An Apache helicopter takes off at Michael Army Airfield, Dugway Proving Ground, Utah, on 22 September 2011 as a Shadow unmanned aircraft is readied for its flight onto the battlefield. The two aircraft were involved in a manned-unmanned teaming demonstration known as the Manned Unmanned System Integration Capability activities. (Photo courtesy of the U.S. Army)

Kicking the Beehive

Reimagining Manned-Unmanned Teaming in Multi-Domain Operations

Capt. Clayton B. Jaksha, U.S. Army

Technology is not going to limit our ability to compete in multi-domain operations (MDO)—humans will. Although the human brain is skilled at learning and adapting, existing schemas and systems tend to constrain our otherwise unlimited imagination. For Army aviation to compete in MDO, we must refrain from allowing our perceptions of current aircraft, technologies, and tactics to muddy our vision of future employment techniques. U.S. Army Training and Doctrine Command (TRADOC) has identified five key tasks to succeed in MDO against antiaccess/area denial (A2/AD) adversaries: compete, penetrate, dis-integrate, exploit, and re-compete.[1] Army aviation's principal challenge will be operating in highly contested airspace and gaining the requisite situational understanding to execute effective cross-domain maneuver.[2] Manned-unmanned teaming (MUM-T) between manned aircraft and unmanned aircraft systems (UAS) will be decisive for Army aviation to penetrate, dis-integrate, and exploit the enemy, but MUM-T in its current form is unable to conduct cross-domain maneuver effectively. MUM-T will only be effective in MDO after a materiel shift to swarming systems, the embrace of artificial intelligence in mission command and targeting processes, and the reorganization into multi-domain formations at the platoon level.

Presently, Army aviation defines MUM-T as "the integrated maneuver of Army Aviation [rotary wing] and UAS to conduct movement to contact, attack, reconnaissance, and security tasks," stove-piping its definition by participating systems and functional tasks.[3] While defining the term, doctrine writers envisioned an AH-64E and an MQ-1C or RQ-7B working in tandem through various levels of interoperability (LOI). Early in UAS development, NATO recognized that nascent UAS integration required standardization across the NATO battlespace. NATO Standardization Agreement (STANAG) 4586 gave rise to the definitions of LOI 1-5, which the Army embraced in its own MUM-T doctrine.[4] Each LOI represents an increasing level of integration and interoperability between one UAS and one manned rotary wing platform, going so far as allowing the manned aircraft to take control of the payload or flightpath of the UA (unmanned aircraft, LOIs 4 and 5).

By definition, the LOI framework limits MUM-T to two systems: manned and unmanned. Furthermore, greater LOIs actually remove combat power from the fight. When an AH-64E executes LOI 3 or 4, the copilot-gunner has to abandon his or her own sights and weapons in order to manipulate the UA's payload, effectively neutralizing the Apache as a weapons platform during MUM-T operations. Meanwhile, the UAS payload operator in the ground control station becomes surplus manpower as the Apache usurps the UA's sensor—it is an inefficient and clumsy use of manpower. Current MUM-T systems and architecture require a redesign for MDO; fortunately, future vertical lift allows for the ground-floor integration of many technologies that will allow Army aviation to compete on the future battlefield.

Materiel Transformation in Manned-Unmanned Teaming

The substantive materiel changes required for MUM-T in MDO will ultimately need to occur on unmanned aircraft rather than manned aircraft. Manned aircraft must carry humans and are therefore limited in its size, maneuverability, and ability to assume risk. Alternatively, UASs have extraordinary potential for growth. Military UAS development in the preceding decades resulted in large, fixed-wing UASs with expensive sensors, powerful radios, and streamlined air vehicles designed to loiter for long periods over the same geographic location. The counterinsurgency mission drove this perception of UASs as intelligence, surveillance, and reconnaissance platforms, but UASs will take on a new role in MDO. In order to be successful in MDO, the Army must develop fully automated, inexpensive UASs capable of swarm operations.

