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Predictions of widespread adoption of UAVs for every airpower task are over-zealous. This article uses innovation theory to critically analyze the likely future of UAVs using a framework of expected benefits and costs of adoption across core air force missions: air superiority; intelligence, surveillance, and reconnaissance (ISR); rapid global mobility; global strike; and command and control (C2). While UAVs will certainly take on an expanded role in warfare, predictions of universal military adoption of UAVs are over-zealous because they fail to incorporate the total costs associated with adoption of new technology for a large organization.

Key Words: *UAV, Drones, Military Innovation*

Contemporary projections of massive unmanned aerial vehicle (UAV) proliferation have become commonplace, with some extreme forecasts of a gloomy Armageddon of a world run by robots (Kreps and Zenko 2014). These predictions of widespread adoption of UAVs for all military and law enforcement tasks portend a dynamic shift in the very character of war. Yet, these predictions tend to be oversimplistic, ignoring the major obstacles to widespread adoption. This article uses innovation theory to critically analyze the likely future of UAVs using a framework of expected benefits and costs of adoption across core air force missions: air superiority; intelligence, surveillance, and reconnaissance (ISR); rapid global mobility; global strike; and command and control (C2) (Rogers 2003, 233). While UAVs will certainly take on an expanded role in warfare, predictions of universal military adoption of UAVs are overzealous because they fail to incorporate the total costs associated with adoption of new technology for a large organization.

In February 2014, a conference at The Pentagon brought together academics, defense contractors, and military practitioners to discuss the future of small UAVs. Many of the attendees had an untempered enthusiasm for the future of UAVs. On the commercial side, their thoughts paralleled Lev Grossman's predictions for UAVs: "Police departments will use them to study crime scenes. Farmers will use them to

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watch their fields. Builders will use them to survey construction sites. Hollywood will use them to make movies" (Grossman 2013). These commercial predictions largely focus on technological early adopters who will use UAVs simply because they exist and are economically feasible. Economic feasibility was largely driven by forecasts, like Grossman's, that 50 dollars and a smartphone will buy you a complete UAV system. However, the economic feasibility argument relies on the presumptive logic that because a technology is (or will be) developed and could fulfill a function, it will be an effective and efficient tool for that function.

On the military side, economic feasibility propelled debates on the potential for widespread adoption of UAVs. Interestingly, there was a divergence between policy-centric forecasters and the mainstream scholarly discourse. Policy forecasters focused on the adoption of UAVs for additional tasks while the academic community analyzed the proliferation across countries. For example, defense forecasters argue that miniature UAVs will be used to "swarm" the enemy in order to defeat complex networks such as an adversary's air defense system (Scharre 2014). United States Air Force (USAF) policy projects that UAVs will eventually conduct every core airpower mission including command and control, airlift, air refueling, aeromedical evacuation, search and rescue, air and missile defense, and electronic warfare (USAF 2014, 49). There is little scholarly debate on whether or not these missions are appropriate for a UAV. Instead, the current scholarly debates about the future of UAVs are fixated on the potential proliferation of armed UAVs to additional countries.[1] To an extent, this fixation is driven by ethical and legal concerns that are largely not applicable to unarmed UAVs .

This study begins by applying military innovation theories to the development of UAVs. After a brief review of current UAV capabilities and limitations, the core of the study is an analysis of the potential use of UAVs for future missions including air to air; intelligence, surveillance, and reconnaissance (ISR); mobility; strike; and command and control (C2). While the analysis for potential future use is valid for all UAV programs across the globe, it is most applicable to the USAF since it has the most developed and best funded program and will, therefore, most likely be the first to test future concepts.

