabilities as part of their training workups).

From the aviation perspective, Marine aviators are Naval aviators. Marine aviators fly some of the same types of aircraft (even if the models/series are different) as the Navy, and Marine squadrons can and do deploy with Navy aircraft. So at the individual simulator level, Marines and Sailors often use the same systems, Marine aircraft fly off of Navy carriers, and Navy aircraft can – and do – provide ground support to Marines. At the individual aircraft level, Navy and Marine aviators may appear interchangeable and (despite individual pilot opinion), in some ways they are. But when it comes to organizational compatibility between Marines and Navy there are still stark differences.

Having pointed out the above differences and issues, the reality is that at the staff level, the need for "LVC" remains limited. Both the Navy and Marines tend to use constructive simulations, or even live, master scenario events list (MSEL) inject lists, to stimulate Blue (Navy) and Green (MAGTF) staffs, and let them integrate via their actual C2 systems. This does not mean there are not opportunities for LVC to be integrated into Naval training and exercises. For example, one of the problems with constructive entities and injects is that they tend to be rather "antiseptic" in the sense that things don't go wrong (at the worst possible moment, in accordance with Murphy's Law), people don't get confused, and messages don't get garbled with "pucksters and response cells" are providing the inputs. The ability to incorporate individual, team/crew and small unit L and V capabilities into Blue/Green staff level exercises could bring that element of uncertainty and "fog of war" to those exercises. But at present, the Navy and Marine Corps are more focused on getting back to figuring out just what *Naval integration* means above the ARG/MEU level than they are on such niceties. So there are potential opportunities in the Navy/Marine arena, but the nature and extent of those opportunities remains to be seen as both Services try to determine the way ahead for amphibious/expeditionary operations above the ESG/ARG MEU(SOC) level.

Navy

We've already broached the topic of Navy/Marine integration for amphibious and expeditionary operations above. These issues are real, they are changing as the Navy and Marine Corps focus on getting "back to their amphibious roots" at levels above deployed Naval forces, and we do not by any means intend to minimize those challenges. But for the Navy writ large, the LVC challenges are different than they are for the Army, Marines, or even Naval expeditionary/amphibious forces. The Navy's basic training problem is scope and diversity of requirements.[27] In a sense, the term "Navy" implies an integration among communities that works well in warfare, but from a training and readiness perspective underestimates the extent of diversity contained within the Navy. Despite the marketing and common environment image of the slogan "haze gray and under way," the reality is that the Navy is segmented into "5 tribes" that have very diverse training requirements, because they have very different operational imperatives. The communities (tribes) are: 1) Air Warfare; 2) Surface Warfare; 3) Undersea Warfare; 4) Command and Control (currently expres-sed as net-centric warfare (NETWAR) and force network (FORCENET); and 5) Navy Expeditionary Combat, which rolls up multiple auxiliary but important functions such as amphibious transport ships, port and terminal operations, riverine operations, port security, Navy construction battalions ("Seabees") and others.

The point is that the Navy has a dizzying array of training requirements for individual MOSs and various ratings, as well as community and integration training at the platform level. Furthermore, although it is tempting to think that Navy training requirements are all very technical, the fact is that the Navy has both highly-technical console operators at one extreme, very non-technical security force/Seabee personnel at the other, and a wide variety of other specialized yet not necessarily high-tech training requirements. The point is that Navy individual training requirements are extremely diverse; on top of that, systems are updated and upgraded frequently. As a result, ships in the same class often have different "mods" of what are nominally the same systems. Furthermore, the Navy has two distinctly different environments for which training is needed: shipboard, requiring simulations to stimulate and provide training for a wide variety of personnel involved in "fighting the ship," and ashore refresher training for those who are not assigned to ships yet need to maintain their MOS proficiency. The bottom line is that the watchwords for Navy training are diversity and availability across a wide range of individual skills. And individual skill trainers are needed both for shipboard/deployed training (simulators for onboard systems) as well as refresher training for shore billets (simulations/refreshers for those to whom neither the combat system nor a direct simulator is available).

But beyond the myriad individual skill training/refresher training requirements, the ability to provide sims that can enable platform-level as well as squadron, battle group and fleet training exercises are needed. This is where LVC capabilities can contribute. Budget constraints affect all the Services, and the Navy's steaming days are restricted. As a result, a lot of squadron, battle group and fleet exercises that used to be conducted at sea are being conducted pier side. To enable these exercises, simulations and stimulators are needed that can inject virtual or constructive entities into individual live consoles (e.g., radar tracks) as well as augment the decision-making in the combat information centers (CICs) on board ships, and that enable group commanders to allocate ships and resources to the various functions. The key takeaway is that the Navy's need for LVC capabilities extends from individual console operators (with a variety of consoles) to fleet level exercises. The Navy needs scalable LVC capabilities for training exercises, along with individual training to sustain the skills of those in shore billets and to refresh those skills when they return to shipboard billets.

Air Force

On the surface, it is tempting to think of the Air Force as uni-dimensional, particularly in comparison with the Navy. After all, the Air Force operates in the aviation domain, and aviation has embraced simulators for years, so do they really need new capabilities that LVC may provide? The Air Force really has two issues: scale and overcoming separation. We'll address each of these in turn.

From an aviation perspective (which applies to Air Force, Navy and Marine pilots), the "Snoopy syndrome" – alone and unafraid, scarf waving, individual aviator fighting an individual foe is culturally appealing (the rugged individualist making his way through a difficult world). The problem is that image does not reflect either the reality or the complexities of aviation operations. The Air Force (and Navy, Marine Corps and Army) has had individual simulators for a long time.[28] The problem is that warfare is a collective endeavor, even in the aviation realm. The current concept of operating F35s in 4-plane teams recognizes that reality. Furthermore, the Air Force has recognized the requirement to train not for 1 vs. 1 encounters, or even 2 vs. 2 encounters, but for many vs. many, is the current imperative. Even within the many vs. many realm, the many must address more than one warfighting domain: the Air Force has multiple missions in the air domain, including gaining air superiority (sweeping the skies of enemy aircraft), strike (bombing strategic, operational and tactical targets), and close air support (CAS).[29] In addition, each of these missions includes a range of support functions from aerial refueling to intelligence gathering, targeting, planning and allocating aircraft, and generating the air tasking order (ATO). These apply just to the air domain; the Air Force is also primarily responsible for the space domain, which brings a different set of training requirements.

That is, the issue is not just scale, but also the ability to overcome the inherent tendency to separate domains that may appear distinct, but in reality are related.[30] For example, an aircraft may be initially assigned an integrated air defense (IAD) mission that would be conducted purely in the air domain, but once launched could be diverted to a ground domain CAS mission. While the ivory tower purist may opine that such changes happen only infrequently, actual combat indicates otherwise. And this is just one example: an overcome IAD mission (whether radar penetration, suppression of enemy air defenses [SEAD], or other) may very quickly become an anti-air, fighter vs. fighter mission when unforeseen circumstances occur. There are many other examples. The point is that we cannot always predict what our pilots will encounter before they launch, so we have to train not only for individual, predictable missions, but for the overall, multi-domain (anti-air warfare, strike, CAS, or other) problems the Air Force (and other sister aviation Services) are likely to encounter. The reason is that individual or small groups (2-4) of aircraft operating at the tactical level must fit into the overall operational campaign plan.

As a result, the Air Force is not seeking 1 or 2 vs. 1 or 2 training capabilities for future operations, but for *flexibility* and *scalability* in aviation training that covers the range of missions and requirement. That is, the Air Force is not looking for the "point solutions" that it already has in specific instrumented ranges and training programs such as Red Flag that focus on individual or small number engagements.[31] What the Air Force is seeking is the ability to scale to a multiple aircraft – and changing environment/aircraft requirement/mission as circumstances change – environment, and for training that covers both tactical and operational levels. In addition, the larger scale requirement brings with it a larger air space requirement. Air space dedicated to training is limited; the existing instrumented air ranges are well equipped, but they can only handle a few aircraft at a time. In order to address operational level challenges, the Air Force needs to be able to supplement live training/instrumented ranges with VC capabilities that enable effectively expanding the air space, and thus the available exercise scale, to theater level.

Furthermore, the Air Force is looking forward to the next generation of conflict, in which we may not be able to separate the mission/impact of a single aircraft or flight of aircraft a priori. That is, we may predict that aircraft X will accomplish mission Y, but what if that doesn't happen? In other words, the Air Force needs larger scale exercises and supporting tools, and also seeks tools that will enable them to train their pilots for missions in which they must address unplanned missions and changing circumstances literally "on the fly." Thus, the Air Force is looking to LVC as a way to introduce uncertainty and increase individual pilot proficiency to adapt to changing circumstances. At the same time, the Air Force is seeking to expand the scale of training to the operational level (which includes tactical level activities), with the associated air space requirement, which can only be reasonably accomplished by a combination of LVC capabilities.[32]

Summary: Challenges and Opportunities for Live, Virtual, and Constructive

The discussion above addresses individual Services' current state of training and education, and notes their individual issues and needs. We present challenges and opportunities that may be addressed by LVC. We begin with a brief overview of the current status of common and individual Services' LVC efforts, and conclude with a discussion of the opportunities for LVC to help all the Services improve their training capabilities for the future.

Live Training: No Longer Sufficient

Until recently, the use of sims for all the Services focused mostly on (1) virtual simulaTORs for individual training (with a long-standing recognition that simulators allow them to do things they cannot safely do live – especially in the aviation communities), and (2) constructive simulaTIONs for commander and staff decision-making training. As a result, all the Services have individual virtual simulators that were designed to train individuals, and therefore not designed to operate together. For commander and staff training, constructive simulations are designed to provide a full spectrum of stimuli that enable the commander and staff to work through their decision-making processes.

The issue with constructive simulations is that nothing is actually real – so their utility depends on the abilities of those who are generating the stimuli to generate realistic environments for command/staff action. Those environments seldom address realistic unforeseen circumstances. At the opposite extreme, individual simulators are the epitome of unforeseen/unanticipated circumstances, and are designed to allow individuals or crew to respond to such circumstances in a safe environment (e.g., where the aircraft doesn't actually crash, or the tank doesn't really drive into/get stuck in the tank trap). So where simulations tend to be somewhat antiseptic (depending on the imagination of those who are setting them up to inject the unexpected that is so often the norm of actual combat), simulators routinely inject unanticipated results to stimulate pilots and crews to deal with unpredictable situations. Why can't the two be combined? This is the genesis of LVC capabilities that all the Services are currently exploring.

Recently, all the Services have explored federating, integrating, or otherwise combining L, V and C training capabilities to improve team/unit/collective, and therefore ultimately operational command and staff level, training.[33] They all recognize that doing so via training networks (Joint and Service specific) allows geographically distributed units to do so "better" without having to physically assemble in a common location. So the Services have invested in networks, and the networks are "there" (not that they provide perfect solutions, or even all the needed bandwidth), but what lags behind is the ability to federate/integrate the various L, V and C systems. When it comes to integration and federation, connecting V and C capabilities has been the focus of most (certainly not all) of the various Service efforts. This is mainly because injecting virtual or constructive events and physical entities has not been possible – until recently.

Recent developments in Augmented Reality (AR)[**] (e.g., the Marines' Augmented Immersive Team Trainer, "AITT")[34] are beginning to enable better connections between VC and L – but these are still at the relatively fledgling stage. The aviation communities are concerned about the safety issues of having VC injected into L (e.g., they don't want a pilot in a live aircraft to conduct an avoidance maneuver in response to a V inject that endangers the actual aircraft). The ground communities have only just begun, and the bandwidth and processing power to do significant numbers of VC injects into AR headsets currently do not exist – so there remains a technology challenge. Importantly, AR provides the previously "missing link" that enables V and C objects and events to be inserted into a live environment, e.g., by overlaying them on see-through displays (Google Glass is a first generation example of such).[35]

But doing so requires significant technology development so that the live participants can see those objects and events from their different perspectives, those perspectives can be updated, and the richness of V and C injects can handle the volume and variety of effects. For example, if a soldier is firing a machinegun at an enemy position but missing (so the enemy's I-TESS harness is not adjudicating him as "dead"), how does that soldier know that his rounds are missing two feet to the left, for example. In an actual combat situation, that soldier could see the bullets "splash" on the building wall or ground, but with current training capabilities (such as I-TESS) he or she cannot. So AR would overlay those splashes on the building or wall, and the soldier could adjust his/her fire to the right to bring it to bear on the enemy.

The example above assumes a live exercise augmented by virtual/constructive capabilities. Live training was once the only way to train, and remains the "gold standard" for all the Services – but they all recognize that (1) they cannot afford to rely on live alone, (2) that live is resource intensive, especially if participating units are geographically distributed and must assemble in a common location, (3) even "live" training isn't fully realistic, and (4) that there are reasons other than safety to incorporate virtual and constructive training with live to expand their capabilities.

Service Unique Live, Virtual, and Constructive Approaches

The Services haven't yet determined exactly how to do all that – so they all continue to seek solutions, but they are proceeding cautiously because in the current budget environment they cannot simply "buy their way" out of the problem. Budget constraints introduce a challenge, but the Services' collective recognition that they need to leverage LVC offers opportunities. Before proceeding with our thoughts on where those opportunities are, let's first briefly reprise the various Services' unique approaches to LVC capabilities.

1. The Army recently decided to take a step back from trying to integrate dissimilar sims, and is working to conceptualize the next generation of sims that will be designed to be fully integrated and immersive at all levels.[36] In so doing, the Army is currently at

** The terms augmented reality and mixed reality are often used, and some draw distinctions between the two; for the purposes of this paper, we will use augmented reality as the term for injecting virtual or constructive objects and events into a live training environment.

the concept stage, has adopted a structure of "live-synthetic," but does not have specific solutions: which means the field is wide open.

2. The Marines are still hoping to federate existing sims, though they are proceeding cautiously and systematically. Their focus is on the challenge of federating their ground sims with aviation (ADVTE).[37] Because their ground sims generally operate at the unclassified level, and aviation sims are secret, the dual "elephants" in their room are successfully federating sims that were never designed to work together, and when they connect ground to aviation, multi-level security (MLS).
3. The Navy's biggest problem is variation: the sheer numbers of MOSs and ratings, and the fact that each ship is generally unique relative even to other ships in the same class. On top of the individual sims, the Navy is emphasizing squadron, battle group, and fleet training using LVC because they cannot simply all go to sea frequently, meaning they need to integrate multiple individual consoles/watch stations and also be able to fight ships/groups of ships effectively. And they need to be able to do this across their different "tribes" (communities) of aviation, surface, undersea, network/C2, and Navy expeditionary (including the Marines).
4. The Air Force is seeking to scale from individual/small number engagements to theater level exercises that address both tactical and operational levels. They realize that doing so requires operating areas far beyond what they can achieve via live-only exercises, and so they are seeking LVC solutions – much like the Navy – that allow them to fight groups and wings, not just aircraft.

Having summarized their unique approaches, there are also challenges common to all (or at least multiple) Services. *All Services* experience problems of maintaining proficiency when in non-tactical unit billets. All have the problem of multi-level security (MLS, especially with the F35, which is "a flying SCIF") when networking L, V, and C for collective training. For example, Marines' ADVTE operates at secret level, ground sims at unclassified/FOUO, and F35 at TS/SCI.[38]

Cross-Service Opportunities

All the Services are currently experiencing tightened budgets, and budget constraints are expected to continue for the foreseeable future. These constraints have significant implications for all programs, including training – none of the Services can afford to "throw money at the problem" of training.[39] As a result, all Services are expanding the emphasis on and use of LVC. They all realize that combining the advantages of each of these can help offset the disadvantages, but they have not yet determined how to proceed. As a result, they all have their Service-unique approaches. But in areas where they have similar issues, such as Army/Marines ground operation, Marine/Navy aviation operations, Air Force/Navy/Marine security classification associated with fielding the F35, they are working together more than ever before. Perhaps this is because they all know they cannot afford Service unique solutions to common problems. Whatever the reason, there are common challenges – which means opportunities – to develop and offer solutions that all the Services would be interested in. Not surprisingly, these are all currently hard problems; but with hard problems come great opportunities for those who can offer solutions. So let's turn to and summarize those common problems – each one offering potential opportunities to those who can solve them.

The Universal Bridge/Translator

The Universal Bridge or Universal Translator that allows Services to tie together multiple L, V, and C capabilities seamlessly, efficiently and effectively has, to date, been in the category of "unobtainium" despite multiple attempts to create such capabilities. Because their sims were not designed to work together, in general it is extremely difficult to even write specifications for such a system, much less develop one. The Services *do* have common standards such as DIS and HLA,[40] but neither solves the synchronization problems of both space and time (the "fair fight" problem) between sims.