Inexpensive and expendable. Consider the A2/AD integrated air defense threat—large, slow UAs at middle altitudes are prime targets for enemy air defense. Worse yet, the Army's own doctrine often depicts UAs loitering directly over enemy formations, as if the enemy would not attempt to disable or destroy that UAs with kinetic or nonkinetic means.[5] The Army does not possess large quantities of UASs capable of MUM-T and cannot reconstitute them

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at a rate that allows commanders to routinely risk their destruction in A2/AD bubbles. The challenge of creating inexpensive and expendable UASs underpins the materiel and mental shift required for MDO. The end state of this paradigm shift is increasing the quantity of UASs by two to three orders of magnitude while decreasing the price per UAS by similar orders of magnitude.

The logistical value of inexpensive, high-quantity UASs is self-evident: commanders risk less by allowing those systems into the A2/AD bubble and the Army can easily reconstitute its losses. The easiest way to begin accomplishing this goal is by decreasing the size of UAs. Using standard Department of Defense terminology, mass-produced, inexpensive UASs for MDO should be group 1 or 2 UASs.[6] Its value goes beyond dollars though—deployed en masse, small UAs conducting swarm operations present a complex tactical dilemma to the enemy and offer friendly forces cover in the A2/AD bubble.

Swarming. Recall the opening ceremony of the 2018 Winter Olympics in Pyeongchang: a swarm of 1,200 commercial UAs lit up the sky with dazzling constellations of snowboarders, ice skaters, and curlers.[7] While stunning, the display was a wake-up call to the world that intelligent UA swarms are not only feasible but also downright terrifying. UAs capable of swarming can move in front of their manned partner to saturate targeting systems, present myriad dilemmas, and overwhelm the enemy decision-makers. TRADOC recognizes that swarms will act as "protective measures for formations and individual systems, defeating incoming projectiles prior to close protection systems engaging to defeat them."[8] Put simply, one member of the larger drone swarm is destroyed rather than the protected element. The swarm's inherently defensive benefits allow for offensive operations by the protected element.

Swarming capitalizes on an underutilized means of defeating radar: physically overwhelming the system. Fundamentally, jamming achieves this effect through electromagnetic means, but it requires a strong emitter and the correct frequency, and it is usually limited to a particular radar system. Even without emitting, UA swarms jam in the physical domain and gum up radar displays by simply moving in large quantities. UA swarms would be the offensive linemen for manned platforms penetrating A2/AD bubble to attack critical nodes. Integrated air defense elements would not be able to detect an Apache maneuvering behind a cloud of UAs; the deluge of physical targets would dis-integrate the air defense system and create chaos. Beyond its role as air defense fodder, the Army could outfit individual UAs in the swarm with a variety of low-cost sensors; this creates a shield that simultaneously defends against threats while collecting on those same threats. As swarm technology develops, it will disrupt air defense technology and doom current systems to obsolescence. Leveraging UA swarms and MUM-T, brazen overtness might be the key to penetrating the A2/AD bubble.

Human augmentation and autonomy. A major issue with extant MUM-T is the inefficient use of human capital in system employment. MUM-T in MDO must not seek to remove human input, but rather augment human judgment and automate anything that does not require a human decision. Current LOIs relegate MUM-T to controlling the UA's flight path and its sensor point-of-interest, but that level of control is unwieldy in MDO. Imagine a small UA swarm and the impossible task of controlling each aircraft's flight path and payload operation. Even for an operator on the ground whose sole task is to manage the swarm, it would be impossible. Instead, the swarm must possess a certain amount of autonomy to control its own flight path and payload utilization. The human should command broader tactics and priorities to the UA swarm. The swarm then seeks human only input when it requires a decision or acquires critical information about the operational environment.

Ultimately, TRADOC already views "swarms of massed, low-cost, self-organizing unmanned systems directed by bi-mimetic algorithms to overwhelm opponents [as a viable] alternative to expensive, exquisite systems."[9] However, swarms will not entirely replace large UASs; systems like the MQ-1C will still have a place in MDO. Larger UASs will need to perform network management and host heavier, more sophisticated payloads. MUM-T relies on teaming and integrating manned, unmanned, and autonomous systems into the team. Automated systems of systems like UA swarms will be tools to aid systems with humans "in the loop." The human provides irreplaceable tactical, operational, and ethical judgment; the UA swarm exists to augment the power of human decision.