Innovation Theory and UAVs

Military innovation theory provides a framework to empirically analyze the potential adoption of UAVs for additional missions or by additional military forces. The framework starts with the identification of key factors that enable or constrain the adoption of military technologies (Schwartz 1996, 101-102). Despite the advantages of military innovations, they are not automatically adopted by other organizations or militaries. Organizational adoption is constrained partly by finances

[1] See, for example, Franke (2015); Joshi and Stein (2013); Horowitz and Fuhrmann (2014) and Kreps and Zenko (2014).

and partly by organizational culture (Horowitz 2010, 3-5). Organizations must adapt their doctrine and get leadership buy-in. Military leadership has a significant impact on technology adaptation because leaders influence promotions and can protect junior officer innovators (Rosen 1991, 21). General McMaster criticizes that many military leaders are overly fixated upon UAVs and the "widely accepted yet fundamentally flawed conception of future war: the belief that surveillance, communications and information technologies would deliver 'dominant battlespace knowledge'" (McMaster 2008, 21). Some leaders may be influenced by the desire for prestige and maintaining the appearance of being on the leading edge of technology (Horowitz and Fuhrmann 2014). Of course, military innovation is not only controlled by military leadership. Civilian overseers can also impose adaptation to overcome the conservative influences of military tradition (Posen 1984, 224-226). It was only after the success of the Central Intelligence Agency's armed UAVs that the Air Force decided to adopt the innovation (Ehrhard 2010). Arguably, the innovation leader is more likely to be effective if they can effectively articulate the strategic necessity of technology (Goldman and Ross 2003, 374). UAV advantages such as long loiter time and low political risk make them ideal to counter terrorism and for sensitive missions such as patrolling disputed territory. The reduced political risk enables countries to consider military options that were not feasible with other weapons systems (Byman 2013).

Financially, military innovations are often far more complex than they may at first appear. Cost models that focus exclusively on the cost of the unit and the control device are inadequate. While this may be a suitable cost model for the hobbyist, it is not sufficient for military operations since it does not account for related overhead and operating costs. For large organizations, adoption of a new technology has cost implications, both monetary and man-hours, across the spectrum of DOTMLPF (Doctrine, Organization, Training, Materials, Leadership, Personnel, and Facilities). Technology adaptation typically drives requirements for new organizational policies, safety procedures, training for pilots and maintainers, logistics (fuel and spare parts), maintenance, scheduling, supervision, and facilities (for storage). If the UAV is replacing a helicopter or other type of manned aircraft, then the change in overhead costs is minimized. But, if the UAV is replacing a function currently performed by personnel on the ground, the overhead costs could become a serious obstacle to technological adoption. For ground operations that might be more effective from the air (for instance, due to the field of view, point of view, or speed), resource limitation is often the inhibiting factor in the use of manned aircraft.

In the zero-sum budget world of the Department of Defense, adoption of new technology involves additional risk because the cost must be offset by another program. Unlike the corporate world, the military cannot offset the additional costs of technology adoption by using the new tool to create a new revenue stream. Therefore, increasing costs are scrutinized because the zero-growth budget requires the identification of cost offsets, a difficult and often politically charged process. To put the potential benefits and costs of future UAVs into context, this article will first review the existing benefits and costs of UAVs relative to manned aircraft.

Contemporary UAVs

Early UAVs had limited benefits. Regular combat use for UAVs, primarily for ISR, began in the 1960s. Initial datalinks, inadequate precision navigation, line-of-sight range limitations, and susceptibility to electronic warfare jamming limited the usefulness of early UAVs (Ehrhard 2010). The primary benefit of early UAVs was reduced risk to personnel in a high-threat air defense environment. In an ironic foreshadowing of the future, the U.S. Air Force largely abandoned its UAV programs after the Vietnam War since they were not suitable for conventional warfare in Central Europe against the Soviet Union (Ehrhard 2010, 45). It was assessed that the mobile surface-to-air missiles of the Soviet would make short work of UAVs over the Fulda Gap. Modern-day UAVs began in the mid-1990s with the MQ-1 Predator.

The contemporary UAV performs a variety of combat missions that tend to fall into one of the two categories: support to ground forces or participation in the joint targeting process. UAV support to ground forces includes close air support (CAS) for troops in contact, route reconnaissance, security overwatch, communications relay, and support for counter-battery fire. For targeting, UAVs are especially useful for target development, target clearance (to minimize collateral damage), and battle damage assessment (BDA). However, none of these missions are unique to UAVs. Each can be accomplished by manned aircraft. In fact, even the UAVs dual role as ISR and attack platform is also available in a manned aircraft version. Yet, the demand from the combatant commanders for UAVs far outstrips supply.