So even if one or the other standard were adopted across the board, the need for middleware to translate between programs while ensuring the space/time synchronization required to enable a fair fight is a "wicked hard" problem. To date, no one has been able to solve this problem, but if an approach could be developed that solves even a single Service's federation/integration problem, that approach could be extremely lucrative.

Universal Terrain/Environment Tools

Though not as difficult at the universal bridge/translator described above, development of an effective Universal Terrain tool that allows multiple sims to leverage the same terrain databases – to include overlaying those with different levels of resolution (e.g., a C2 center wants a map of the city, an infantry squad wants a detailed 3D terrain model of the three blocks they are operating in) remains a problem. Though there has been a lot of progress made in this area, and the geospatial intelligence community is working with the training communities; this latter is a fairly recent development due to the generally different classification levels of training and "real world" C2 systems.[41] The Joint Staff J7 has supported numerous technical development initiatives in this arena, and the Services are participating in these efforts and working together because they all have similar problems.[42]

But all this collaboration does not mean all the problems have been solved. In particular, the requirements for training sims are very different from the terrain visualizations that people, for example, in tactical/combat operations centers (TOCs and COCs) and shipboard combat information centers (CICs) at the various operational and tactical levels, need. A C2 system providing a visualization tool for commanders and staffs really only needs to display a well-rendered image – people know they cannot walk through walls and drive over ravines. But sims do not know such things a priori, and therefore the sim's programming has to "tell it" how the interactions of different people, vehicles and weapons actually work with various terrain features (e.g., a rifle bullet gets stuck in a tree, but a tank main gun can blow up that tree). So there are still opportunities here, and the technology challenges are not as difficult to overcome, so these kinds of capabilities are not considered to be in the "unobtainium" category.

High-capacity Augmented Reality

High capacity AR.[††] What is AR and how is it different from virtual reality (VR)? VR is simply immersing the human trainee into a completely virtual world – a classic example of a sophisticated virtual world would be an aircraft simulator.[43] In a well-designed simulator, the trainee gets the full flight training experience, but with the advantage of a "reset" button – if something goes wrong and the aircraft crashes, the simulator can be reset and the trainee can go through the scenario again. AR inserts virtual objects into the real (live) world. Perhaps the most common example of AR is the first down line in a football game. That line is generated by a computer and overlaid on the image of the field, then both are transmitted together through your TV. The line is not really there, but it looks like it is. So AR is not new, but it has been difficult to apply to military training because military forces don't generally train by watching TV. Which means that AR for military use needs to be mobile and, especially for dismounted individuals it cannot be ungainly or weigh too much. The ultimate goal of AR is to be able to overlay virtual or constructive objects and effects (e.g., weapon impacts) onto a viewer that is the size/weight of ballistic glasses – or as close to that as possible – for dismounts, and onto cockpits, viewers or windshields for aircraft and vehicles – much like heads up displays (HUDs) have been doing for years, but at higher fidelity/realism.[44]

The reason AR is so important is that it provides the until-recently missing link that allows Virtual and Constructive to be inserted into L training. V and C have been able to exchange information for some time, and to ingest information from L (e.g., PLI, health status from MILES or I-TESS systems). But realistically inserting V and C participants, objects and effects into L training has been the missing link. The

†† We are not going to get into the current technical debate over the differences or similarities between AR vs mixed reality (MR). We use the term "AR" to refer to the ability to inject virtual or constructive objects and effects into the live environment.

Marine Corps recently transitioned an individual AR system from the S&T prototype level into the acquisition system. The system provides the ability to show a dismounted Marine (infantryman, forward observer, or JTAC) where mortar, artillery, or aircraft ordnance are landing and their visual (the shape of the explosion) and auditory effects (the boom).[45] It's a good first start, but it does not have the computing capacity to show many virtual objects simultaneously, nor does it support multiple Marines using the systems simultaneously and correctly rendering the V/C effects from their different viewpoints. So it's only a start.

What is needed is the ability for teams and units to train together, each seeing what they could actually see in a combat situation. For example, laser-based systems such as MILES and I-TESS have been used for decades to simulate weapons effects. They work well if the trainee hits what he is shooting at and sets off the "death alarm." But if he is missing the target, he has no idea where his rounds are going. It's going to take a lot of computing speed and processing capacity to be able to realistically portray all the weapons effects in force-on-force training. But at this point, AR has been demonstrated to work. So the Marines and Army are very interested in these capabilities.

The Navy aviation and Air Force communities have not been so enthusiastic about AR, at least not yet. Although their cockpits have had HUDs for years, both are legitimately concerned about having virtual and live aircraft flying in the same airspace. They do not want a live aircraft conducting evasive maneuvers that put the pilot or his/other aircraft in danger based on a reaction to a virtual aircraft or missile. So there is still work to be done to demonstrate that AR can be useful in aerial environments.

Unobtrusive Data Collection and Rapid After Action Review Generation

Another opportunity, particularly as L, V and C capabilities start getting federated and combined, is unobtrusive data collection for after action review (AAR). Services with instrumented ranges already do this extremely well, but in the large-scale LVC exercises envisioned for the future, and in which geographically distributed units can participate from their home stations, it is unlikely that many of the participants will have access to such instrumented ranges. Traditionally, the challenge for data collection has been in the live environment. Currently, for live exercises (on non-instrumented ranges), much of the data collection is based on direct observation by observer-controllers or other exercise evaluation personnel. These people "take notes" and provide verbal AARs at the conclusion of events – after which, the data and associated training assessments are frequently lost.

At the opposite extreme, the computer-based systems used in the V and C arenas generally record every single event or action of every entity within the system. The challenge associated with collecting this level of detail is being able to sift and sort it to identify the "nuggets" that are important to the AAR. For this reason, exercise control personnel originally watched the system to identify those nuggets (tagging them by time, for example), or simply played back the entire event. But computer-based training systems have been around for quite a while, and trainers have developed automated capabilities to record significant events for incorporation into AARs, particularly for repetitive training (e.g., a series of pilots running emergency procedures in an aircraft simulator). So for V and C, the automated AAR tools are in general further along than the data collection methods for L training in non-instrumented ranges.

The Services' desires to combine L, V and C therefore have the potential to improve the unobtrusive, automated data collection for AAR. For example, if the live participants are using I-TESS ("laser tag"), that system has the ability to record where each participant is in time, when he/she fired their weapons, and the effects of those weapons. Combining that level of tracking with associated virtual simulators and constructive simulations – particularly as AR systems are used to increasingly tie live to virtual and constructive – offers opportunities to enrich the data set by combining all three types of sources. And because these opportunities would simply leverage the capabilities they already have, this richer AAR data could be made possible without dramatic increases in cost: in essence, it proposes to add automated processing to the data collection mechanisms already being used.

Multi-level Security

Multi-level security (MLS) is a problem in real-world operations. Rightly so, the Services need to impose security measures to protect sensitive and classified information for systems that work at different classification levels. And there are very well developed protocols, and systems (such as Radiant Mercury), that specify when and how information can be transmitted between the different levels. When going from higher to lower classification in particular, those protocols/systems must be carefully applied to "scrub" information that cannot be allowed outside particular compartments, for example.

The problem is even more difficult for training systems that operate at different levels, which occurs routinely; in general, aviation training systems operate at Secret level (though the F35 may operate at Top Secret), and ground training systems operate at Unclassified/For Official Use Only (FOUO) levels. Furthermore, while people can often afford a delay of a few minutes for messages to work their way through Radiant Mercury, delays of even a few seconds can cause massive problems in the "fair fight" area between sims operating at different levels. Imagine a rapidly changing air and ground fight where a flight of helicopters (helos) is attacking a convoy of ground vehicles: helos shooting their chain guns at the vehicles, vehicles shooting their machine guns back at the helos. All while both are moving. If a HMMWV is moving at a leisurely 25 kph while a helo is shooting at it, if there is a processing delay of 1 second while the helo rounds make their way from the Secret simulator to the unclassified convoy simulator, that HMMWV will have moved out of the pathway of the helo's rounds by the time they arrive.

So solutions to the MLS problem are sorely needed. One might question why a Service would not simply operate those ground and helicopter simulators at the highest classification level, alleviating the need to transmit data back and forth between the levels. The problem is that many ground troops, both soldiers and Marines, do not have security clearances (generally, sergeants and above in both the Army and Marine Corps get Secret clearances). The bottom line is that the current safeguards between different security levels work well in the operational realm, but the training realm needs much faster ways to transmit data back and forth without violating security protocols.

Distributed Learning

The Services focus on LVC capabilities to increase scope, scale, geographic area, and other potential advantages predicated on a simple premise: The individuals and small teams that make up large-scale military organizations and formations have the individual skills they need. We focused on the Navy's challenge in this area in the discussion above, but the reality is that individual/small team skills are a challenge in all the Services. In the same way that "all politics are local," one can say that "all operations are tactical." In short, if the individuals and small teams (such as vehicle crews) are not competent in their jobs, then trying to assemble them into larger scale events by leveraging LVC capabilities is (no pun intended) an exercise in futility.

We noted the expense of assembling various units within a large-scale exercise into a single geographic area, but considering the number and variety of individual skills in the military Services, this expense is amplified by sending individuals to traditional "schoolhouses" for training. The Services simply do not have the capacity needed in existing schoolhouses to train everyone at all skill levels; even if they did, the personnel "overhead" (the T2 aspect of P2T2 – prisoners, patients, transients [those traveling] and trainees) of sending everyone to a traditional schoolhouse simply is not affordable.

Civilian academic organizations are recognizing the same challenges, and online universities are becoming more common. Far different from the self-paced courses of the past, by leveraging modern technologies, academic organizations are creating the full "university experience" in the virtual world by offering on-line education via distributed learning (DL). This style of learning includes interaction between instructors and students, on-line discussions, student discourses, and very closely mirrors the physical university experience, but the students live at home and do all their interactions on-line.

Initially, military DL was limited to on-line versions of self-paced courses in "required," courses such as protecting personally identifiable information (PII), security procedures annual refresher training, and other topics which military and DoD civilians were required to complete, but that were often considered nuisances. Only recently has the DoD started looking into adopting academic online university practices, or even adapting them to unique DoD needs. As a result, there are huge opportunities to offer the Services DL methods and technologies for training individuals and small teams in core topics such as MOS skillsets so that when larger-scale LVC training exercises are conducted, or even the increasingly scarce opportunities for large-scale live exercises are available, the individual/small team participants are up-to-speed on the skills they need to take maximum advantage of such opportunities.

4. How are Select Partners and Allies Using Live, Virtual, and Constructive?

Select countries globally view modeling and simulation – and more specifically LVC – to be a key enabler for their future force. Synthetics are seen as a mechanism to provide a training edge in future conflict – at both the tactical and operational level. However, the rationale for various countries' consideration for LVC training, the development of broad based cultural buy-in, and the degree to which they believe synthetics should be blended with live training do differ. Moreover, the policy and governance instruments used to enable LVC training diverge.

What follows are a series of case studies of select countries that are considered unique in their adoption and/or approach to LVC training. While the selected countries are certainly not exhaustive, the Potomac Institute for Policy Studies recognized that certain countries and military services are "leading the pack" in their use of LVC for training and chose to focus on those countries in more depth.

The Royal Canadian Air Force: A Model for Current Live, Virtual, and Constructive Usage?

The Royal Canadian Air Force (RCAF) Simulation Strategy 2025 is currently considered the key reference for nations working to develop a rationale for simulation usage. RCAF defines its simulation vision as follows:[1]

> *By 2025 the RCAF will have a simulation focused training system, which skillfully leverages live, virtual, and constructive (LVC) domains within a networked common synthetic environment. The systems will optimize the means by which RCAF aviators achieve and maintain readiness, fully exploiting advances in both technology and training methodologies, to deliver world-class capabilities for the full spectrum of operations.*

This systems of systems vision, that connects new and legacy training devices, is designed to create an integrated battlespace to train aviators. While the vision is specifically focused on aircrew training, its implementation will provide a foundation for synthetic training and procurement across the entirety of RCAF.[2] While RCAF has a long history of delivering innovative training – through the British Commonwealth Training Plan (BCATP) in the Second World War, the creation of the NATO Flying Training in Canada (NFTC) program in the 1990s, and the recent fielding of training solutions for the CC-130J Hercules and the CH-147 Chinhook – the adoption of the "RCAF Simulation Strategy 2025" represented a paradigm shift in strategic thinking. As a RCAF Colonel noted, "We have historically acquired simulators to meet singular training objectives to a given weapon system. By the mid-2000s, senior RCAF leadership realized that we needed to think more broadly than just training on an individual weapon system; we needed to look at a series of networked systems that achieves readiness goals in a collective fashion, making the resultant training outcome much more significant than the cumulative sum of individual training events."[3]

In order to fulfill RCAF's goal of developing "more effective, efficient, and smarter training,"[4] RCAF developed a strategic roadmap to achieve its synthetic vision. The strategic vision forms parts of the overall RCAF Campaign Plan and consists of five main development thrusts: simulation focused training; the development of a virtual battlespace; the creation of a C2 governance and policy to maximize the usage of modeling and simulation; the establishment of the requisite support infrastructure to host all components of the virtual battlespace; and service delivery for procurement and support services to meet the user in-service needs of the virtual battlespace.[5]

RCAF has already made progress implementing its strategic vision and its roadmap, including a recent Air Force order directs a "simulation first" concept, such that when a simulator and an aircraft are both equally capable of achieving a training outcome, the simulator will be the primary training aid.[6] The RCAF Ontario-based 450 Tactical Helicopter Squadron (THS) located at Canadian Forces Base Petawawa has emerged as a center of training excellence for its integration of synthetics. The squadron is set to receive a delivery of fifteen Boeing CH-147 Chinooks, which will increase Canada's responsiveness for air logistics at home and overseas. The CH-147 operational training flight syllabus originally designated a 95% training simulation goal, however in February 2015, that was altered to an initial 60% simulation supported training. It is expected that as the program matures, the synthetic training will increase.[7]

In October 2015 the Canadian government released a tender to industry for its future Future Aircrew Training (FAcT) project, expected to be worth at least CAN $4 Billion (US $3.2 Billion). The project is expected to be put in place over the next five years, with a contract set for 2021 lasting a 20-year period.[8] The project will combine two existing RCAF programs, the NFTC program, which deals with lead-in fighter training and the Contracted Flying Training Services, providing basic flying training, as well as helicopter and multi-engine conversion.

As RCAF works to implement more of its simulation strategic vision, it hopes to pioneer new ways to have operational C2 impact its tactical level simulation training, through building linkages with air mobility; fighters; intelligence, surveillance, reconnaissance (ISR) simulators; among others. RCAF has identified LVC as key enabler to deliver world class capabilities, which is demonstrated through its policy development, governance, and strategic plan. However, resources have not been allocated and the program is competing against other Canadian armed forces programs.

The UK: Structural Innovation Towards a Capability Approach to Training?

The UK defense has broadly recognized the capability benefits provided by LVC and has sought to foster an environment that does not favor platforms over key enablers. While this policy direction is now provided to services from the joint level, the origins of this shift in strategic thinking can be traced back to 2011.

In 2011, a non-partisan report entitled, "Defence Reform: An Independent Report into the Structure and Management of the Ministry of Defence," was released to the UK public. The report, since dubbed "the Levine Report" after its key author, assessed the key drivers of the Department's financially overextended programs, with the goal of providing structural proposals for costs saving, while ensuring needed defense capabilities.[9] As part of the report's fifty-three recommendations, the report proposed a future Defence Operating Model for structural reform.

The goal of the Defence Operating Model was to move towards a defense mindset that focused on the development of capabilities, rather than platforms. As part of this ongoing focus on capabilities over platforms, there is a greater move towards the use of simulation and synthetics.[10]

Building on the momentum generated by the Defence Operating Model, in April 2015, the UK released the Defence Policy for Simulation. The documented notes that:[11]

> *By 2020, Defence will have a coherent framework of simulation capabilities that are cost effective, interoperable, and rapidly configurable. This will be supported by Defence Training, Education, and Simulation Centre that together will provide common, shared enablers in order to maximize the utility of simulation to enhance operational capability and use Defence resources efficiently.*

The Defence Training, Education, and Simulation Centre (DTESC) is, at present, not fully completed with an estimated launch date of 2018. DTESC falls under the mandate of Defence Training and Education Coherence (DTEC), which seeks to ensure training and educational unity across defense, while reducing costs.[12] In the interim, the Defence Simulation Centre (iDCS) was created, which provides a focal point for all simulation in the Ministry of Defence, while directing supporting the DTEC Technical Authority.[13] Through iCDS support to DTEC's Technical Authority, iCDS links to Joint Forces Command (JFC) Capability Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISR) – the overall authority for governance of defense virtual simulation.[14]

Regardless of the broad-based structural reform that is providing the UK Defence Ministry, and its services, the ability to think more strategically about simulation, particularly LVC, there are still mass hurdles to adoption – most notably culturally. Interviewees, across all services, noted that the adoption of LVC would require long-term cultural change, not just within their requisite services, but also within Defence. For example, the most recent 2015 National Security Strategy and Strategic Defence and Security Review (SDSR) makes no mention of the use of simulation or synthetics as a key enabling technology for training.[15] The 2010 SDSR, however, did identify a Defence wide requirement to move elements of live training into the synthetic environment.[16]

A broad based overview of current military service efforts to adopt a capabilities-based model for training follows:

The Royal Air Force. The RAF has been pioneering the most advanced use of emulation and LVC via their new Lead-In Fighter Training of the Hawk T2 aircraft at RAF Valley. The Hawk T2 aircraft uses a state-of-the-art advanced avionics suits and sensor simulation software to help make the transition between a trainer aircraft and the Typhoon (the RAF's fourth generation aircraft) easier.[17] Pilots are receiving better quality training during the initial Lead-In Fighter Training, which allows the RAF to reduce training on more costly advanced jets. This program is now becoming an example to follow by Canada and the US, with the T-X program.