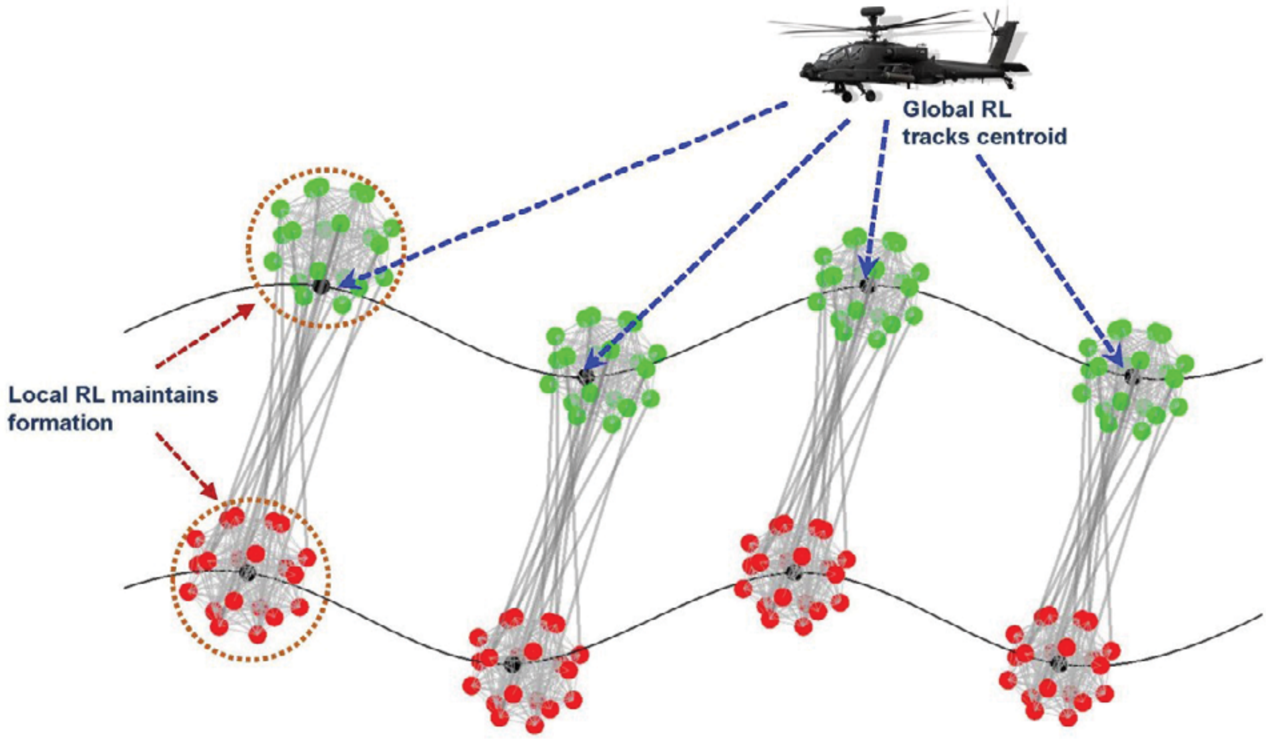
Manned-Unmanned Teaming Effects and Targeting Doctrine

MDO engagements require proficient, practiced dynamic targeting techniques to maintain tempo. Contemporary dynamic targeting doctrine (find, fix, track, target, engage, assess) requires extensive human input throughout the targeting loop.[10] This is for good reason—the decision to allocate resources, determine effects, and ultimately kill requires intense situational understanding and informed judgment. However, staff meetings, briefings, and committee decision-making bungle up the process and slow the targeting cycle. In MDO, the viscosity of human interference will allow certain targets to escape the grasp of our effects. Targeting doctrine does not require substantive change, but MDO will force the existing process to accelerate. Commanders in MDO must leverage technological augmentation to rapidly destroy high priority targets. Future targeting operations require fused sensor networks that intelligently pair shooters with targets to deliver cross-domain effects.[11] MUM-T between unmanned sensor swarms and attack helicopters allows for a cross-domain sensor-to-shooter network organic to Army aviation.