Current UAVs have a variety of competitive advantages that make them more desirable for certain missions or operations than their manned aircraft counterparts. UAVs have a smaller logistics footprint. UAVs can operate out of austere locations or navy destroyers. Smaller, less capable UAVs can be carried in a backpack. Compared with most other ISR platforms, UAVs are less observable, and have superior on-station time. Compared with strike aircraft, UAVs provide superior target discrimination, less potential for collateral damage, and reduced risk to the aircrew. This makes UAVs ideal for unconventional missions such as counter-terrorism, counter-insurgency, or other missions with a negligible air threat.

Of course, current versions of UAVs have a variety of disadvantages. They tend to have lower thresholds for adverse weather, a smaller field of view, and lack defensive countermeasures. These weaknesses make UAVs a suboptimal platform for high-risk missions, broad area surveillance, or operations in anything other than a low-threat environment. Ironically, current UAVs are not significantly cheaper than their manned counterparts. The MQ-9 and the U-28 have similar purchase, maintenance, and operating costs. UAV cost advantages are primarily limited to small, short-range, unarmed UAVs such as the Ravens, which have no equivalent manned counterpart. Over time, the increasing costs and production times to create survivable manned aircraft will increase the comparative cost advantage of UAVs.

From an incremental innovation standpoint, the most likely near-term advances in UAVs will begin by decreasing the existing disadvantages and increasing the advantages. Considering that the U.S. Air Force is the primary provider of UAVs to the joint commander, this study will approach the costs and benefits of UAV innovation through an Air Force core missions framework: air superiority; intelligence, surveillance, and reconnaissance (ISR); rapid global mobility; global strike; and command and control (C2).

Air-to-Air Combat UAVs

Today's UAV plays essentially no role in air superiority. From an aircraft design perspective, UAVs have the potential to be far superior air-to-air fighters than a manned aircraft. Optimization of manned fighter maneuverability is limited by the weight needed to support a human: life support systems, an ejection seat, the control interface, and backup systems. Moreover, high maneuverability fighters have a limiter on maximum G-forces to prevent the pilot from blacking out. The design of the UAV is not constrained by these limitations. However, to conduct air-to-air missions, new UAV designs would need to make significant upgrades in radar, weapons, and defensive countermeasures. If the UAV could be made inexpensively and en masse, perhaps the defensive countermeasures could be overlooked. To dogfight in a visual engagement, major improvements in pilot field-of-view would be necessary. The most significant challenge for a design with these additional capabilities would be meeting the challenge for additional bandwidth.

While the bandwidth challenge could be overcome with fully autonomous UAVs, near-term adoption of fully autonomous UAVs for lethal combat missions is unlikely in the near term due to concerns over ethics, the quality of target discrimination, and Air Force cultural resistance. Air-to-air target discrimination is technically feasible (Byrnes 2014, 48-75). It is far less complex than air-to-ground target discrimination. Even so, to negate ethical and target discrimination concerns, the actual decision to destroy a target could be reserved for a command center such as the Combined Air Operations Center (CAOC) or Airborne Warning and Control System (AWACS). The autonomous UAV would simply be responsible for executing the attack mission given to it by the command center. From a target discrimination perspective, this is not significantly different from a fighter firing a long-range missile beyond visual range after AWACS declares a target hostile and authorizes engagement.

The proliferation of mass numbers of UAVs necessitates adoption of increasingly semiautonomous UAVs for noncomplex flight operations. Defense companies are working on UAVs with multi-day loiter times. These exponential increases in loiter times will require an increasing reliance on semiautonomous navigation. However, automating the mission and the sensor operator will be a far more difficult challenge. Semiautonomous flight operations will enable a single pilot to control multiple aircraft. UAVs spend a considerable amount of time transiting to/from and orbiting over the target. These simple maneuvers can easily be executed by current autopilot technology. Of course, such an implementation would limit the flexibility and responsiveness of the UAVs.

Advanced ISR UAVs

Along with additional loiter times, new UAVs will carry multiple sensors increasing the load for sensor operators. One DARPA project claims to use more than 300 mini-sensors to create 65 video feeds. While this is an incredible increase in capability, these developments will entail significant costs in manpower and bandwidth. Adoption of this technology will naturally lead to additional emphasis on automated sensor operations. A semiautomated UAV could certainly conduct a significant portion of preplanned and ad-hoc ISR collection including still imagery photographs, communications intelligence, electronic intelligence, and some specialized measuring and signals intelligence. Programming a UAV to track mobile targets using full motion video would certainly be more complex, but is in the realm of the possible.