By 2020 the Royal Air Force (RAF) plans to have a 50/50 balance of live and synthetic training. Every new platform procurement is meant to have a simulator that is interoperable with overall synthetic training.

Facilitating the RAF's synthetic training is the Air Battlespace Training Centre (ABTC) at RAF Waddington, Lincoln. ABTC is designed to be a cutting-edge synthetic training organization, providing UK forces operationally relevant environments and scenarios across air, land, and maritime domains. The ABTC conducts thirty-eight weeks of collective training per year, which have acted as technology demonstrators and have also helped to drive broader cultural acceptance of synthetics within the military.[18] For instance, there was initial skepticism among special operations forces (SOF) on the benefits associated with synthetic training. However, the success of the STEEL DRAGON exercises at ABTC, which delivers Joint Terminal Attack Controller (JTAC) training to Royal Artillery Units has caused the SOF community to now become some of synthetics biggest advocates. As two Air Force officers told these authors, "When you are having a bad day in Afghanistan, you now call it a STEEL DRAGON day." The goal, they noted, is to "train hard and fight easy."[19] LVC is making that a reality.

However, it is not just STEEL DRAGON that has yielded results. ABTC also holds the VIRTUAL FURY exercises that provides air-to-air training for the 4th generation Typhoon Force with supporting air elements, while integrating in Royal Navy (RN) elements. The RAF counts the ongoing linkages between the Typhoon and the RN's Type 45 destroyer as a success. Their goal, moving forward, is to find a way to link the Typhoon and the F-35, so that their 5th generation and 4th generation fighters can work together.

Designing a training solution for the F-35 is no easy task. As Air Force leadership noted, a key challenge is building a White Force.[20] Typically, a White Force is provided by former RAF members that are also former operators. Given, the F-35 is an entirely new platform, providing that training capability is problematic. Moreover, training can't necessary emulate the full spectrum of conflict.[21]

At present, the RAF in conjunction with the RN,[22] are funded for three F-35 simulators and have put in a bid for an additional two to be forward deployed. The simulators will not be full mission rehearsal, but will be linked to live joint strike fighters while deployed. They will not, however, be linked to the soon-to-be commissioned Queen Elizabeth Carrier (QEC) due to bandwidth issues.[23]

The Royal Navy. In 2014, the RN had nineteen escort vessels, frigates, and destroyers in service – it had no reserve ships.[24] As a result, the RN is operating at absolute efficiency to maintain defense. As one naval commander told these authors, "the platforms are hot, with little shore time. The operating schedule is tight. By sending ships to sea [for training], you are de-heating the force."[25] As a result, synthetics are viewed as an opportunity to provide necessary training, while ensuring the RN vessels can remain in operation. Yet, the RN at present does not have the money to go into the LVC arena. As one Commander sees it, the RN is in the process of a period of incremental change.[26]

At present, the RN has operated a unique synthetic training model for its Astute Class nuclear-powered fleet submarines. Rather than purchasing simulators and training equipment to provide submariners the requisite capabilities to undertake sea-trials, the RN hired a prime contractor to design, develop, and operate the training facilities for a 30-year period. Training is purchased as a service, forcing the prime contractor to update training as required or resolve unforeseen technical issues.[27]

In the 2015 SDSR, the UK government allotted £642 Million (US $908 Million) for the production and procurement of a new fleet of Trident missile-armed nuclear submarines, under the "Successor" project.[28] The Successor-class submarines are meant to be the replacement for the RN's Vanguard-class of nuclear-powered ballistic missile submarines (SSBNs). The RN views the replacement as an opportunity to improve training. As Commander Orton noted with the Successor SSBN, a federated simulation system is the aspiration. He'd like different levels of interoperability to be put in place: first, linking trainers; followed by linkages within the RN; then broader inter-service linkages across Defence; and lastly linkages with allies.[29] Building on that, Charlotte Rhodes, a Submarine Training Systems Program Manager at Defence Equipment and Support (DE&S), noted, "With the Successor, we'd like to do lower-end collective training shore-side and then do a high-end work up at sea to full mission rehearsal with a carrier group. Currently this can't be achieved."[30]

Despite, the RN's future vision. The RN does face certain challenges. While there is broad-based cultural buy-in of the benefits of synthetics, it is not a priority area. As one Royal Navy Commander noted, "bits of kit are sexy, submarines are sexy, training is not sexy."[31] When budget allocations are made, embedded training is the first to be cut. Orton went on to note that, "I've got many aspirations, but realistically I won't be able to achieve them. Training is squeezed."[32]

The British Army. The British Army has a proven track record of leveraging simulation based systems to enhance, as well as replace, live training via synthetic alternatives: Tactical Engagement System (TES) for live training, Combined Arms Tactical Trainer (CATT) for virtual training, and the Combined Arms Staff Trainer (CAST) for constructive training.

The TES is a live training platform that allows Army personnel to train using real equipment, while experiencing the friction of the terrain and weather in warfare. The TES substitutes lasers and laser detectors for live ammunition to provide the British Army a high-level of fidelity for force-on-force training.[33] The CATT integrates Army drivers and ground forces into digital missions, using vehicle simulators to increase the tactical level of complexity. Prior to deploying in Iraq, some British Army soldiers undertook a five-day course on the CATT. The CAST, likewise, trains headquarter personnel through a week-long exercise, testing their operational plans and their command of operation room staff.[34] As one Army officer of Training Capability Development in the Army Training Branch in Army Headquarters noted, however, that "LVC technology has greater use than just for training. The future work by the British Army is investigating LVC's ability to support operational training, operational mission support, and force development evidence gathering." He went on to note, that "in addressing these objectives, one of the major challenges is overcoming the institutional belief that the significant upfront costs in bringing LVC capabilities into service are not outweighed by the benefits."[35] The officer attributed this institutional cultural reticence to a failure on the part of the British Army to produce evidence the substantiates the effectiveness and efficiency claims made by LVC advocates.

At present, the British Army is undertaking a Collective Training Sustainment (CTS) review, that is designed to combine TES, CATT, and CAST training elements. The UK MoD's DE&S notes that the "CTS seeks to achieve efficiencies that lead to greater flexibility and better value for money and outcomes."[36] At present, the current annual cost of the Army's collective training environment is budgeted at £38 Million (US $55 Million).

The French Air Force: An Alternative Relationship with Industry?

The French Air Force (FAF) has been operating at a high capacity and operational tempo. FAF sorties are deployed in high-numbers as France has played a pivotal – and at times unilateral – role combatting violent extremism throughout the Sahel, Maghreb, and the Middle East. Indeed, as part of Operation Inherent Resolve, or Operation Chammal as the French call it, the FAF has conducted dozens of strikes against ISIS strongholds in Iraq and Syria.[37] Training through simulation alleviates the training burden on live FAF aircraft, while also delivering more cost efficient and effective training.

As a result, the FAF has developed a training vision and roadmap for the future of synthetics in the Air Force. The FAF describes their vision for the enhanced use of simulated training in four parts: 1) Train as we fight; 2) Do what cannot be done via live training anymore; 3) Make the best and most efficient use of reduced flight hours; and 4) improve the cost effectiveness of training.[38]

France's ultimate objective is to achieve distributed air operations and virtual flags for tactical training; create a distributed mission operations center with an effective white force; and implement a robust LVC capability.[39] France envisions its future LVC capability to enhance live training by providing a more complex tactical picture through the insertion of more assets – friendly and non-friendly – using virtual and constructive means through Link 16.[40] France views the next step towards that end as adding Rafale and Mirage 2000 simulators. As part of its FAF's roadmap, France expects to achieve its LVC goals by mid-2018.

As France looks to achieve its LVC vision, it is looking to industry for support. However, as Colonel Jerome Lacroix Leclair Commander Flying Schools Command French Air Force noted, they are not looking for new platforms, instead they are interested in a system."[41] Interconnectivity of new and legacy simulators is key to the FAF. Conversations with the FAF leadership supported this view. He noted that the French want an architecture for connectivity. The FAF's key problem with industry is that industry does not sell connectivity – they sell assets.[42]

Like other countries, France faces challenges as it looks to adopt and integrate synthetics – in particular LVC. Lieutenant Colonel Le Bot noted that while the FAF can effectively train individual crew members, they lack the ability to train collectively. He likened this to an orchestra. While each instrument can play a tune, an orchestra without a rehearsal, is "not good music."[43] Moreover, France faces interconnectivity challenges as many of its simulators are legacy platforms and used primarily for limited tactical training. The FAF acknowledges it needs to broaden its "simulation spectrum" in order to meet its synthetic vision.[44]

Finally, France faces various structural challenges to get the needed funding for synthetics. The funding for equipment is at the Joint Level of the French military. Members of the FAF acknowledged that finding the requisite funding for new initiatives is a struggle at the Joint Level. It is often difficult to get buy-in. Moreover, France faces an upcoming election in April and May of 2017. It is unlikely that the FAF will receive the civilian leadership required to drive additional funding towards LVC until after the elections. As one officer coyly told these authors, "Politicians are politicians. They don't think like me. They see the TV."[45]

While strategic discussions on LVC in France are taking place at a high level, no joint consensus or direction has emerged. The FAF has a vision and objectives, but at present no official policy, implementation strategy, governance, or resources are allocated to allow the FAF to meet that vision. Change must occur at the cultural and structural level in order for the FAF to meet its LVC objectives.

Australia's Cultural Adoption: A Model of Future Organizational Innovation?

It is perhaps the duality of self-reliance and cooperation with a great power ally (the US) that one can best understand the drivers behind Australia's growing pursuit of LVC.[46] Indeed, as a member of the "Five Eyes" (FVEY) alliance, Australia's military engagements and procurements have been pursued in close cooperation and consultation with the US – the planned procurement of the F-35A Lighting II is the latest manifestation of that trend. However, unlike the other members of the FVEYs, Australia's geographic isolation, when combined with its proximity to a rising and more assertive China, compels Australia to adopt more cutting-edge training solutions. As one Royal Austrailian Air Force (RAAF) senior officer told these authors, "Australia is a big country at the end of the earth – connecting synthetically is the way to go."[47] This mindset broadly permeates the thinking of the military and the civilian leadership. Australia's broad-based cultural adoption of the benefits of LVC is reflected in industry tenders, the recent 2016 Defence White paper, and service strategy documents.

JP97-11 and the 2016 Defence White Paper. In 2016, the Australian government released will release a tender for Joint Project 9711-1 "The Core Simulation Capability (CSimC) project." The industry tender is designed to provide the Australian defense establishment with the capability to "realise a persistent (available on demand), integrated and distributed simulation service, including enhancement and sustainment services." The goal of JP9711-1 is to develop a synthetic solution that would allow the Australian Defense Force (ADF) to conduct single-service, joint, and combined simulation-enabled training.[48] JP9711-1 represents one of the first tenders, worldwide, that has sought to develop a whole of military solution for synthetic training with industry input from day one.

Also, in 2016, the Australian government released its most recent Defence White Paper. Unique compared to previous White Papers, the 2016 document is the first Australian White Paper released with the intention of being fully funded. Moreover, while past documents have focused heavily on investments for large-scale military platforms, such as ships, aircrafts, and vehicles, the 2016 document reversed that trend.[49] Recognizing that past investments have often occurred at the expense of enabling and integrating systems, such as training, the 2016 document emphasizes the importance of a balanced investment portfolio that includes both platforms and force enablers.[50]

As a result, the Defence White Paper advocates for "enhanced training opportunities, with investments in advanced training enabling capabilities, including training and testing ranges, equipment and simulation systems."[51] The goal, the document notes, is for future advanced joint training ranges that will "include platform simulators and systems that link multiple real-life activities and simulators together to allow for large-scale joint training and mission rehearsal."[52] JP9711-1 together with the 2016 Defence White Paper are indicative of the growing support for LVC among the civilian leadership of the government. Both documents reflect the strategic vision of Australian Ministry of Defence – a civilian and military apparatus. This is a positive trend for Australia. Indeed, with broader civilian support, one RAAF senior officer suggested that Australia has an opportunity to build a single federation where the services play nicely together.[53]

Yet, despite growing civilian support, the initial drivers of LVC within Australia can largely be attributed to the services. What follows is an overview of each services' policy documents and vision.

The Royal Australian Air Force. The RAAF is developing a roadmap for their air synthetic vision, which they plan to achieve by 2020, with some outcomes (a particular priority being tactical level LVC training for air combat group) to be realized by 2018. The RAAF Plan Jericho, was arguably the vanguard of LVC strategic thinking at the ADF. Plan Jericho provides a framework for the RAAF's transformation into a 5th generation fighting force.[54]

Plan Jericho has facilitated a broader emphasis on LVC within the RAAF, not only for future training, but also for maintaining an edge in future conflict – or as the RAAF characterized it maintaining a "transient advantage." Despite new procurements, adversary nations are quickly able to achieve technical parity with RAAF. The RAAF must develop alternative strategies to maintain an advantage. "Transient advantage," one senior officer stated, "is based on fundamental inputs to capability."[55] LVC, as a capability input, falls under that rubric. Indeed, within Plan Jericho, "Enhance Air Force's Live, Virtual, and Constructive Ranges Capability," is called out as a key program area. The program, expected to commence in the 3rd quarter of 2016, with a completion date of 2020, is designed to ensure that LVC and range capability gaps are identified and remediated for future force generation.[56]

Culturally, there is broad acceptance of LVC within the RAAF. LVC is delivering the RAAF better training outcomes, particularly as the 5th generation of fighters come onboard. Simulators are providing more flying hours to pilots.[57] Moreover, this extends beyond individual training; RAAF crews are also obtaining a higher level of training through simulation. However, broad based cultural buy-in is also apparent structurally, as the RAAF recently inaugurated their new Air Warfare Centre and the Joint Air Warfare Battle Lab.[58]

Despite the widespread buy-in, two schools of thought have emerged within the RAAF for the adoption of LVC. One hopes to link all RAAF military platforms and simulators together, regardless of legacy or generation.[59] The second, described as a "targeted fidelity" model, links simulators based on training audience and needs.[60]

The Royal Australian Navy. Like the RAAF, the Royal Australian Navy (RAN) also has a strategic vision – Plan Pelorus. Plan Pelorus released in April 2015 outlines the RAN's vision for acquiring more capable individual platforms, but also gaining essential capability inputs at the task force level by 2018.[61] Speaking on Plan Pelorus at the 2015 Williams Foundation Seminar in Canberra, Australia, former Director General for Navy Capability Plans and Engagement, Andy Gough noted that Pelorus fundamentally recognizes the need for the delivery of effective and efficient training, which is based in increased use of simulation.[62] He noted that LVC is not simply an option when selecting simulation to enable delivery of training, it is always the answer.[63] Moreover, when considering the procurement of new platforms, simulation is always considered in the package. The Navy Modelling and Simulation Office suggested that simulation is now thought of up front.[64] It is no longer an after-thought.

As a result, the RAN has made a concerted effort to increase simulation usage and in 2016 released its Navy Modelling and Simulation Strategy describing three strategic goals related to culture, systems and workforce, and governance. With a strong pedigree of participation in US led Fleet Synthetic Training reaching back to 2001, in 2015, the RAN undertook its first solely Australian-run distributed synthetic exercise, entitled "Triton Simulation." With support from the Australian Defence Simulation and Training Centre, Triton allowed the crews of the HMAS Sydney, Perth, and Melbourne to exercise warfare skills in a multi-ship environment using simulation systems ashore in HMAS Watson and Stirling and afloat in the HMAS Sydney.[65] The RAN provides white force, simulation and technical services from within the Maritime Warfare Training System, delivered in 2004 into HMAS Watsons under project SEA1412. The current system has limitations, and will require update in order to keep pace with the growing demand for distributed mission training according to the Navy Modelling and Simulation Office.