[Artist's concept] Army researchers develop a reinforcement learning approach called Hierarchical Reinforcement Learning that will allow swarms of unmanned aerial and ground vehicles to optimally accomplish various missions while minimizing performance uncertainty on the battlefield. (Photo courtesy of the U.S. Army/Shutterstock)

Fused collection. TRADOC already recognizes that "targeting [will employ] fused sensor data" to enable "friendly units operating dispersed to see and fight over wide areas."[12] The concept of distributed battlefield sensors is far from novel, but the Army has never deployed them on the scale or density that MDO requires. Furthermore, the preceding decades of counterinsurgency have trained leaders to consider full motion video (FMV) the gold-standard intelligence requirement for targeting. While FMV greatly enhances situational understanding, it also requires sensor line-of-sight and devours bandwidth—both of which are dangerous and untenable in MDO. In order to leverage the power of distributed UA sensor swarms, the Army must outfit these small UAs with a blend of lightweight, low-power sensors. This is far from a pipe dream; TRADOC predicts that "the shrinking size and power requirements of many [electronic sensors] makes them more suitable for employment by remote, robotic, and autonomous systems."[13] Specifically, airborne networks of direction finding (DF) antennae, ground moving target indicator (GMTI) radar, acoustic sensors, and limited electro-optical/infrared (EO/IR) cameras will provide MUM-T the sensor network for commanders to successfully target in MDO. None of these technologies are new, but their decreased size and proliferation will modernize the finding, fixing, and tracking of dynamic targets with limited human input.

DF systems are already the smallest, lightest, and most mature technology that can be employed by UA swarms. Interestingly, one of DF's first applications was in avionics: automatic direction finders provide bearings to aircraft flying to or from omnidirectional radio beacons on the ground. DF is the process of determining an emitter's location by receiving and processing its signals, analyzing its strength, and providing the user a direction to the emitter. Typically, one DF system will provide only an azimuth; two or more will provide a grid location with increasing levels of confidence. These systems passively detect enemy emissions and



Army researchers envision a system of hierarchical control for ground vehicle and air vehicle coordination supported by reinforced learning (RL) that allows swarms of unmanned aerial and ground vehicles to accomplish various missions simultaneously. (Graphic courtesy of the U.S. Army)

must therefore be widely deployed to generate accurate triangulations. The Army's limited electronic warfare formations today already employ man-portable DF systems.[14] If one-quarter of a UA swarm was equipped with DF systems, then they could quickly pinpoint any emitter on the battlefield and then cue or mix other assets onto that location. DF is a powerful find and fix tool, especially when confirmed by GMTI.

Airborne GMTI systems have traditionally been too large for small UASs; the E-8C Joint Surveillance Target Attack Radar System, a Boeing 707 air vehicle, is the most prolific system. But GMTI is shrinking: the technology recently found a home on the MQ-1C Gray Eagle.[15] As the name implies, GMTI is radar that detects and tracks movement of ground systems. It is a critical link in the find, fix, and track stages, but its price and size will likely limit its employment. Even over the next two decades, GMTI will likely still be limited to larger UASs and a few small UASs. Employed across the MDO battlespace, it could cue other systems to new detections or track high-priority targets before weapons employment. Alone, GMTI provides the manned-unmanned team exceptional sensory reach, but it also requires sensors to defend the team and provide close targets.

Enemies can try to mask their appearance, emissions, and radar cross-sections, but it is far more challenging to mask acoustics. An armored column will sound like an armored column whether it is camouflaged or not. UA swarms could employ sensors similar to those found in anti-helicopter mines, which detect specific acoustic signatures, and use them for close-in targeting.[16] Acoustic sensors are ineffective when mounted on larger airborne platforms due to engine, rotor, and propeller noise, but small UAs present a much quieter noise profile for sensors to overcome. Imagine detecting the characteristic sounds of a T-80 starting or a turret traversing a kilometer away. While that information alone would be inadequate for anything but the find phase of targeting, it could be the first of many fused sensors to collect on that target. Even more, it prevents enemy ground forces from surprising the manned-unmanned team.

Lastly, modern EO/IR systems are already small enough for employment in UA swarms. The gimbaled cameras themselves are not a technological limiter, but the challenge of exporting FMV over long distances with low-gain antennae is a problem. Instead of seeking persistent overhead FMV, EO/IR systems should be used in the fix and track phases, using onboard processing to automatically classify and transmit highly compact still images to other nodes in the system. Because commanders ultimately require visual confirmation on certain targets, the Army cannot completely abandon EO/IR in MDO, but reframing its use will free up bandwidth for other targeting data. Fused collection in multiple domains presents multiple dilemmas to the enemy, provides confident targeting data, and feeds smart networks of intelligent manned-unmanned teams.