Arguably, the proliferation of small, inexpensive UAVs could lead to the adoption of UAVs to do other functions such as tactical weather forecasting, base security, and nuclear, biological, and chemical detection. While expanding situational awareness for these tasks, this expansion creates additional DOTMLPF development in order to avoid overloading the existing UAV system. On the technology side, improved communications will be necessary to handle the additional bandwidth requirements. On the personnel side, semiautomated intelligence processing, data storage, and video search capabilities will be necessary for the intelligence community, which is already overwhelmed with data from existing sources. The military R&D community continues to explore methods to automate the intelligence fusion process. While automated systems helped with data integration and visualization, the heavy lifting of intelligence fusion is still dependent on the gray matter. Meanwhile, this proliferation of many UAVs presents an opportunity to create extended networks. UAVs could act as sensor and relay nodes for air-to-air surveillance, air-to-ground surveillance, electronic surveillance, and communications.

Mobility, Strike, and Command: A Mixed Bag for Future UAV Missions

To make an adoption of a massive fleet of small UAVs feasible, new UAVs will need to be logistics conscious. The concept of a single pilot flying multiple UAVs is one method to reduce the logistical burden. More importantly, the UAVs will need to reduce their footprint downrange. Perhaps this will involve maintenance robots using a three-dimensional printer for spare parts. On the other hand, UAVs may be part of the logistics solution. Using UAVs to haul cargo is a relatively simple venture as long as the aircraft can be made reliable enough to minimize risk of losing the cargo. A proven safety record would also likely lead to adoption for UAVs for air-to-air refueling. Fully autonomous mobility aircraft are intriguing because they represent tremendous manpower savings. Besides, UAV transports would be especially useful for high-risk cargo delivery missions such as airdrops near enemy forces and firefighting. In Afghanistan, the Marine Corps used an experimental UAV helicopter to transport goods in areas that involved high risk for helicopter take off and landings. Using a UAV to transport personnel is possible, but less likely. A wide-body UAV used for transport negates many of the traditional advantages of UAVs. The wide body will not have the reduced logistics footprint or low observable capability. If there are personnel in the back, then reduced risk to aircrew becomes an irrelevant advantage. The safety record would need to be formidable before safety concerns became secondary to the incremental manpower savings.

On the opposite extreme, the fully automated air-to-ground strike UAV is a far less likely innovation. Of course, many countries already have fully automated weapons to use against fixed targets or ships; we call them cruise missiles and ballistic missiles. But, these weapons are not good at target discrimination. These weapons certainly have their uses. In cases where the potential for collateral damage is extremely low (e.g., a remote building or a ship on the open ocean) or cases in which collateral damage is a tertiary concern, weapons with limited target discrimination capabilities will continue to be employed. To expand the potential target set of autonomous UAVs, significant effort will need to be made to enable target discrimination logic that is typically derived from subjective judgments.

For most UAV strike targets, the current process in the Air Operations Center involves a detailed cross-check between the Battlefield Control Detachment (to deconflict with friendly ground forces), the Special Operations Liaison Element (to deconflict with Special Operations Forces), lawyer (to ensure the target meets Law of Armed Conflict requirements), targeteer (to estimate anticipated collateral damage, and match preferred weapons to target type and desired effects), airspace deconfliction (to clear path from aircraft to target), and the offensive duty officer (to assign the target to an aircraft). Much of this coordination involves subjective judgments that will be difficult to automate. Alternatively, it may be possible to partially automate the process, flagging issues that require subjective interpretation by a human operator.

In the interim, a more likely innovation would be an *Ender's Game* style virtual control center. In Orson Scott Card's book and movie, the main character, Ender, controls a fleet of spaceships from his 360-degree virtual command center. While not unmanned, the spaceships followed Ender's commands to the letter. Technology is certainly within reach today to enable a single person to control a fleet of UAVs. In this case, the UAV follows pre-programmed logic for specific tasks but still involves a human-in-the-loop to provide subjective decision making such as strike decisions. This type of innovation would be a useful method to take advantage of the decreasing cost of UAVs. Lots of UAVs controlled from a minimal number of command centers would "bring mass back to the fight" in an era of dramatically rising aircraft per unit costs (Scharre 2014, 6).