Looking forward, the RAN plans to be enabled through platform system centers, whereby platform specific development and training would be consolidated in a single facility. Most recently the $90M state-of-the-art Navy Simulation Training Centre for LHD training at Randwick in Sydney's shows how the RAN will revolutionise the way it prepares marine and electrical technicians for sea-service in the Canberra Class amphibious ships and Hobart Class destroyers. The RAN cites the USN "Cruiser in a Cornfield," as a model for future synthetic training. In Southern New Jersey, the USS Rancocas, located in a field of corn, is home to a USN Combat Systems Engineering and Development Site. Despite its landlocked location, Rancocoas is a commissioned naval vessel manned by USN sailors. It allows USN and industry personnel to conduct research and development in tandem, while also providing an environment to test next-generation systems before they are put to sea. Moreover, the site provides sailors the opportunity to conduct training on the same equipment they will use at sea.[66]

The Australian Army. In 2011, the Australian Army announced the Plan Beersheba, which is intended to change the Army's force structure to provide a wider range of sustainable land forces. The Plan is designed to drive the service from an "analogue to an information-age Army."[67] Yet, despite the clear information age focus of Beersheba, the hooks for LVC in Beersheba were not obvious. The Army has traditionally not systematically invested in LVC. As a result, LVC and how to employ it is not widely understood. Mangin went on to explain that as an example it was "easier for [him] to call in a real airplane in Afghanistan five years ago, than to do it using a simulator linked to an aircraft simulator today."[68] The Australian Army recently completed a deliberate planning initiative, which culminated in an August 2016 release of their "Army Simulation Concept – Silicon Warfighting: A Strategic Narrative for Army's Simulation Capability." Silicon Warfighting builds on past lessons learned by the Army and provides a strategic vision to better guide the Army's future investment, employment, and management of simulation. It is a unifying concept describing how simulation capabilities are to be considered, linked, and structured as a system supporting Army Force Development and Force Generation today, and Force Management and Employment in the future.[69]

Silicon Warfighting identifies the importance of simulation as an enabling capability for the Army. Importantly, it describes the requirement for Army to transition its thinking and management of simulation from a tool to a capability in its own right. And while simulation is central to the Army's training systems, it is also a core capability in the conduct of both research and development and decision support. Over the next 10 years the Army will be transformed as a result of programed capital acquisition directed by the Defence Integrated Investment Plan. As a consequence of this investment approximately AS$4 billion (~US$3.6 billion) will be spent on simulation over the coming decade. In order for Army to realize the true potential of this investment, simulation will be managed as a key enabling capability in the same fashion that is currently the case for Army's nine major capability programs. As part of this commitment and investment in simulation, several areas are to be targeted including: synchronizing simulation capability investment with the Army's Training Management Framework, improving the awareness of the benefits of Army's simulation capabilities to achieve its preparedness outcomes; developing an Army simulation policy and governance system to guide investment and manage capabilities across its life cycle; and the integration and exploitation of key technologies delivered under JP97-11; among others. The Army intends to integrate with JP97-11 technologies within the next four to seven years.[70]

Despite clear buy in from senior leadership and pockets of expertise across Army, that understanding of LVC and its value to the organization is not broad. In order for the Army to successfully implement its vision, building that cultural awareness at all levels of the value of employing LVC will be crucial.

Live, Virtual, and Constructive for Coalition Warfighting Training

While each of these countries are working to develop their own unique ways to integrate LVC into their training apparatus, there is also extensive cooperation across services and countries. There was potential to create a European-wide F-35 synthetic training community in the UK. It was posited that such a center of excellence could save the European community money, while working to build collective rapport across countries and services.[71] While these ruminations took place before the UK's Brexit vote, such an initiative could still take place under the rubric of NATO.

Moreover, future military operations are likely to take place as a coalition, driving the need for more opportunities to train among partners and allies. While coalition partners and allies have trained live at Red Flag, hosted at Nellis Air Force Base, for years, a virtual element has now been integrated into Red Flag. Coalition Virtual Flag, which coincided in 2015 with Exercise Red Flag 15-4, is an annual, real-time, tactical to operational level exercise using land, space, cyber, and maritime distributed scenarios to promote joint and coalition operational integration by training airmen in a high-fidelity virtual environment. The March 2015 combination of Red Flag and Virtual Flag was a first. While the live training of Red Flag took place over the 15,000 square mile Nevada Test and Training Range (NTTR), the virtual component covered a simulated 1,320,000 square miles. The inclusion of Virtual Flag to Red Flag increased the participation, scope, and complexity of the training, while also reducing cost.[72]

Moving forward, countries will not only have to grapple with the challenges associated with building their own in-country virtual battlespace, but also linking those systems to other countries – that may be operating with different standards and frameworks. A review of challenges, helps to identify potential solution sets for the implementation of LVC across services, countries, and coalitions.

5. Hurdles to Live, Virtual, and Constructive Adoption

While LVC promises to transform military training and education, significant technical and institutional hurdles exist. This section explores institutional hurdles to achieving various militaries' LVC vision. Based on both direct experience with US Services' training programs and interviews with select allied countries, four key impediments are examined: 1) standards, interoperability, and intellectual property issues; 2) bureaucratic constraints (silo approaches to innovation) and cultural issues; 3) an acquisition process that favors technology over capability; and 4) security challenges, such as cybersecurity, information assurance, and classification.

In previous sections, we provided visions of the future, descriptions of current challenges, and perspectives of allies and partners of LVC. Those descriptions cover a lot of ground, including the potential of LVC, challenges all are currently working to overcome, and how different nations' perspectives vary. We believe the challenges to LVC adoption are cultural, technical and budgetary, and we'll describe them in more detail below.

There are challenges to adoption of *any* computer or information technology (IT) system, and those challenges also apply to LVC. These "common" challenges include standards and interoperability, intellectual property (IP) issues, cybersecurity/information assurance (IA), and multi-level security (MLS) issues of operating different components at diverse classification levels.[1] So before we delve into the hurdles associated with LVC, let's briefly review the challenges that apply to all computer or information technology systems.

The first, common standards and their affect on interoperability, has remained a challenge for decades. Unfortunately, unlike Internet business ventures, DoD simply cannot afford to "throw away" technologies that are unable to adapt as technology advances. The harsh reality of the competitive, commercial world was demonstrated dramatically in the "dot com" heyday of the 1990s, which was followed immediately by the dot com bust of the early 2000s.[2] New firms were created, and then failed, seemingly overnight based on changing standards and competitive advantages (or failures). The dizzying pace of establishment, development, and competition, as well as the commercial "death" of those who could not keep up with the pace of change was either amazingly lucrative – or devastating – to myriad dot coms during that era.

DoD simply does not operate that way. Standards developed years or decades before are maintained well beyond any notion of commercial applicability because DoD has invested so heavily in them, cannot afford to revamp the standards and all the affected systems, and therefore needs to continue to use them whether commercially viable or not. As a result, DoD "hangs on" to standards that in competitive, commercial terms are out of date. This is true of individual computer/IT systems as well as federations, and thus also affects LVC. But because it is so prevalent, and therefore well known to DoD IT professionals and providers, we merely note here that such issues apply to LVC as well as individual IT systems.

The second "common" challenge is security. Whether cybersecurity – preventing hacker attacks – or IA – reducing vulnerabilities of system and process misuse – (the precise notions of these terms are variable and potentially convergent) the DoD has an established, entrenched security establishment that, quite frankly, has a valid argument: National Security is more important than commercial/financial security standards. In short, the commercial realms, and in particular financial organizations, have serious security challenges and concerns. But those concerns can be expressed and remedied in financial terms (which makes their risk assessments very different from government, and particular DoD, approaches). DoD, on the other hand, cannot simply "buy its way" out of serious security breaches. As a result, the DoD's cybersecurity and/or IA security-related *standards* tend to be more stringent than in the commercial sector.[3]

So the ability of the commercial world to adopt new technologies is simply more agile and facile than DoD's because (a) DoD believes the risks of *being wrong* are much greater, and (b) DoD does not have a financial return on investment bottom line, which leads to difficulty determining when the reward of changing exceeds the risk. As a result, the DoD is significantly more careful about adopting new technologies until the security community fully understands the risks and ability to mitigate those risks. Again, this cautious approach is not limited to LVC, but LVC is as affected by it as are other government/DoD IT/computer system approaches and programs.

Within this context, the rest of this section addresses hurdles that apply not to IT/computer systems, in general, but to LVC specifically. Because LVC proposes to combine three types of training capabilities into a common environment, there are indeed challenges that are unique to LVC concepts. Each of these challenges, which we have categorized as cultural, technical, and budgetary, is summarized below (see Section 3, and also parts of Section 2, for more specific details).

Cultural Hurdles

DoD organizations are by nature conservative. Those who have experience within this realm understand why: the cost of being wrong is often expressed in blood, not dollars. It is one thing to take a calculated risk investing dollars in hopes of a higher return; it is another thing entirely to risk the lives of America's sons and daughters in lethal conflict. Within DoD, live training has been the *only* way to train for combat until the advent of the Internet (developed in the 1960s and 1970s, but only realized in widespread use in the 1980s and 1990s).[4] As a result, the notion of training in other than live environments has been possible for less than a generation. So expecting DoD to embrace training other than live simply because it is *new and innovative* fails to recognize the DoD's inherently conservative nature.

Having said that, simulations and simulators have now been in existence for over 20 years. So DoD organizations now have, literally, decades of experience using them. But that experience has been almost uniformly "unitary" – using a single simulation or simulator for a narrow, very specific purpose. Examples include individual simulators for pilot or ground vehicle crew training, or collective simulations to stimulate staff level training. Why tie them all together?

Proposed and potential answers to this question are detailed in Section 3. In that section, we posit that combining the advantages of L, V and C can overcome the disadvantages of each, and we provide several examples of how that can be done. But that does not mean that skeptical DoD audiences actually *believe* such postulates. In a sense, it seems ironic that the various Services all seem to be embracing LVC capabilities. At the Service training (and requirements) organizations, this appears to be true, but the real question is "do those actually conducting the training really believe in LVC?" That question remains to be answered.

Finally, from a cultural perspective there will always be those who view anything other than live training as an attempt to *replace* live training opportunities rather than supplement them. These individuals point to the fact that military budgets are always "zero sum games," so if something is added then inevitably something else will be taken away. Therefore, they reason that adding V and C capabilities, or combining them into LVC, must mean that there will be fewer opportunities for what they see as the "gold standard" of live training. Furthermore, they can point to multiple occasions where one or the other high-level official (often from OSD) has either made, or strongly implied, that they want to *replace* live training with simulation rather than complement or supplement live.[5] Whether these occasions are misstatements, misunderstandings, or genuine intentions based on the belief that simulations can substitute for live training (and the answer is likely "all of the above"), those military trainers who are skeptical of the value of simulation will always point out that if they accept more V and C, then they are going to have to pay for doing so with less L.

Counters to the above argument normally hinge on one or both of two approaches. The first is the acceptance that budgets are shrinking, and then pointing out that V and C can indeed provide "crawl" – or "walk"-level training at lower cost, so that the inevitably fewer live training opportunities can be maximized within a given budget level because V and C are generally less resource intensive than L. Secondly, by proper sequencing – including adding V and C to overcome the inherent limitations of L, resulting in LVC – a multi-faceted approach can be designed that leverages the advantages of all three to offset their inherent individual limitations. The second point is often combined with the first to assert that LVC increases overall training value within shrinking budgets; In other words, even in a zero sum budget, gains can be made by smart application of technologies and techniques, to include integrating L, V and C.

Which assertion/approach is correct? Hard data supporting either position are difficult to find, and more difficult to compare directly. The bottom line is that there will probably always be a few skeptical detractors from V and C, and by extension LVC, regardless of the data, analytic results, or the storyline associated with LVC.

Certainly all the Services are exploring LVC capabilities for training. Certainly all the Services recognize that the next generation has grown up "immersed in technology." Therefore the Services are interested in seeing how LVC might not only better reach and engage that generation, but might also provide training and improvement of their ability to accomplish combat missions. Each of the Services have traditions and tendencies based on what has worked in the past – so, with this in mind, don't expect any of the Services to adopt "new" simply because of its "newness." The Services are the ultimate "show me" community – but most Service members are sufficiently open-minded that they can be convinced of the value of LVC – if a convincing case is made.

Technical Hurdles

There are two technical hurdles that, if not resolved in some fashion, could "kill" LVC as a viable and applicable solution set. We have discussed both in positive terms (Section 2) and current-situation terms (Section 3). Unfortunately, the first hurdle is basically a "self-inflicted wound" – the Services have all developed simulations and simulators that were never intended to work together.[6] So LVC "federations" (meaning that sims work together through middleware, which introduces problems of latency and synchronization that affect the "fair fight" issue – (Section 2 for more detail) may offer capabilities for existing sims to be stitched together to provide a whole that is greater than the sum of individual parts. Or they may provide disastrous counter-examples by attempting to federate dissimilar sims that, if they don't work, would convince yet another generation that trying to make V and C federate with limited L to "substitute" for live training at lower cost is simply an exercise in futility.

The point is that the opportunity is great, but at the same time the possibility of convincing a conservative training establishment that combining LVC (whether federated or integrated) weighed down by existing designs does not work, is just as great. At present, the Marine Corps is doggedly attempting to federate sims that were not designed to work together, while the Army has recently taken a step back and is attempting to build an integrated generation of sims designed from inception to integrate.[7] The Navy and Air Force are somewhere in between. So from the standpoint of interoperability – be it federation or integration – the "jury is out" on whether LVC offers significant advantages over simply using V and C in the "crawl/walk" stages and reserving the limited L opportunities to conduct "run-" level training with or without V and C. In sum, if the technical hurdle of interoperability by whatever means (federation or full integration) is not solved, then LVC could be viewed as an idea that simply did not pan out.

The second fundamental technical challenge is enabling LVC to automate functions that have "traditionally" been conducted manually. These challenges include 1) injecting V and C entities and results into L, realistically (for which augmented reality is a big enabler); 2) being able to do so across multiple security levels (the MLS issue); and 3) the ability to provide automated support for exercise reconstruction and analysis to provide rapid after action review (AAR). And beyond those issues for large-scale exercises, the distributed learning capabilities to enable individual soldiers, sailors, airmen and Marines to acquire and polish their skillsets, are all wrapped up in the technical "hope" that LVC will enable the next generation of training and, in general, learning.

An outside observer may view these hurdles, some of which are specific and some of which are much broader, as an "unfair set" of LVC challenges (e.g., why blame LVC for failures in individual skillset training). But the Services have invested so much effort and intellectual capital into LVC that it has become the label of what is in the process of becoming the "holy grail" of next-generation learning. The upside is that all the Services are interested in LVC; the downside is that if it doesn't work out, then they may retreat back into their individualized approaches in which L, V, and C capabilities all have their "traditional" roles – and there is no recognition of how LVC adds value by combining them.

So the bottom line of technical challenges is risk. This is similar to the civilian/commercial concept of correlated risk and return (high risk carries the potential for high return, and vice versa). Recognizing that the DoD is inherently conservative, and thus risk averse, LVC offers great potential by combining advantages of each to offset their conceivable disadvantages. But if it does not work – and even worse does not work at least somewhat in early trials – then the "hope" invested in LVC can result in a backlash of conservatism ("see, we tried but it didn't work") that could have adverse affects equivalent, if not greater, than the advantages if LVC *does* work. For example, the M16 rifle still has a reputation for being unreliable long after the cause of the initial reliability problem was resolved.[8] The technical hurdles of LVC are indeed the classic definition of high-risk, high-return – which carries with it a similarly negative implication: if it doesn't work (early/fast), then that has the potential to "prove" that LVC was a bad idea in the first place.

Budgetary Hurdles

Finally, whether LVC technically works or not, and whether the cultural hurdles are overcome or not, the final hurdle remains: budgets. In the last 2-3 years, the DoD has been whipsawed from the "horn of plenty" as our military forces were fighting active conflicts, to the "age of austerity" because those conflicts are over and now commercial/civilian economics are "more important" (at least, according to the current administration).[9] The associated budgetary obstacles introduce (at minimum) two challenges: 1) Actual monetary hurdles that prevent adoption of useful/effective solutions no matter how good they *really* are and 2) Financial arguments and constraints that prevent promising technical solutions from actually coming to fruition. And while related, each of these hurdles has different implications, so in this section they are treated as separate hurdles.

Ironically, the first hurdle seems the most difficult: "no matter how good the argument, we just don't have the money." But in reality, funding changes yearly, so the "no $ in year x" argument can be completely supplanted in year x+1. A good argument for LVC capability may seem to be unviable in year 1, but that situation can change very quickly. So while specific budget year constraints can be a hurdle, in general such hurdles are not "permanent" because they change from year to year. A good idea unfunded in one particular budget year can indeed become funded in a subsequent year. So annual budget variations can be frustrating, but budget arguments are seldom fatal compared to technical proposals that do not prove to meet expectations.