Mesh networking. Distributed airborne sensors collecting fused intelligence is only worthwhile if that data can move somewhere for processing. With the amount of autonomy afforded to future swarms of UAs, we must abandon modern notions of a ground control station with a single high-gain radio datalink to the platform. MUM-T in MDO requires each UA to automatically synchronize with both the swarm's behavior and the manned system's priorities. If every UAS attempted to individually coordinate with the manned platform, it would overload available bandwidth and processing power. Instead, the processing power must be distributed within the swarm and routed throughout the swarm using a form of mesh networking. Mesh networks are dynamic networks with flexible topologies and data pathways—there are no central nodes and the nodes self-organize.[17] In a mesh network, a data packet travels from its sender node to its receiver node by "hopping" between other nodes using adaptive routing algorithms. Modern mesh network technology already allows for deploying sensors on combat vehicles in constant motion where the network topology must "constantly and automatically adapt" to varying distances and terrain.[18] Within a node-dense, highly arrayed swarm of sensors, an individual UAS could share data and process that data in a cloud methodology with the swarm to then provide fused intelligence to the manned platform.

Artificial intelligence and machine learning. Artificial intelligence (AI) sounds almost too futuristic to take seriously, but it is the key cognitive augmentation that enables MUM-T in MDO. AI is a type of computing engineered to process information, reason solutions, and execute action; the process by which AI gains the ability to conduct these executive functions is machine learning. A basic example of machine learning is training software to recognize a face by providing it hundreds of images of that face from different angles, aspects, and lighting conditions and then asking it to use AI to pick that face from FMV of a crowd of people.[19] AI automatically classifying targets from still images and videos has readily apparent military value, but that application is hardly the cross-domain maneuver required for success in MDO.

When well-trained, the speed of AI's analytical and predictive capabilities makes it lethal on the battlefield. Incorporating AI into dynamic targeting doctrine will allow it to predict enemy behavior and pair targets with strike platforms and munitions. The Army is already testing the validity of incorporating AI into deep area strikes, and that technology could be expanded into MUM-T.[20] AI could process fused intelligence collected by a UA swarm and then provide manned attack aircraft target locations, velocities, recommended weaponeering, and simultaneous engagement cueing. Pairing AI with Single Multi-Mission Attack Missiles will empower AI to mass effects on an unsuspecting enemy with a proportionally small friendly force.[21] Incorporating AI into dynamic targeting is about flipping the doctrinal paradigm of automation: instead of humans cueing machines onto targets, machines should be cueing humans to targeting decisions. TRADOC envisions decision cycles accelerated "with AI-enabled intelligence conducting collection … freeing up warfighters to do what they excel at—fight and make decisions."[22] The manned platform acts as the quarterback, managing by exception: information flows to the human in the loop. The fundamental change to targeting doctrine is not the process, but rather who—or what—accomplishes each step.

Multi-Domain Formations and MUM-T Employment Vignettes

The materiel and doctrinal changes engendered by MDO necessitate marked reorganization of MUM-T formations. One of TRADOC's three tenets to succeed in MDO is the employment of multi-domain formations—those combat formations that have the ability to "conduct independent maneuver, employ cross-domain fires, and maximize human potential."[23] Correctly organized, Army aviation can leverage MUM-T to generate cross-domain formations at the platoon level. Modern air cavalry squadrons are currently the most integrated MUM-T formation in Army aviation; each line troop possesses eight AH-64 Apaches and four RQ-7 Shadows.[24] However, fighting as a cross-domain formation requires UASs to be organic not just to air cavalry troop, but the air cavalry platoon. Platoons will be the functional unit fighting together on the multi-domain battlefield, not troops. Manned reconnaissance and attack platforms must regularly train and fight with its own organic UA swarms. This will enhance the manned team's trust in the unmanned team and also better inform the AI of the unmanned systems.