Improving UAV Survivability

For many of the UAV missions discussed above, a major factor in potential adoption will be overcoming the aircraft survivability challenge. While the development of defensive countermeasures such as a jamming pod and a flare dispenser are plausible, the addition of the extra weight and expense runs counter to the inherent cost savings of using UAVs. Therefore, current efforts focus on one of the three methods: stealth, mass, and miniaturization. Stealth is certainly proven technology. But, the high cost of stealth will limit this option for widespread adoption. While the technology is already proven, reliance on high-priced UAVs will leave the fleet lacking in sufficient quantity to meet operational demands. There just will not be enough to go around.

A swarm is one method to improve UAV access in an advanced air defense environment. If UAVs were cheap enough, it would enable the creation of mini-UAV "swarms." Advanced software algorithms already exist which will enable groups of UAVs to fly cooperatively. Swarm theory is reminiscent of classic airpower theorist Gulio Douhet's argument that aerial defense is inefficient due to the dispersion of resources to cover the variety of potential routes and targets (Douhet 1983, 15-19). A swarm "complicates an adversary's targeting problem and allows graceful degradation of combat power as assets are attrited" (Scharre 2014, 6). The development of a swarm provides lots of possibilities for offensive use. An inexpensive UAV kamikaze would be useful for nearly any type of lethal mission. Swarms would also present a complex challenge for adversary air defenses simply due to overwhelming numbers or act as cheap decoys designed to absorb surface-to-air missiles (Ehrhard 2010, 25). Moreover, the high-quantity, low-cost swarm makes some attrition acceptable.

Instead of expensive methods to make large aircraft stealthy, platforms can attain reduced observability through miniaturization. The invention of nano UAVs opened a new path for low observability without expensive radar-evading technology. To get the full functionality of nano UAVs, they need to be capable of beyond-line-of-sight (BLOS) operations and operate inside buildings. Unfortunately, this tends to require increased power for range and communications that grow the UAV beyond the nano size. An alternative to BLOS is dropping the nano UAVs from a mother ship such as a C-17. Unfortunately, without a stealth mother ship the concept is limited to operations where the adversary has limited air defense capabilities.

Advances in nanotechnology also birthed the feasibility of bio-drones. When a University of Colorado Boulder professor brought the concept up at a recent conference, the inherent advantages were not obvious. Considering that animal rights groups convinced the U.S. Army to stop using pigs to teach combat trauma first aid, it seemed unlikely that the military would turn animals into UAVs. Since the technology requires some type of brain control, the cruelty involved seems unlikely to meet the military necessity threshold.

But, there is some room for innovation here. A dolphin is more agile and faster than any remote control submarine. The Navy uses dolphins to help detect underwater booby traps and mines. Putting a GoPro-like camera on one of these dolphins is a simple solution. However, this lesson does not seem to transfer to the ground or air domain. There seems to be no advantage to putting a small camera on a trained pigeon. Regardless, implementing some type of brain control of a dolphin or bird seems to cross some sort of ethical red line.

Interestingly, humans seem to have less empathy for insects. A company called Backyard Brain developed RoboRoach which uses neuroscience to attempt to control the movements of a live roach. Insect drones could be the ultimate clandestine ISR, becoming the proverbial "fly on the wall" to watch and listen to the adversary. But, the fact that an insect can be controlled by remote control does not necessarily make it a good candidate for a UAV. The major technological challenge will be solving the power problem for the mini camera and the two-way communication packages that will enable the roach to go BLOS. Moreover, the insect will still need to eat and rest.

To mitigate the challenges of biological functions, technology is already starting to create man-made insect UAVs. The Harvard Monolithic Bee and Robugtix's Spider are but two early examples that suggest that the development of a realistic looking robot insect can be used as a UAV. Besides, a robot insect may be able to overcome the power limitation. Ideally, a robot insect can harvest energy from the environment such as solar or wind. For high-power needs, the robot can plug into power lines or electrical outlets.