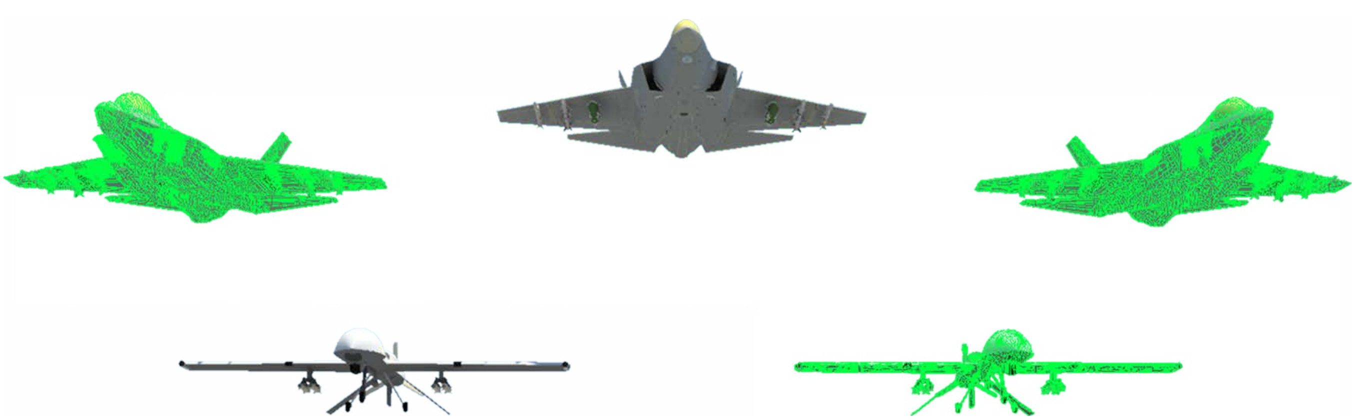
The second difficulty is closely related to the first, but its fundamental point is that of skepticism: no matter the technical merit of an idea, proposal or even project, there will be some who simply will not believe. And rather than openly attack technical merit, these people will default to the simplest counter-argument: "the potential solution looks good, but how can we know it works?" The good news about such arguments is that that is *exactly* why S&T organizations were established. Unlike operational organizations, which function in the realm of near-term operational requirements and ongoing operations, S&T organizations function in the realm of risk reduction and demonstration of possibilities.[10] Thus, S&T organizations can freely operate in the "age of skepticism" because that is precisely their role – to demonstrate the art of the possible to skeptics.

Rather than getting weighed down by the inevitable arguments of skeptics, it is possible to embrace that skepticism and work toward solutions that can be demonstrated to overcome skeptical arguments – which is precisely what DoD S&T organizations were *designed* to do for technical issues. And S&T organizations are not alone. The Services all have experimentation organizations that can experiment with the operational utility of new technologies as well as developing initial tactics, techniques and procedures for employing them.[11] That is, there is both a tension and a balance between skepticism and solution, and that nexus occurs exactly at the S&T organization, whether cross-DoD (DARPA) or Service-specific (e.g., ONR for Navy and Marines, etc.); and S&T organizations that can demonstrate the overcoming of technical hurdles can feed directly into Service experimentation to "try it out" and prove technical and tactical functionality. So as both skeptics and budgeters toss "monkey wrenches" into the solutions bowl, rather than hunkering down and hoping for the best, all the Services can be pro-actively seeking and exploring opportunities. Instead of wringing hands over shortcomings, seeking opportunities to collaborate and advance the state of the art can be a successful endeavor because there are DoD organizations (S&T and experimentation) whose mission is to do just that.

In summary, we have no intention of minimizing the challenges of exploring, exploiting, and implementing LVC capabilities and we recognize the challenges do not all fall into a single, convenient category. Moreover, the categories we propose are related, so focusing on a single dimension is not a particularly lucrative approach. As a result, to summarize both the challenges and recommendations for the way ahead to overcome hurdles in this extraordinarily complex environment, and regardless of current solution approaches, we recommend the following:

1. Explore the benefits and costs of adopting and adapting specific approaches based on LVC current capabilities vs LVC near-term, future capabilities. We do not recommend naiveté, but rather a structured, realistic approach to LVC federation at the individual and small-unit sim level. Working with the Services and DoD training organizations can facilitate this approach.
2. In conjunction with the above point, take a balancing "long-term" view of aspects and capabilities currently unavailable – but that in future, with a reasonable amount of time and funding, may be available – and explore the benefits and limitations of available/reasonable funding. Working with the Services and DoD S&T and experimentation organizations can enable this approach.
3. Finally, do not discount the potential value of "wild ideas." The methodical current capabilities/gaps to challenges/approaches/solutions approach is tried and true, but in reality, sometimes we can go from capabilities straight to viable solutions. The challenge is managing "good ideas" within the realm of the possible. The Potomac Institute for Policy Studies has assisted multiple customers in managing expectations across a wide range of venues.

In the next section, we examine overcoming challenges and the potential benefits of both institutional and organizational changes in light of LVC developments.



6. The Potentialities of Institutional Innovation

LVC has the potential to help transform military training. By combining live platforms with virtual and constructive simulations, military forces can train for larger, more variegated operational scenarios that involve both kinetic and non-kinetic elements such as cyber-attacks, electromagnetic spectrum warfare, saturation attacks of precision guided munitions, and elaborate cross-domain operations. But training is not the only arena in which LVC can be employed. Combinations of LVC capabilities have the potential to provide the capacity to test technologies in "high-fidelity" scenarios, allowing services to develop and experiment with new innovative operational concepts, and train forces with those concepts that appear most promising.

In this section we will make the case that LVC an enabler, but what leads to innovation is a combination that includes several elements: concepts, technologies, experimentation and training. As the US and allies work to define the third offset strategy, we believe we will need to combine all these elements to develop capabilities for the increasing complexity of future warfare. History demonstrates that military success arises from such combinations. We will explore two historical case studies to show how concepts combined with technologies, experimentation and training can yield disruptive capabilities on the battlefield. With these historical examples as context, we return to show how LVC can provide a rich and realistic environment for technological experimentation can facilitate military innovation.

Technological Disruption and Military Innovation and Experimentation

History demonstrates that technology alone is not sufficient to ensure the disruptive innovations that contribute to military success. Rather, it is the manner in which technology is folded into a broader vision defined by innovative warfighting concepts, experimenting to refine and confirm those concepts, selection of the technologies needed to support them, and then training the force in how to employ new capabilities that makes the decisive difference.

The German Development of Blitzkrieg Warfare

During WWI the British and the French developed the technological means for conducting modern armored warfare. The tank, slow and difficult to maneuver, was designed to cut across the "killing zone" between enemy trench lines in an attempt to break enemy defenses.[1] In World War I, the tank provided a protected platform that was used to punch holes in the stalemated trench-lines, enabling following infantry to exploit the resulting breaches. While the British and the French were the first to design and field this technology, they both viewed it primarily as an infantry support vehicle – due in no small part to the resistance of high-ranking cavalry officers who refused to see the value of tanks as anything but an infantry support weapon. Both the allies and central powers developed and employed tanks in WWI, and certainly these vehicles helped finally break the stalemate of trench warfare, but tanks were not a game-changing innovation during the first world war.

It was instead the Germans who saw the tank as an enabler for mechanized maneuver as part of a combined arms approach in what eventually was called the *Blitzkrieg* ("lightning warfare") concept that was the game changer. Being on the losing side of WWI undoubtedly helped the Germans, who were not tied to old concepts that had led to failure. As a result, they developed a new concept for fighting the next war, experimented with it extensively even without the necessary advanced technologies – for example, early German "tanks" were bicycles or cars with wooden cut-outs – and then trained their commanders and tactical units in how to employ this new concept, that almost enabled them to win the war against technologically and numerically superior forces. French tanks in particular were, one on one, technologically far superior to the early (1940) German tank designs in both armor and firepower. Yet the Germans were able to overrun France against a numerically superior French/British alliance in a few weeks. Let's explore how this happened.

During the interwar years, French thinking was largely informed by the grinding, relatively static form of trench warfare that the allies eventually won with in WWI. French leadership, including Marshal Pétain, argued for the creation of a long, ultra-modern trenchline – a defense in depth strategy. The result was the Maginot Line, a line of concrete fortifications, obstacles, and weapons installations that extended from Le Ferté to the Rhine River. The French were planning to fight WWI again.[2]

However, French failure did not lie exclusively in developing a defensive minded doctrine via the Maginot Line. In fact, as Williamson Murray notes, "the French doctrine was offensively minded, and it paid little attention to the problems of defensive warfare. Unfortunately, doctrinal innovation, influenced strongly by a misreading of the last war, particularly the lessons of 1918, led to the creation of a stylized, tightly controlled conception of tactics that provide unsuited to the modern battlefield, particularly one inhabited by Germans."[3] Indeed, the French emphasis on "carefully controlled and tightly centralized" firepower prevented the French recognizing that German infiltration tactics during WWI could be combined with technical improvements in tactical mobility for lethal results.[4]

Likewise, structural and cultural barriers in the British army prevented innovation in the interwar years. The irony is that British experiments with armored warfare between 1926 and 1934 contributed to German conceptual thinking that led to the creation of the German panzer forces. However, during the interwar years, the British army's administrative structure, culture, and class attitudes remained those of the prewar army.[5] These structural and cultural barriers, when combined with the overall lack of support for innovators – from both inside and outside the army – caused those voices to marginalized.

Conversely, German losses in WWI caused them to fundamentally rethink their operational concepts. German thinking was predicated on five core beliefs: the belief in maneuver, an offensive mindset, the decentralization of operations to the lowest levels possible, the belief that officers and non-commissioned officers must display battlefield judgment, and that leadership must display initiative at all levels.[6] With these core ideas in mind, the Germany undertook a series of experiments to test new operating concepts.

While General Hans von Seeckt was not a proponent of armored warfare, he did believe that a small, elite mobile force operating within a combined arms concept could yield military advantage – and he recognized that tanks could be part of that vision. As a result, von Seeckt had "training tanks" made of wood and canvas and mounted them on cars and bicycles. These training tanks were used to conduct mobile force-on-force maneuvers. The German experiments yielded a form of maneuver warfare that became known as *blitzkrieg*.[7]

The German creation of a combined arms concept with lightning thrusts – *blitzkrieg* – allowed them to defeat the allied forced and conquer France in six weeks. It was not just the tank that delivered Germany battlefield victory, but the intellectual breakthroughs and organizational innovation that led to new operational concepts.[8] In sum, the Germans employed a "combined concepting" approach that started with innovative concepts, tested these concepts in experiments in battlefield maneuvers, selected the technologies needed to enable them – and then trained their forces to employ them effectively.

The Development of Carrier Warfare

In 1914, pressure from First Lord of the Admiralty Winston Churchill forced the Royal Navy to convert some small passenger liners into seaplane tenders. On Christmas Day, three of these ships transported floatplanes near the North Sea port of Cuxhaven to bomb a German zeppelin base. The mission was ineffective, however it set precedent: air strikes could be launched from sea. By the close of WWI, the British had the world's only aircraft carriers.[9]

However, the same structural and cultural barriers that hampered the development of innovative new concepts for armored warfare during the interwar years also affected British naval aviation. By the start of WWII, the British lead in seabased aviation was gone.

Conversely, during this same time period, under the early enthusiastic leadership of Rear Admiral William A. Moffett, the US began a series of experiments to test the operational utility of airpower at sea. In 1921, target ships were anchored off the Virginia Capes and Army and Navy aircraft attempted to sink them – successfully. This was the first step in additional experimentation that eventually succeeded in achieving Moffet's goal of turning aircraft carriers into an offensive striking force. By the time war broke out in December 1941, the Navy had seven major aircraft carriers, second only to Japan, who had ten (based in part on observing US experiments and developing their own sea-based aviation). However, no agreement existed over the role of an aircraft carrier in battle – would they act in support of a traditional battle line or replace it?[10]

While the US had been experimenting with naval aviation during the interwar years, the Japanese had been doing the same. In April 1941, Isoroku Yamamoto created the First Air Fleet with five carriers grouped together in one strike force, with battleships, cruisers, and submarines sailing in a supporting role: this was the first version of a new concept in which aviation was the striking arm, and the rest of the fleet's role was to protect the carriers. On December 7, 1941, the Japanese innovative operational concept was demonstrated at Pearl Harbor, to devastating effect. The attack highlighted the power projection capability provided by a carrier task force.

The Japanese attack on Pearl Harbor forced an evolution of American strategic thinking from a battleship-centric organizing concept to one focused on carrier task forces. By May 1942 – in what was the world's first carrier battle – the US and Japan were facing-off near the coast of New Guinea. Apart from being the world's first carrier battle, the Battle of the Coral Sea also had the notable distinction of being the first battle where the opposing fleets never came within sight of each other – it was entirely fought from the air. While in the end the battle was considered a draw, it set the stage for a future US victory. The Japanese fleet carriers – Shokaku and Zuikaku – were so damaged they were unable to participate in the Battle of Midway the following month.

After Midway, the US Navy cancelled plans to acquire more battleships and put all its energy into procuring more carriers. By 1943, the US had deployed *Essex* class fast carriers that were superior to the carriers in operation by the Japanese. Moreover, the Grumman F6F Hellcat, the Lockheed P-38 Lightning, and the Vought F4U Corsair were far superior to the Japanese Zero.[11] This potent combination of a new concept for naval employment, innovative naval warfighting tactics, in conjunction with new technologies and training to combine all these into an effective naval striking force, resulted in a US Navy that was staggered after the attack on Pearl Harbor achieving military victory over the Imperial Japanese Navy.

Generating the Conditions for Military Innovation

The two examples above are only brief cases studies of the substantial military innovations that occurred between the two world wars. During this same period, the Marine Corps revamped amphibious warfare: no small feat, given that after the Allied disaster at Gallipoli many of military experts declared that amphibious operations were no longer viable in the face of modern weapons such as machineguns and long range artillery. In addition, the Navy was not the only Service experimenting with aircraft. During the same period, the Army Air Corps (now the US Air Force) was experimenting with concepts and technologies for strategic bombing in land campaigns (and the Germans certainly included tactical ground support – what is now called close air support (CAS) in their *Blitzkrieg* concept).

The point is that during a period of severely austere budgets (and particularly in the case of the Germans, treaty restrictions on military technology), innovations in all domains of warfare were pursued, and those innovations were employed to great effect during WWII. Further, they all had several characteristics in common:

- A *concept* basis. Innovations all started with new thinking about different ways to approach military operations. Though not known for sure, the phrase "Gentlemen, we have run out of money; now we have to think" is often attributed to Winston Churchill. Whoever said it, across the board the innovations that were employed on the battlefields of WWII all started with concepts. Innovative military concepts express new ways of thinking about future warfare.

- Extensive use of *experimentation* to test the concepts. New ideas are one thing, proving them out is another. So all the innovators during the period between the wars conducted extensive experiments to determine how well their concepts would work in practice, to modify and refine the concepts, and then conduct additional experiments to test the modifications.
- Identification of key *technologies*, either existing or needed, within both concepts and experiments. Concepts envisioned new uses of existing technologies such as the tank that was a centerpiece of blitzkrieg, and new technologies such as the Norden bombsight to support strategic bombing. Experiments tested both existing and new technologies within the context of the concepts, resulting in adjustment and adaptation in both concepts and technologies.
- Programs of *training* to make sure that military forces could effectively adapt to and employ the resulting innovations. Certainly, forces in experiments had to be trained in the new tactics associated with concepts and the associated employment of new technologies. Beyond that, once the concepts, experiments and technologies were "finished," military forces had to be trained in how to employ them all.

History demonstrates that disruptive innovation in warfare combines all of the above. As the US works to refine its "third offset" strategy, again during austere budgetary times, the Services need to embrace all of these key elements to develop an effective strategy for future warfare, supported by innovative concepts, identification of useful technologies, testing them in experimentation, and then training the future force in the "winners" of the innovation process.

This is not an easy task. As Max Weber once argued, "the essence of bureaucracy [is] routine, repetitive, orderly action."[12] Large bureaucracies, like the DoD, are slow moving beasts. They are not designed for nimbleness and disruptive change or innovation, in part because the cost of being wrong is often paid in blood, not dollars or euros. This is why military experimentation is essential to future innovation. And the difference between military training exercises and experiments is in their purpose, not so much how they are conducted. In fact, because the cost of sending large forces "to the field" is so high, experiments are often embedded within major exercises. This can be successful, but can also lead to conflicting purposes: if the exercise goal is to "test" the capabilities of a force to execute current concepts, and the experiment goal is to "test" the viability of a new concept, then those elements can (and sometimes do) conflict.