Compact, organic MUM-T formations are a powerful tool in MDO because they complement dichotomies unique to the new operational environment. TRADOC identifies four dipoles that frame the changing character of warfare, two of them are particularly relevant to MUM-T: "finders vs. hiders" and "strikers vs. shielders."[25] Manned attack platforms will be hiders, easily detectable and susceptible to lethal and nonlethal engagements, but they will also be strikers, capable of delivering lethal ordnance with direct or indirect fire. Meanwhile, a UA swarm equipped with distributed sensors is an excellent finder and a shielder, protecting manned platforms by maneuvering in front of them or along its flanks. Therefore, a multi-domain platoon-sized element organic to Army aviation would be capable of spanning the spectrum of operations in a changing warfare environment. The following vignettes demonstrate the power of the multi-domain platoon as Army aviation penetrates A2/AD bubbles.

Vignette 1: Finders and strikers. An air cavalry platoon executes a movement to contact into an A2/AD bubble. An enemy air defense radar emits in a search pattern as part of an integrated air defense network. The UA swarm ahead of the manned attack team uses DF to calculate an approximate location of the system. A Group 4 UA overhead stares at the grid with EO/IR and conducts an AI-powered search trained to hunt for integrated air defense nodes with AI. After determining the location of its command and control, power generation, radar, and missile sites, the large UAS assigns targets to organic manned attack helicopters, long-range fires, and participating joint platforms. The AI then presents the strike package to the battlespace commander's main command post. Upon approval, the strike platforms utilize multiple simultaneous engagement technologies like Single Multi-Mission Attack Missiles to dis-integrate and penetrate the air defense network.

Vignette 2: Shielding against electronic warfare. Similar to the first vignette, a UA swarm detects an air defense radar through fused collection methods. Only this time, the enemy employs its electronic warfare capabilities and turns on jammers in the vicinity of the swarm. This disables a sizable portion of the swarm, but the majority are out of range of the jammer, are able to sense the threat, and reposition. Because the UA swarm operates on a mesh network topology, it is able to reorganize and reconfigure while providing early warning to the manned platform behind the swarm. Using AI, the network of unmanned airborne sensors analyses the jamming signal, assigns strikers, and awaits the command to engage from a human with decisional authority.

Vignette 3: The human factor. A Group 4 UAS utilizing GMTI detects a cluster of vehicles moving toward friendly forces. The UA swarm leverages DF on enemy chatter to triangulate its position. A large UA conducting ISR automatically slews EO/IR to position and, via AI, classifies the image as a large quantity of technical vehicles. Target confidence, rate and direction of march, and size of force triggers a target handover to a manned attack helicopter. The manned asset views the imagery and recognizes that the vehicles are pickup trucks carrying refugees away from the battle zone. The manned asset applies judgment, rejects the targeting package, and ensures they pass safely.

Conclusion

The materiel advancement required for MUM-T to succeed in MDO seems like science fiction, but that advancement is the product of technologies that already exist. Though the UA swarm seems far-fetched, all signs point to its possibility and potential. The Army is already researching methods for future vertical lift aircraft to manage three or more UASs at a time.[26] Incremental technological advances will march on, but Army aviation must not allow its doctrine and its formations to lag behind as MUM-T develops. The community of Army aviators must learn to embrace the unmanned half of MUM-T and find ways to make the team tactically sound while MUM-T transitions to MDO.

Perhaps the greatest challenge to developing future MUM-T will be the psychological shift necessary to trust an increasingly intelligent unmanned partner. Trusting UASs will be uncomfortable and, much like its enabling technology, will require incremental change. Long before aviators kick the beehive and loose a UA swarm on the battlefield, aviators must build trust with their unmanned systems through regular training. Army aviation today must saddle UASs with increasing responsibility and build its relationship with manned aircraft by demonstrating competence in collective, live-fire training. Ignoring MUM-T training today corrodes the trust that future formations will require in MDO. Therefore, Army aviation's ability to compete with MUM-T in MDO hinges decisively on its ability to train with MUM-T now. Whether out of inconvenience, frustration, or indolence, the decision to abandon MUM-T today is a decision to fail at MUM-T in MDO. The technology will be ready soon—we cannot limit ourselves. ■

The opinions expressed herein are the author's alone and are not the opinions of the U.S. Army or the Department of Defense.

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