One drawback of any nano UAV will be its survivability in an electronic warfare (EW) environment. Two key factors in EW are power and distance. The nano UAV will have problems with both. It is designed to be extremely close to the adversary and far from the friendly communications node. Its small size will inherently limit its total power to transmit clearly through enemy jamming. Even with advancements in technology, the nano UAV is likely to be at a comparative disadvantage relative to the adversary's EW system. This suggests that nano UAV will be most appropriate for environments in which there is a low threat of electronic attack. This suggests that stealth or swarms are the more likely answers for access against an advanced air defense system.

As UAVs continue to proliferate, there will be increased demand to reduce the command and control burden of UAVs. A major effort underway in this arena is detect and avoid technology in order to help reduce the probability of a midair collision. While this technology will improve safety at congested military bases, it will also be a boon to help the job of the Federal Aviation Administration to define rules to enable UAVs and manned aircraft to share the same airspace. One of the likely side effects of the military's research efforts on UAV detect and avoid technology will be increased domestic use of UAVs by law enforcement entities such as the Federal Bureau of Investigation, Border Patrol, Secret Service, Coast Guard and local law enforcement.

Conclusion

The evolution of UAVs will be exciting to watch. Advances in technology present a multitude of options for innovation of UAVs for military operations. Yet, just because a UAV can do a function does not mean that it will be adopted for that function. Many of the advances in UAV technology require additional advances in power, communications, electronic protection, and/or miniaturization to make them fully functional in an operational environment. This is a dramatic increase in expense that most militaries are unlikely to take until costs are significantly reduced. Those countries that do invest in state-of-the-art UAVs will have difficulties producing them in quantities desired by the warfighter.

Increases in automation are likely to enable the proliferation of more vehicles without requiring additional manpower. Fully automated UAVs, though, are likely to be limited to combat support roles, not the employment of lethal force. Even with advancements in radar, target discrimination, weapons, and defensive countermeasure, the decision to employ lethal force is not likely to be delegated to the automated platform. While an automated UAV may employ lethal force, it will be at the direction of a manned command and control platform.

Advancements in UAVs to survive in advanced air defense and electronic warfare environments face significant challenges. New UAV technologies such as nanotechnology and neuroscience will thrive in the irregular warfare environment, but are a long way from use in a conventional war. Reduced observability and a small forward footprint will enable more and more countries to engage in low priority, low visibility missions that they would normally assign to another instrument of national power such as diplomacy or economic manipulation. Efforts to make UAVs survivable in a high air defense threat environment via the creation of UAV swarms or large fleets of stealth UAVs increase the cost exponentially. There are perhaps a half dozen countries in the world that could afford such a venture. However, it would require serious tradeoffs in other military equipment, which is not likely in the near future.

The corresponding overhead costs in training for pilots, sensor operators and maintainers, fuel and spare parts, maintenance, and communications are not cheaper than manned alternatives. Advances in ISR will increase manpower costs as each additional sensor will require additional processing and exploitation capacity. Alternatively, the future is likely to see a proliferation of low-cost, non-survivable, small UAVs. These small UAVs have a much small cost footprint since there is no communications cost. Perhaps most important is the low manpower cost: a single individual acts as pilot, sensor operator, maintainer, launch and recovery, and as transporter. The use of these small UAVs will continue to expand into nontraditional ISR missions, irregular warfare, and disputed territory monitoring.

The large UAV's advantages in loiter time and target discrimination give it tremendous advantages over manned aircraft for some mission sets. Fully autonomous air-to-air and air-to-ground combat UAVs are unlikely. More likely is a semiautonomous system in which a man-in-the-loop system provides the decision making for multiple armed UAVs. But, for the most part, the UAV will continue to be a niche player. While that niche will expand over time, the manpower and infrastructure costs associated with UAVs will prevent it from becoming the universal replacement to all manned military aircraft missions. Over the long term, many of these costs could become negligible: inexpensive bandwidth and stealth materials and designs; significant improvements in semiautomation software to exponentially increase the productivity of pilots and intelligence analysts; and major improvements in power and electronic protection for small UAVs. In the meantime, militaries will continue to integrate their UAVs to work interactively with their manned aircraft.

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