LVC offers a way out of the dilemma of how to best use the limited opportunities for large-scale live exercises vs. experiments. We make the claim above that the difference between training exercises and military experiments is essentially in their goals, not the details of how they are conducted. Let's explore that claim briefly, because if true, then how LVC can enable innovation as well as high-quality training becomes evident.

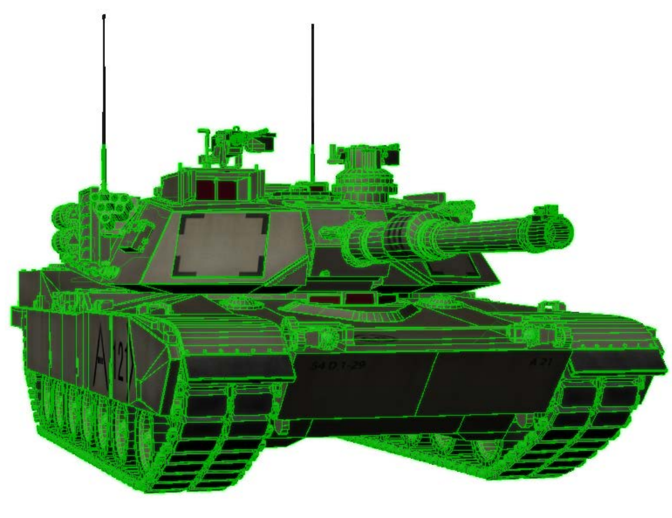
Military experiments differ markedly from laboratory experiments. Although the scientific method (form a hypothesis, etc.) is often used for both, laboratory experiments are much more controlled than military experiments. For example, every scientist knows that a good laboratory experiment controls all the variables but one, and involves multiple trials to confirm that success in a particular case was not a fluke. Even such basic procedures are virtually impossible to enact in military experiments. For one thing, warfare is a fundamentally human enterprise: a contest of human wills. And humans make terrible "lab subjects" because we learn: if we did something in trial 1 that did not work, we will inevitably try something different in trial 2. Furthermore, repeatability (through many trials) is extremely difficult to include in military experiments because of their complexity and the number of resources required to execute them, especially at larger scales. In addition, being able to control variables in military experiments is also exceedingly difficult, particularly for large-scale experiments in which senior leaders want to maximize the outcome of that experiment.

So if military experiments are so different from their laboratory counterparts, how *are* military experiments designed and executed? Done well, military experiments start with a new concept, and that concept may include variations in any or all of the DOTMLPF-P[13] elements. Where the new concept differs from existing concepts (e.g., replacing existing Doctrine with new Tactics, Techniques and Procedures (TTPs)), the experiment design must allow for training the experimentation force execute the new elements (whether they are TTPs, organizational changes, new technologies, and/or other elements). Once trained, the experimentation force generally practices the new elements to make sure they can successfully execute each, and then the experiment is conducted. This is exactly how military forces are prepared for major training exercises. The differences between the two are the concept that forms the basis (new, innovative or existing concept) and thus the event's objective: in the case of an experiment, to test the viability of the new concept (often in comparison to an existing one); in the case of an exercise, to test the force's ability to successfully execute that concept to the existing standard.

From the standpoint of the military forces involved, the *process* for preparing for and conducting an exercise or experiment is almost identical. This structural similarity is one of the reasons experiments are often embedded in exercises. In fact, units involved in military experiments often remark that preparation for the *experiment* was some of the best *training* they ever received.[14] In short, the main differences between the two are the concept and the associated purpose of the event. From the standpoint of many of the junior personnel who are experiencing the foundational concept for the first time, there is no difference at all.

Throughout this paper, we have made the case that LVC can provide cost-effective capabilities for future training. That being the case, we also argue that LVC can provide cost-effective capabilities for future military concept-based experiments en route to exploring innovative capabilities for future warfare. And in fact, because innovative concepts often require technologies that differ from those that already exist, the ability to "program" new or needed technologies' capabilities into V and C components can result in new avenues of cost-effective enablers for military experimentation. In sum, the same LVC capabilities that can enable training, with "tweaks" to incorporate expected technologies (or, alternatively, to vary technology capabilities to determine which works "best" or "well enough") provides efficient and cost-effective means to test innovations in high-fidelity scenarios, allowing services to design and test new innovative operational concepts.

Today the US and its allies find themselves facing an increasingly complex security environment.[15] The potential for mid – and long-term technological parity has emerged between the US and great power competitors – China and Russia. Iran and North Korea are expanding their precision-guided munitions stockpiles, and an extremist proto-state has been particularly adept at exporting its terrorist philosophy abroad. The US recognizes that it must develop alternative strategies to maintain military primacy and buttress the defenses of its allies around the world. As the DoD pursues a "third offset" strategy to maintain military superiority, LVC can help explore the value of innovative operational concepts to enable that strategy. History shows that the combination of innovative concepts, experimentation, incorporation of advanced technologies, and training the force in successful concepts is the way to prepare for future military victory. LVC offers new capabilities that can enable such innovations.



Conclusion and Recommendations

Combining LVC capabilities is a relatively recent concept for innovation in training. All the Services, and several of our close allies, are exploring ways to do so that improve the effectiveness of training and control costs to provide affordable alternatives to live-only exercises. Potential savings offered by LVC include reducing wear and tear on operational equipment, reducing travel cost and time by allowing geographically distributed units to train together, and reducing the cost of gathering the data needed to provide high-quality after action reviews. These are just some of the possibilities, and as LVC capabilities continue to develop there may be others that have not yet been foreseen.

Cost savings are only one dimension of the potential offered by LVC. By leveraging the advantages of each to offset the weaknesses of the others, combinations of L, V and C capabilities can provide improved realism relative to previous methods, as well as expanding the scale at which training exercises can be conducted. Furthermore, the foundational technologies needed to do so exist. That is not to say those technologies are as advanced as they need to be to provide high-fidelity training across the three domains, but rather that no technological breakthroughs are needed to support LVC. In short, the basics are there, and at this point what is needed is to flesh out the details – including both techniques and technologies.

Throughout this report we have explored, documented and discussed examples of the value of LVC as well as remaining challenges. We have provided an illustrative vision of future LVC capabilities, balanced by a catalog of current challenges. We have explored hurdles to adoption of LVC, balanced by the potential for significant reform. And we have explored how select partners and allies, as well as how the US Services, are thinking about and using LVC. In this concluding section, we raise the level of the conversation from the "what" of LVC to our views and recommendations of the "so what" as LVC continues to develop. In this vein, we believe there are three significant areas conclusions and recommendations. These areas include LVC's role in the Third Offset Strategy, the value of common standards, and implications for future systems acquisition. We briefly address each area in turn as we conclude this report.

Live, Virtual, and Constructive and the Third Offset Strategy

The opening section of this report discusses how training programs such as Red Flag were developed to improve our fighter pilots' capabilities during the Vietnam War. Interestingly, Red Flag was developed during the period of the First Offset (nuclear weapons), but at a point where our adversaries had for the most part caught up with our technological advantage in nuclear weapons. During that time of what many called Mutual Assured Destruction in a potential all-out war among the superpowers, the superpowers generally avoided direct lethal combat between themselves. Having countered our nuclear advantage, our adversaries also managed to counter the technical advantages of our latest aircraft. As a result, both our fighter pilots and the enemy's were equipped with aircraft that had similar capabilities. So the Air Force turned to a different solution: *train* our pilots to outfight the enemy's pilots.

Today, technology is proliferating at increasing speed. So even if, like the first two offsets (nuclear and precision weapons, respectively) a technological advantage is identified, we posit that it won't last long. And as yet, just exactly what the "big advantage" of the Third Offset is has not been identified. Having said that, our strategists have proposed that accomplishing missions at a favorable cost exchange ratio should be a part of that strategy. Therefore, improving our warfighters' training could in fact become a significant contributor to the Third Offset, particularly given the capabilities envisioned in LVC: reducing use, wear and tear and maintenance costs on operational equipment, enabling geographically-distributed forces to train together without having to travel to a common location (and thereby reducing "overhead" costs), and increasing the scale of exercises so that both small units and major staffs can train at the same time (and simultaneously leverage each others' capabilities to improve realism), all combine L, V and C capabilities to both offset each domain's shortcomings and reduce the cost of training. That is a tall order, but one that, as we have described throughout this report, LVC done correctly offers the potential to provide.

In this arena, one of the most critical LVC capabilities is the ability to enable geographically distributed (but network connected) forces to train together. This is critical for the Services; for example, networked LVC can enable an Army air cavalry unit at Ft Hood to conduct screening for a supported infantry unit at Ft Polk, LA, or a Marine fighter/attack squadron stationed at Yuma, AZ being able to provide close air support to a tank/infantry task force at Camp Lejeune. But it is probably even more important for Joint and Combined forces that are not even "normally" habitually associated with each other. So, for example, a Norwegian air defense unit can train in existing (and perhaps experiment with new) air superiority techniques with a US fighter squadron.

By being able to train together, both US and allied forces can work out differences in their SOPs, establish working relationships at the staff level, and so on – and do so at reduced cost. LVC capabilities can enable both horizontal (peer level units, such as an infantry unit and its supporting aviation organization) and vertical (higher to lower level staffs and maneuver units) training among geographically distributed forces. Avoiding the time and cost of assembling all those forces in the same area, and all operating their operational equipment along with simulators and simulations for selected combat systems, can indeed contribute to achieving favorable cost ratios in preparation for potential future operations. Further, by enabling "crawl" and "walk" level training to be conducted by geographically distributed units, those units can conduct "run" level training during the infrequent occasions when they *do* assemble for major exercises.

LVC and Common Standards

Having made the case that LVC can be an enabler for the Third Offset Strategy, the next logical question is perhaps "what is most needed to enable LVC?" We believe the answer to that question is to adopt a single common standard and set of specifications for LVC systems. All the Services (and our allies) currently have legacy training systems that were never designed to be integrated. Furthermore, even those systems that do follow one of the two existing standards (DIS or HLA) are often not compatible because the existing standards are themselves not interoperable. As a result, to federate current LVC capabilities, middleware is needed that can "translate" among the various systems based on whatever standards they use. Adding middleware increases cost, and potentially introduces processing delays or requires additional bandwidth, and therefore can adversely affect the "fair fight" issue even if the middleware works as intended.

The notion of common standards is not a new, but we believe it is an issue that needs to be addressed *eventually* if the different DoD Services and our allies are going to be able to take full advantage of LVC capabilities. As to which standard should be adopted, that is a technical issue beyond the scope of this report. We are aware, however, that both US as well as some of our allies have been exploring the Common DataBase (CDB) standard that is part of the Open Geospatial Consortium's (OGC's) best practices specifications. Such explorations are a step in the right direction. We cannot say whether CDB will be able to meet all the needs of LVC, or whether CDB is one of a set of specifications that may become the common standard, or some other standard will emerge that replaces CDB. But we recommend that the US and close partners and allies continue to explore common standards and specifications in order to promote interoperable LVC capabilities in the future.

The Services will undoubtedly continue to use existing legacy LVC systems for some time, and federating those systems may be the best near-term approach. But those systems will eventually reach the end of their service lives, and will be replaced by new LVC capabilities. Therefore, we believe that DoD and allies would be well served to explore, establish and adopt common standards and specifications for new LVC systems sooner rather than later to promote interoperability by design as new systems are developed in all three domains.

LVC and Future Acquisition

In the section above we recommend adoption of common standards as a step toward being able to fully realize LVC capabilities. In addition to dedicated training systems, the Live component of LVC implies a need to explore the ramifications of LVC on future operational systems acquisition in general in order to fully leverage the inherent capabilities of being interoperable with V and C training capabilities. Given the broad range of operational systems DoD (and our allies) employ, it is extremely difficult to make recommendations that apply across the board. But we do believe it is prudent to examine how common standards or specifications should be applied in the acquisition of (live) military systems to make sure they are interoperable with training systems.

Of course, interoperability is a 2-way street, so its impacts on acquisition need to be addressed both within the live and virtual/constructive system domains. As we said in the "Imagining the Future" section, there are no fundamental technology breakthroughs needed to make LVC a reality. But that is a far cry from ensuring that future systems in all three domains will be interoperable, and ensuring that the technologies needed to fully develop LVC are sufficiently supported. What we are recommending is that the Services should be forward thinking about the integration of training technologies along with actual live systems, so that they can move forward from the current situation in which training sims were designed as separate systems. We believe the primary needs for interoperability between L and V/C will be in communications and visualization components. Great strides are being made in voice recognition (and translation to digital formats) that can provide the "last piece of kit" for communication components. So the "pacing" item for full interoperability is likely augmented reality technologies, which are still in the early stages of development.

The bottom line, though, is that it is now possible to integrate L, V, and C, so addressing LVC capabilities and connections in new acquisition program planning – for both operational and training systems – can enable DoD and allies to leverage developing capabilities for integrated training. At present, LVC is more of a concept than a reality, but all the "pieces" exist to make that concept a reality. We do not mean to minimize the challenges to budgets and priorities in developing systems, but we do propose that it is *possible* to make LVC a reality. Doing so offers potentially game-changing opportunities for both US and allied forces to train together more often, more realistically, and to create larger scale training exercises at lower cost by enabling geographically distributed forces to "train at will." This capability can indeed be a foundation for the future – as advanced training has been a pillar of innovation in the past. LVC may well be the catalyst for enabling future training that can support achievement of the Third Offset Strategy.

Notes and References

1. The Challenge of Maintaining 21st Century Military Supremacy

1. Brian D. Laslie, *The Air Force War of War,* (Lexington, KY: University of Kentucky Press, 2015): Section 1.
2. *Ibid.*
3. The 1991 Persian Gulf War *Operation Desert Storm* seemed to herald a new era as it marked the first combined use of precision guided weaponry, information technology, and satellite communications and reconnaissance and was subsequently designated by some as a 'revolutions in military affairs' (RMA) or a 'military-technical revolution' (MTR). For more on RMA's see: Michael G. Vickers and Robert C. Martinage, "The Revolution in War," *Center for Strategic and Budgetary Assessment* (December 2004) and Andrew Krepinevich, "Cavalry to Computer: The Pattern of Military Revolutions," *The National Interest* 37 (Fall, 1994).
4. See former Secretary of Defense Chuck Hagel's speech: Chuck Hagel, "Defense Innovation Days," *Secretary of Defense Speech* (Opening Key Note, Southeastern New England Defense Industry Alliance, Newport, RI, September 3, 2014).
5. For an excellent overview of the third offset strategy, see: Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014).
6. Jon Harper, "Live, Virtual, Constructive Training Poised for Growth," *National Defense,* (December 2015): 45.
7. Melvyn P. Leffler and Odd Arne Westad, *The Cambridge History of the Cold War Vol. 1* (Cambridge, UK: Cambridge University Press, 2010): 289.
8. John Lewis Gaddis, *The Cold War: A New History* (New York, NY: The Penguin Press, 2005): loc. 1017.
9. Peter Grier, "The First Offset," *Air Force Magazine* (June 2016): 56.
10. John Lewis Gaddis, *The Cold War: A New History* (New York, NY: The Penguin Press, 2005): loc. 1002.
11. Steven Metz, "Eisenhower as a Strategist: The Coherent Use of Military Power in War and Peace," *Strategic Studies Institute* (February, 1993).
12. Secretary Dulles, "The Evolution of Foreign Policy," January 12, 1954, reprinted in Sam C. Sarkesian and Robert A. Vitas, *US National Security Policy and Strategy: Documents and Policy Proposals,* ed. (Westport, CT: Greenwood, 1988): 54.
13. John Lewis Gaddis, *The Cold War: A New History* (New York, NY: The Penguin Press, 2005): loc. 1049.
14. Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014): 8-9.
15. William J. Perry, "Technology and National Security: Risks and Responsibilities," (Conference on Risk and Responsibility in Contemporary Engineering and Science: French and US Perspectives, France-Stanford Center for Interdisciplinary Sciences, April 7-8, 2003): 2 and Michael G. Vickers and Robert C. Martinage, "The Revolution in War," *Center for Strategic and Budgetary Assessment* (December 2004): 8.
16. Harold Brown, "Department of Defense Annual Report Fiscal Year 1982," *Department of Defense* (1981) in Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014): 13.
17. William J. Perry, "Technology and National Security: Risks and Responsibilities," (Conference on Risk and Responsibility in Contemporary Engineering and Science: French and US Perspectives, France-Stanford Center for Interdisciplinary Sciences, April 7-8, 2003): 5 and Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014): 14.
18. Richard H. Van Atta, Michael J. Lippitz, et all, "Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs, Vol. 1 – Overall Assessment," *Institute for Defense Analyses,* (April 2003).
19. See: Stephen Peter Rosen, *Winning the Next War: Innovation and the Modern Military* (Ithaca: Cornell UP, 1991), Williamson Murray and Allan R. Millet, *Military Innovation in the Interwar Period* (Cambridge: Cambridge UP, 1996), and Max Boot, *War Made New: Technology, Warfare, and the Course of History 1500 to Today* (New York: Gotham Books, 2006).
20. See Barry Watts overview of technology, friction, and military failure during the Persian Gulf War in: Barry Watts, "Clausewitizian Friction and Future War, Revised Edition," *McNair Paper* 68 (2004): 37-58.
21. See: James R. Clapper, "Statement for the Record, Worldwide Threat Assessment of the US Intelligence Community, Senate Armed Services Committee," *Senate Armed Services Committee* (February 9, 2016), https://www.armed-services.senate.gov/imo/media/doc/Clapper_02-09-16.pdf and Tom Wright and Iskander Rehman, "The State of the International Order," *The Brookings Institution* (Draft Report).
22. As paraphrased by Rear Admiral Michael Manazir at the Sir Richard Williams Foundation Seminar. RADM Michael Manazir, "The Future Challenges of the Pacific Theater – USN Approach," *New Approaches to Air Sea Integration in the Evolving Extended Battlespace* (Sir Richard Williams Foundation Seminar, Canberra, Australia, August 10, 2016).
23. "The Shia Crescendo," *The Economist,* May 28, 2015, http://www.economist.com/news/middle-east-and-africa/21647367-shia-militias-are-proliferating-middle-east-shia-crescendo.
24. Keith Johnson, "Iran's Hollow Threats to Close the Strait of Hormuz," *Foreign Policy,* May 5, 2016, http://foreignpolicy.com/2016/05/05/irans-hollow-threats-to-close-the-strait-of-hormuz/.
25. James R. Clapper, "Statement for the Record, Worldwide Threat Assessment of the US Intelligence Community, Senate Armed Services Committee," *Senate Armed Services Committee* (February 9, 2016): 6-7.
26. *Ibid,* 7.
27. Dean Cheng, "The US Needs an Integrated Approach to Counter China's Anti-Access/Area Denial Strategy," *The Heritage Foundation Backgrounder #2927 on National Defense and Security* (July 9, 2014).
28. Edward Sobiesk, "Redefining the Role of Information Warfare in Chinese Strategy," *SANS Institute: InfoSec Reading Room,* March 1, 2013.
29. See: Brian D. Dailey and Patrick J Parker, *Soviet Strategic Deception* (Lexington, MA: D.C. Heath and Company, 1987) and Peter Pomerantsev and Michael Weiss, "The Menace of Unreality: How the Kremlin Weaponizes Information, Culture, and Money" *Institute of Modern Russia, The Interpreter* (November 22, 2014).
30. Steven Pilfer, "Pay attention, America: Russia is upgrading its military," *Brookings,* February 5, 2016, https://www.brookings.edu/opinions/pay-attention-america-russia-is-upgrading-its-military/.
31. Michael Mazarr, "Mastering the Gray Zone: Understanding A Changing Era of Conflict," *Advancing Strategic Thought Series* (Carlisle, PA: Army War College, December 2015): 35 and Jakub Grygiel and A. Wess Mitchell, The Unquiet Frontier: Rising Rivals, Vulnerable Allies, and the Crisis of American Power (Princeton, NJ: Princeton University Press, 2016), 43.
32. Michael Manazir, "The Future Challenges of the Pacific Theater – USN Approach," *New Approaches to Air Sea Integration in the Evolving Extended Battlespace* (Sir Richard Williams Foundation Seminar, Canberra, Australia, August 10, 2016).
33. Dan Parsons, "Technology Alone Cannot Win Future Wars, Senior Military Leaders Say," *National Defense,* October 24, 2013, http://www.nationaldefensemagazine.org/blog/lists/posts/post.aspx?ID=1314.
34. For more on the threat of Iranian, North Korea, Russian, and Chinese precision guided missiles and weapon systems, see: Mark Gunzinger and Bryan Clark, "Winning the Salvo Competition: Rebalancing America's Air and Missile Defenses," *Center for Strategic and Budgetary Assessments* (2016).
35. Deputy Secretary of Defense Bob Work, "Deputy Secretary of Defense Speech," *National Defense University Convocation,* August 5, 2014, http://www.defense.gov/News/Speeches/Speech-View/Article/605598.
36. *Ibid.*
37. Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014).
38. Anti-access (A2) capabilities are employed to prevent or constrain the deployment of opposing forces into a theater of operations, whereas area-denial (AD) capabilities are used to restrict their movement once in the theater of operations. See Andrew F. Krepinevich, Jr., "The Pentagon's Wasting Assets," *Foreign Affairs,* 88, No.4 (July/August 2009).
39. Shawn Brimley and Loren DeJonge Schulman, "Sustaining the Third Offset Strategy in the Next Administration," *War on the Rocks,* March 15, 2016, http://warontherocks.com/2016/03/sustaining-the-third-offset-strategy-in-the-next-administration/.
40. *Ibid.*
41. Robert Martinage, "Toward a New Offset Strategy: Exploiting US Long Term Advantages to Restore US Global Power Projection Capability," *Center for Strategic and Budgetary Assessment* (2014).
42. Steven Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, NJ: Princeton University Press, 2004): 4.
43. For an overview of military readiness, see: Richard K. Betts, *Military Readiness: Concepts, Choices, Consequences* (Washington D.C.: The Brookings Institution, 1995).

44. David Walker, "Presentation to the House Armed Services Committee, Subcommittee on Intelligence, Emerging Threats and Capabilities – FY2015 Air Force Science and Technology," *House Armed Services Committee* (March 2014) from "Going Virtual to Prepare for a New Era of Defense," *Government Business Council* (January 29, 2015): 6.
45. "Going Virtual to Prepare for a New Era of Defense," *Government Business Council* (January 29, 2015): 4.
46. Michael Manazir, "The Future Challenges of the Pacific Theater – USN Approach," *New Approaches to Air Sea Integration in the Evolving Extended Battlespace* (Sir Richard Williams Foundation Seminar, Canberra, Australia, August 10, 2016).

2. Imagining the Future of Military Training and Experimentation for Next Generation Warfare: The Role of Live, Virtual, and Constructive

1. David Vergun, "Live synthetic' Army's next generation of simulation," *Army News Service*, Mar 19, 2014, https://www.army.mil/article/122165.
2. *Ibid*.
3. Jen Judson, "Augmented Virtual Reality Emerging as Games Changer for Marine Corps Training," *Defense News*, December 11, 2015, http://www.defensenews.com/story/defense/training-simulation/2015/12/10/augmented-virtual-reality-emerging-as-game-changer-for-marine-corps-training/77096440/.
4. Staff Sgt. Joel Salgado, "Leader Battalion Field Training Exercise builds Soldiers for future missions," March 21, 2014, https://www.army.mil/article/122373/Leader_Battalion_Field_Training_Exercise_builds_Soldiers_for_future_missions .
5. Peter Buxbaum, "LVC for Integrated Training," *Military Training International*, March 12, 2015, http://www.mti-dhp.com/interesting-post/lvc-for-integrated-training/.
6. *Live, Virtual and Constructive (LVC) Training Fidelity, 2011*, (Arlington, VA: Office of Naval Research), 2.
7. John McHale, "Training in a virtual world is cost effective" *Military Embedded Systems*, October 10, 2012, http://mil-embedded.com/articles/training-a-virtual-world-cost-effective/.
8. *Ground Combat Element (GCE) 2013 Roadmap, 2013*, Appendix 8 to Annex C of Marine Corps Service Campaign Plan (MCSCP), 1-9.
9. *Ibid*.
10. *Live, Virtual and Constructive (LVC) Training Fidelity, 2011*, (Arlington, VA: Office of Naval Research), 2.
11. Davis, Paul K., and Robert H. Anderson. "Improving the composability of DoD models and simulations." *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology* 1, no. 1 (2004): 37.
12. Staff Sgt. Joel Salgado, "Leader Battalion Field Training Exercise builds Soldiers for future missions," March 21, 2014, https://www.army.mil/article/122373/Leader_Battalion_Field_Training_Exercise_builds_Soldiers_for_future_missions.
13. Kevin McCaney, "The military is becoming immersed in virtual training," *Defense Systems*, December 12, 2014, https://defensesystems.com/articles/2014/12/12/army-marines-lvc-virtual-training.aspx.
14. Sgt. Jesse Bauer, "Missouri Guard unit completes National Training Center rotation" August 1, 2016, https://www.army.mil/article/172563/missouri_guard_unit_completes_national_training_center_rotation.
15. "414th Combat Training Squadron 'Red Flag,' " *Nellis Air Force Base*, July 6, 2012, http://www.nellis.af.mil/About/FactSheets/Display/tabid/6485/Article/284176/414th-combat-training-squadron-red-flag.aspx.
16. "Murphy's War Law," *Military Quotes*, http://militaryquotes.org/products/murphys-war-law.
17. David Vergun, " 'Live synthetic' Army's next generation of simulation," *Army News Service*, Mar 19, 2014, https://www.army.mil/article/122165.
18. Amanda Macias, "A look into how much it costs to fly America's military planes per hour," *Business Insider*, August 13, 2016, http://www.businessinsider.com/price-military-aircraft-per-flight-hour-2016-8/#a-10c-1.
19. "RIMPAC Exercise to Bring 26 Nations Together in Pacific," *America's Navy*, June 24, 2016, http://www.navy.mil/submit/display.asp?story_id=95379.
20. *Joint Concept for Rapid Aggregation, 2015*, Distribution Statement A, 6-7.
21. "Marine Corps Aviation Training Systems," *Naval Air Systems Command*, http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=52FD7C22-33DE-47E3-9EB5-AB01B907E722.
22. "Navy Coninuous Training Environment (NCTE)," *Navy Warfare Development Command*, https://www.nwdc.navy.mil/SitePages/ncte.aspx.
23. "The NWDC Mission," *Navy Warfare Development Command*, https://www.nwdc.navy.mil/SitePages/home.aspx.
24. "Instrumented-Multiple Integrated Laser Engagement System (I-MILES)," *Cubic*, https://www.cubic.com/Global-Defense/Training-Systems-and-Solutions/Ground-Combat-Training/Multiple-Integrated-Laser-Engagement-System.
25. "Instrumented Tactical Engagement Simulation System II (I-TESS II)," *Cubic*, https://www.cubic.com/Global-Defense/Training-Solutions/Ground-Combat-Training/Multiple-Integrated-Laser-Engagement-System-MILES/Instrumented-Tactical-Engagement-Simulation-System.
26. "Augmented Immersion Team Training," *Office of Naval Research*, http://www.onr.navy.mil/Media-Center/Fact-Sheets/AITT.aspx.
27. Sydney Freedberg Jr., "DARPA's ULTRA-Vis Augments Reality For Foot Troops," *Breaking Defense*. May 21, 2014, http://breakingdefense.com/2014/05/darpas-wearable-display-augments-reality-for-foot-troops/.
28. "Marine Corps Warfighting Laboaratory," *Marines*, http://www.mcwl.marines.mil/Divisions/Experiment.aspx.
29. *Ibid*.
30. Van Brewer and Capt. Michala Smith, "Army Experimentation Developing the Army of the Future—Army 2020," *Military Review*, (August, 2014): 59.
31. *Ibid*.
32. Lieutenant General Paul E. Menoher, Jr., "Force XXI: Redesigning the Army Through Warfighting Experiments," *Military Intelligence Professional Bulletin*, http://fas.org/irp/agency/army/mipb/1996-2/menoher1.htm.
33. Sgt. Chris W. Cox, "Findings Released on Hunter Warrior Advanced Warfighting Experiment," *Marine Corps News Release*, August 22, 1997, http://fas.org/irp/news/1997/usmc_970822c.htm.
34. "Joint Conflict and Tactical Simulation Enhancements (JCATS)," *Physical Security Enterprise & Analysis Group*, http://www.acq.osd.mil/ncbdp/nm/pseag/capabilityareas/AS/JCATS.html.
35. "Bold Alligator 2016 Exercises Amphibious Forces," *America's Navy*, August 16, 2016, http://www.navy.mil/submit/display.asp?story_id=96230.
36. "ARPANET and the Origins of the Internet," *DARPA*, http://www.darpa.mil/about-us/timeline/arpanet.

3. Where is the US Military Today in Training and Education?

1. "Special Operations Command (SOCOM)," *Department of Defense*, https://fas.org/irp/agency/dod/socom/.
2. Pieerce Evangelista, "CULP Korea Cadets goes through Battle Simulation at Camp Casey," *US Army ROTC Cadet Summer Training*, June 30, 2014, http://futurearmyofficers.com/2014/06/culp-korea-cadets-goes-through-battle-simulation-at-camp-casey/.
3. Henry Canaday, "Practice, Practice, Then Shoot," *Military Training International*, September 15, 2016, http://www.mti-dhp.com/defense-news/practice-practice-then-shoot/.
4. Don Kramer, "New Simulators Get Stryker Drivers Up to Speed," *US Army*, April 27, 2007, https://www.army.mil/article/2881/New_Simulators_Get_Stryker_Drivers_Up_to_Speed.
5. Megan Locke, "Fort Campbell's new helicopter simulator provides virtual training," *US Army*, October 3, 2011, https://www.army.mil/article/66579/Fort_Campbell_s_new_helicopter_simulator_provides_virtual_training.
6. "Distributed Interactive Simulation (DIS)," *Prepar3D*, http://www.prepar3d.com/SDKv3/LearningCenter/getting_started/distributed_interactive_simulation/dis_overview.html.
7. "Training, Testing & Threat Force Systems," *General Dynamics*, https://gdmissionsystems.com/c4isr/training-simulation/.
8. "Assistant Project Manager for Synthetic Environment Core (SE) CORE," US Army PEO STRI, http://www.peostri.army.mil/PM-ITE/SECore.jsp.
9. Mark Pomerleau, "Army outlines plans for the next-generation of virtual training," *Defense Systems*, April 13, 2015, https://defensesystems.com/Articles/2015/04/13/Army-next-generation-virtual-training-simulations.aspx.
10. Staff Sgt. Joel Salgado, "Leader Battalion Field Training Exercise builds Soldiers for future missions," March 21, 2014, https://www.army.mil/article/122373/Leader_Battalion_Field_Training_Exercise_builds_Soldiers_for_future_missions .
11. David Vergun, "Live synthetic' Army's next generation of simulation," *Army News Service*, Mar 19, 2014, https://www.army.mil/article/122165.
12. *Live, Virtual and Constructive (LVC) Training Fidelity*, 2011, (Arlington, VA: Office of Naval Research), 2.
13. "One Semi-automated Forces (ONESAF)," *US Army*, http://asc.army.mil/web/portfolio-item/peo-stri-one-semi-automated-forces-pdm-onesaf/.
14. David Vergun, "Live synthetic' Army's next generation of simulation," *Army News Service*, Mar 19, 2014, https://www.army.mil/article/122165.
15. *Ibid*.
16. Cpl. Ricardo Hurtado, "Marines Call for Fire during Large Scale Exercise 2014," *Marine Corps*, August 12, 2014, http://www.

imef.marines.mil/News/News-Article-Display/Article/535425/marines-call-for-fire-during-large-scale-exercise-2014/.
17. Adam Banicki, "Marine Corps expands its virtual combat convoy training," *Marine Corps Times*, June 7, 2015, https://www.marinecorpstimes.com/story/military/tech/2015/06/07/marine-corps-expands-its-virtual-combat-convoy-training/28313861/.
18. "26th Marine Expeditionary Unit, A Certain Force in an Uncertain World," *Marine Corps*, http://www.26thmeu.marines.mil/About/MAGTF/.
19. "G-3 Operations and Training, MAGTFTC, MCAGCC," *Marine Corps*, http://www.29palms.marines.mil/Staff/G3-Operations-and-Training/MAGTFTC-Simulations/Staff-Training/MTWS/.
20. Cpl. Ricardo Hurtado, "Marines Call for Fire during Large Scale Exercise 2014," Marine Corps, August 12, 2014, http://www.imef.marines.mil/News/News-Article-Display/Article/535425/marines-call-for-fire-during-large-scale-exercise-2014/.
21. "Marine Corps Aviation Training Systems," *Naval Air Systems Command*, http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=52FD7C22-33DE-47E3-9EB5-AB01B907E722.
22. "Preparing Pilots and Maintainers," *F-35 Lightning II*, https://www.f35.com/about/life-cycle/training.
23. "US Navy contracts Lockheed for Radiant Mercury intelligence sharing system," *Naval Technology*, February 27, 2015, http://www.naval-technology.com/news/newsus-navy-contracts-lockheed-for-radiant-mercury-intelligence-sharing-system-4521866.
24. "PM TRASYS 2016 Products & Services Catalog," *Marine Corps Systems Command*, 2016: 8.
25. *Ibid*: 12.
26. "Bold Alligator 2016 Exercises Amphibious Forces," America's Navy, August 16, 2016, http://www.navy.mil/submit/display.asp?story_id=96230.
27. *Live, Virtual and Constructive (LVC) Training Fidelity*, 2011, (Arlington, VA: Office of Naval Research), 5.
28. Robert DeForest, "The Air Force Agency for Modeling and Simulation: Advancing Modeling and Simulation for the Warfighter," *Department of the Air Force*, March 2009: 23.
29. Amy Butler, "USAF Eyes New Era Of Close Air Support," *Aviation Week Network*, March 30, 2015, http://aviationweek.com/defense/usaf-eyes-new-era-close-air-support.
30. Robert DeForest, "The Air Force Agency for Modeling and Simulation: Advancing Modeling and Simulation for the Warfighter," *Department of the Air Force*, March 2009: 28.
31. "414th Combat Training Squadron 'Red Flag,'" *Nellis Air Force Base*, July 6, 2012, http://www.nellis.af.mil/About/FactSheets/Display/tabid/6485/Article/284176/414th-combat-training-squadron-red-flag.aspx.
32. "USAF Seeks Advanced LVC Capabilities," *The Official Daily News Digest of I/ITSEC* 2014, December 3, 2014: 9.
33. Peter Buxbaum, "LVC for Integrated Training," *Military Training International*, March 12, 2015, http://www.mti-dhp.com/interesting-post/lvc-for-integrated-training/.
34. "Augmented Immersion Team Training," *Office of Naval Research*, http://www.onr.navy.mil/Media-Center/Fact-Sheets/AITT.aspx.
35. Jamie Lendino, "Google Glass: Everything You Need to Know," *PC Magazine*, April 15, 2014, http://www.pcmag.com/article2/0,2817,2416488,00.asp.
36. David C. Walsh, "Live Synthetic' goes for the next level in simulation," *Defense Systems*, May 14, 2014, https://defensesystems.com/articles/2014/05/14/army-live-synthetic-simulation-training.aspx.
37. "Marine Corps Aviation Training Systems," *Naval Air Systems Command*, http://www.navair.navy.mil/index.cfm?fuseaction=home.displayPlatform&key=52FD7C22-33DE-47E3-9EB5-AB01B907E722.
38. *Ibid*.
39. Travis Tritten, "Congress reaches deal to cut $5 billion from defense budget," *Stars and Stripes* November 4, 2015, http://www.stripes.com/news/congress-reaches-deal-to-cut-5-billion-from-defense-budget-1.376792.
40. Roger D. Smith, "Military Training via Wargaming Solutions," *Mystech Associates*, http://www.modelbenders.com/papers/potentials.html.
41. Mary-Louise Hoffman, "DISA Seeks Ideas for Joint Military C2 System Development Program," *ExecutiveBiz*, December 8, 2015, http://blog.executivebiz.com/2015/12/disa-seeks-ideas-for-joint-military-c2-system-development-program/.
42. "J7 Joint Force Development," *Joint Chiefs of Staff*, http://www.jcs.mil/Directorates/J7%7CJointForceDevelopment.aspx.
43. Jonathan Strickland, "How Virtual Reality Military Applications Work," *Science How Stuff Works*, http://science.howstuffworks.com/virtual-military1.htm.
44. Sydney J. Freedburg Jr., "Marines Explore 'Augmented Reality," *Breaking Defense*, Septmeber 1, 2015, http://breakingdefense.com/2015/09/marines-explore-augmented-reality-training/.
45. *Ibid*.

4. How are Select Partners and Allies Using Live, Virtual, and Constructive?

1. Royal Canadian Air Force, "New simulation strategy sets road-map for RCAF future," *Royal Canadian Air Force*, March 13, 2015.
2. Jeff Loube, "RCAF Simulation Strategy 2025," *Military Simulation& Training Magazine*, retrievable at: http://bluetoad.com/publication/?i=282993&article_id=2335705&view=articleBrowser&ver=html5#%7B%22issue_id%22:282993,%22view%22:%22articleBrowser%22,%22article_id%22:%222335705%22%7D.
3. *Ibid*.
4. Royal Canadian Air Force, "Executive Summary: RCAF Simulation Strategy 2025," *Royal Canadian Air Force*, March 12, 2015.
5. *Ibid*.
6. Jeff Loube, "RCAF Simulation Strategy 2025," *Military Simulation & Training Magazine*, retrievable at: http://bluetoad.com/publication/?i=282993&article_id=2335705&view=articleBrowser&ver=html5#%7B%22issue_id%22:282993,%22view%22:%22articleBrowser%22,%22article_id%22:%222335705%22%7D.
7. *Ibid*.
8. David Pugliese, "Canada Setting the Scene for Future Pilot Training Program," *Defense News*, November 28, 2015.
9. Lord Levene et all., "Defence Reform: An independent report into the structure and management of the Ministry of Defence," *Ministry of Defence* (June 2011).
10. Interview with a Naval Commander, UK, March 10, 2016.
11. Ministry of Defence, "Defence Policy for Simulation," *Ministry of Defence* (April 2015).
12. Ministry of Defence, "Defence training and education coherence (DTEC)," https://www.gov.uk/government/collections/the-defence-training-and-education-capability-programme.
13. Interview with Training, Education and Simulation Technical Authority, Washington D.C., May 6, 2016.
14. For more information on iCDS, see: Defence Academy of the United Kingdom, "Defence Simulation Centre," http://www.da.mod.uk/dsc.
15. HM Government, "National Security Strategy and Strategic Defence and Security Review 2015," (2015).
16. DFOST, "Maritime Synthetic Training Strategy," *Navy Command* (July 2014): 1.
17. "RAF Valley: Hawk T2 aircraft means fast jet training for pilots faster than ever," *Daily Post*, January 13, 2014, http://www.dailypost.co.uk/news/north-wales-news/raf-valley-hawk-t2-aircraft-6503699.
18. RAF Waddington, "Air Battlespace Training Centre," *Royal Air Force*, http://www.raf.mod.uk/rafwaddington/aboutus/wwwrafmodukairbattlespacetrainingcentre.cfm.
19. Interview with Commanders UK, January 19, 2016.
20. Interview with Air Force leadership, UK, January 15, 2016.
21. Interview with RN Commanders, UK, March 10, 2016
22. The UK Joint Strike Fighter Force is expected to be split 58% RAF and 42% RN. Interview with Commanders, UK, March 10, 2016.
23. Interview with Commanders, UK, March 10, 2016.
24. Alexander Clarke, "What to do about the Disappearing Royal Navy," *US Naval Institute*, January 2015, https://blog.usni.org/2015/01/22/what-to-do-about-the-disappearing-royal-navy.
25. Interview with Commander, UK, March 10, 2016.
26. *Ibid*.
27. Andy Gough, "Combining LVC Capabilities- the RAN Perspective," *Williams Foundation Seminar* (June 3, 2015): 15.
28. "New Nukes: Britain's Next-Gen Nuclear Missile Submarines," *Defense Industry Daily*, March 20, 2016, http://www.defenseindustrydaily.com/new-nukes-britains-next-gen-missile-submarines-07432/.
29. Interview with Commander, UK, March 10, 2016.
30. Interview with Charlotte Rhodes, DE&S MoD Abbey Wood, Bristol, UK, March 8, 2016.
31. Interview with Commander, UK, March 10, 2016.
32. *Ibid*.
33. Jane's International Defence Review, "Fixed, deployable, scalable: TES takes training to the next level," *IHS* (April 30, 2015).
34. Ministry of Defence, "Gaming technology helping UK forces prepare for Afghanistan," *Ministry of Defence*, July 4, 2011, https://www.gov.uk/government/news/gaming-technology-helping-uk-forces-prepare-for-afghanistan.
35. Interview with Lieutenant Colonel, Washington, D.C., February 9, 2016.
36. Trevor Nash, "UK MoD to streamline CATT support," *Military Training & Simulation News* 18.3 (May/June 2016).

37. For more information, see: Jeremy Bender, "France's Military is all Over Africa," *Business Insider*, January 22, 2015, http://www.businessinsider.com/frances-military-is-all-over-africa-2015-1 and Patrick Megahan, "French Deployments in the Middle East and North Africa," *Qualitative Military Edge*, January 8, 2015, http://militaryedge.org/analysis-articles/french-forces-middle-east-north-africa/.
38. Etat-Major del' Armée de l'Air, "Synthetic Training: the French Air Force," (Briefing at the French Ministry of Defense, March 12, 2016).
39. *Ibid*.
40. Link 16 is a military tactical data exchange network used by US, NATO, and nations allowed by the MIDS International Program Office (IPO).
41. Colonel Jerome Lacroix Leclair, presentation at the Military Flight Training Conference, London, UK, March 16, 2016.
42. Interview with FAF leadership, Paris, France, March 12, 2016.
43. Interview with Lieutenant Colonel, Paris, France, March 12, 2016.
44. Etat-Major del' Armée de l'Air, "Synthetic Training: the French Air Force," (Briefing at the French Ministry of Defense, March 12, 2016).
45. Interview with FAF officer, Paris, France, March 12, 2016.
46. Zack Cooper and Iskander Rehman, "Gateway to the Indo-Pacific," *Center for Strategic and Budgetary Assessment* (2013): 1.
47. Interview with senior officer, Canberra, Australia, August 11, 2016.
48. Australian Government, "Core Simulation Capability Industry Update JP97-11," *Aus Tender*, November 2, 2015, https://www.tenders.gov.au/?event=public.advert.showClosed&AdvertUUID=2A49BBAB-F974-DF52-5F8FCFEED273DFC6.
49. Department of Defence, "2016 Defence White Paper," *Australian Government* (2016): 31.
50. *Ibid*, 100.
51. *Ibid*, 106.
52. *Ibid*.
53. Interview with senior officer, Canberra, Australia, August 11, 2016.
54. Royal Australian Air Force, "Plan Jericho," *Royal Australian Air Force* (2015): 2.
55. Interview with senior officer, Canberra, Australia, August 11, 2016.
56. Royal Australian Air Force, "Jericho, Program of Work: Transforming Air Force's Combat Capability," *Royal Australian Air Force* (2015): 19.
57. Interview with military leadership, Canberra, Australia, August 11, 2016.
58. "RAAF's AOSG becomes Air Warfare Centre," *Australian Aviation*, March 7, 2016, http://australianaviation.com.au/2016/03/raafs-aosg-becomes-air-warfare-centre/ and Department of Defence Science and Technology, "Practice Run for RAAF Operators," *Australian Government*, September 22, 2016, http://www.dst.defence.gov.au/news/2016/09/22/practice-run-raaf-operators.
59. Interview with Commander, Canberra, Australia, August 11, 2016.
60. Interview with military leadership, Canberra, Australia, August 11, 2016.
61. Jane's Defence Weekly, "Beyond Plan Pelorus," *IHS* (2015), http://www.janes360.com/images/assets/422/54422/Beyond_Plan_Pelorus__2.pdf.
62. Andy Gough, "Combining LVC Capabilities- the RAN Perspective," *Williams Foundation Seminar* (June 3, 2015): 12.
63. *Ibid*, 1.
64. Interview with Lieutenant Commander, Canberra, Australia, August 11, 2016.
65. Andy Gough, "Combining LVC Capabilities- the RAN Perspective," *Williams Foundation Seminar* (June 3, 2015): 10.
66. *Ibid*, 16 and Lockheed Martin, "USS Rancocas: The Cornfield Cruiser," *Lockheed Martin*, http://www.lockheedmartin.com/us/100years/stories/cornfield-cruiser.html.
67. Michael Ryan, "Australian Army: Beersheba and Beyond," *ASPI: The Strategist*, July 9, 2014, http://www.aspistrategist.org.au/australian-army-beersheba-and-beyond/.
68. Interview with Lieutenant Colonel, Canberra, Australia, August 11, 2016.
69. Australian Army, "Army Simulation Concept- Silicon Warfighting: A Strategic Narrative for Army's Simulation Capability," *Australian Army* (August 2016): 5.
70. *Ibid*, 10.
71. Interview with senior officer, UK, January 15, 2016.
72. Todd Miller, "All You Need to Know about the Latest Red Flag, World's Most Realistic Aerial Exercise," *The Aviationist*, March 16, 2015, https://theaviationist.com/2015/03/16/red-flag-15-2-goes-virtual/.

5. Hurdles to Live, Virtual, and Constructive Adoption

1. John Campbell, et al., "The Future of Multi-Level Secure (MLS) Information Systems," http://csrc.nist.gov/nissc/1998/proceedings/panelF3.pdf.
2. Steve Case, "The Complete History of the Internet's Boom, Bust, Boom Cycle," *Business Insider*, January 14, 2011, http://www.businessinsider.com/what-factors-led-to-the-bursting-of-the-internet-bubble-of-the-late-90s-2011-1.
3. Deparment of Defense Instruction 8500.01," *Cybersecurity,* March 14 (2014), 2. http://www.dtic.mil/whs/directives/corres/pdf/850001_2014.pdf.
4. Fletcher, J. D. "Education and training technology in the military." *Science* 323, no. 5910 (2009), 72.
5. Col Michael Coolican, interviewed by the *Show Daily*, December 4, 2012, 3. http://www.iitsec.org/Documents/IITSEC_2012_Show_Daily/IITSEC12_Day2.pdf.
6. Col Keith J. Wagner, USAF, "Future Joint Simulation System Integrates Training Processes," *Signal*, June 2000, http://www.afcea.org/content/?q=future-joint-simulation-system-integrates-training-processes.
7. David Vergun, "Live synthetic' Army's next generation of simulation," *Army News Service*, Mar 19, 2014, https://www.army.mil/article/122165.
8. C.J. Chivers, "Examining the Complaints about American Rifle Reliability," *The New York Times*, July 7, 2010, http://atwar.blogs.nytimes.com/2010/07/07/examining-the-complaints-about-american-rifle-reliability/?hp.
9. Travis Tritten, "Congress reaches deal to cut $5 billion from defense budget," *Stars and Stripes,* November 4, 2015, http://www.stripes.com/news/congress-reaches-deal-to-cut-5-billion-from-defense-budget-1.376792.
10. *Advanced Technology Investment Plan,* 2016, Vol. VII (Quantico, VA: Program Executive Officer Land Systems, 2016), 7.
11. Cheryl Pellerin, "DoD's Silicon Valley Innovation Experiment Begins," US Department of Defense, October 2015, http://www.defense.gov/News/Article/Article/626602/dods-silicon-valley-innovation-experiment-begins.

6. The Potentialities of Institutional Innovation

1. Williamson Murray, "Armored Warfare: The British, French, and German Experiences," in Williamson Murray and Allan Millet, *Military Innovation in the Interwar Period* (New York, NY, Cambridge University Press: 1996): 6.
2. *Ibid*, 14.
3. *Ibid*, 18.
4. Robert A. Doughty, *Seeds of Disaster: The Development of French Army Doctrine, 1919-1939* (Hamden, CT: 1986): 179 in Williamson Murray and Allan Millet, *Military Innovation in the Interwar Period* (New York, NY, Cambridge University Press: 1996): 18.
5. Williamson Murray, "Armored Warfare: The British, French, and German Experiences," in Williamson Murray and Allan Millet, *Military Innovation in the Interwar Period* (New York, NY, Cambridge University Press: 1996): 24
6. *Ibid*, 38.
7. Brian McCue, "Wotan's Workshop: Military Experiments Before the Second World War," *Center for Naval Analysis Occasional Paper* (October 2002): 27-28.
8. Andrew Krepenevich, "Cavalry to computer: the pattern of military revolutions," *The National Interest* 37 (1994).
9. Max Boot, *War Made New* (New York, NY: Gotham Books, 2006): loc 4730.
10. *Ibid*, 4851.
11. *Ibid*, 5125.
12. Stephen Peter Rose, *Winning the Next war: Innovation and the Modern Military* (Ithaca: Cornell University Press, 1991): 2 from Jennifer McArdle, "Transforming Defense: The Potential Role of 3D Printing," *American Foreign Policy Council: Defense Dossier* 13 (February 2015): 18.
13. Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Policy.
14. See, for example, the Marine Corps Warfighting Laboratory, *Urban Warrior Limited Objective Experiment Two Reconstruction and Analysis Report*, 15 September 1998. Furthermore, the Urban Warrior series of experiments led to the development of a new training program initially called Basic Urban Skills Training.
15. See: James R. Clapper, "Statement for the Record, Worldwide Threat Assessment of the US Intelligence Community, Senate Armed Services Committee," *Senate Armed Services Committee* (February 9, 2016), https://www.armed-services.senate.gov/imo/media/doc/Clapper_02-09-16.pdf and Tom Wright and Iskander Rehman, "The State of the International Order," *The Brookings Institution* (Draft Report).

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