16

Unmanned Aerial Vehicles:

Implications for Military Operations

David Glade, Lt Col, USAF

July 2000

Occasional Paper No. 16
Center for Strategy and Technology
Air War College

Air University
Maxwell Air Force Base

Unmanned Aerial Vehicles: Implications for Military Operations

by
David Glade, Lt Col, USAF

July 2000
Occasional Paper No. 16
Center for Strategy and Technology
Air War College

Air University
Maxwell Air Force Base, Alabama

Unmanned Aerial Vehicles:
Implications for Military Operations

David Glade, Lieutenant Colonel, USAF

July 2000

The Occasional Papers series was established by the Center for Strategy and Technology as a forum for research on topics that reflect long-term strategic thinking about technology and its implications for U.S. national security. Copies of No. 16 in this series are available from the Center for Strategy and Technology, Air War College, 325 Chennault Circle, Maxwell AFB, Montgomery, Alabama 36112. The fax number is (334) 953-1988; phone (334) 953-2985

Occasional Paper No. 16
Center for Strategy and Technology
Air War College

Air University
Maxwell Air Force Base, Alabama 36112

Contents Page

Disclaimer

Acknowledgments

I would like to express my appreciation to my Air War College faculty advisors Dr. William C. Martel and Col (Ret) Theodore C. Hailes for their invaluable encouragement and editorial assistance. I would also like to express my thanks to my wife for her constant support and encouragement.

Abstract

The development of uninhabited aerial vehicles (UAVs) could potentially revolutionize how military force is used in the future. While the early operational experiences with UAVs show great promise, their full range of capabilities is largely unknown. However, it is clear that these technologies will enable military forces to use aerospace power more efficiently, which means at lower cost and with less risk to the humans who pilot aircraft.

The broader question is the wisdom of using unmanned aerial vehicles for employing lethal force, and in particular which air power missions are best accomplished by uninhabited, piloted, and autonomous vehicles. The corollary is to examine the essential roles of human pilots or operators in aerospace operations in the twenty-first century. Since it is common to draw distinctions between vehicles with an on-board pilot, vehicles with off-board operators, and autonomous vehicles, this study explores the essential role of pilots and contrasts it with the roles of remotely piloted and autonomous vehicles.

The assumption is that piloted, remotely piloted, and autonomous vehicles have advantages and disadvantages in military operations, and that these vary in strategic significance for different levels of conflict. Since it is essential for the U.S. defense establishment to consider the strategic and technological implications of these types of aerial vehicles, this study is devoted to addressing the issues raised by the new generation of aerial vehicles.

The Author

David B. Glade, Lieutenant Colonel, USAF, is the Acting Chief of the Air Force Superiority Mission Area Team in the Requirements Directorate of the Headquarters of the Air Combat Command at Langley Air Force Base in Virginia. A flight test pilot, he was the deputy chief of test and evaluation for the F-22 System Program Office at Wright Patterson AFB in Dayton, Ohio, where he was responsible for planning the ground and flight test program for the Air Forces F-22 fighter. He served as an experimental test pilot at Edwards AFB, where he flight tested all models of the F-15, including certifying the F-15E for terrain following operation in weather, testing a ground collision warning system, and numerous radar, flight control, weapons, and engine tests. He also served as the chief F-15 instructor at the USAF Test Pilot School. His operational assignments include a tour at Mountain Home AFB, Idaho, as a flight examiner in the EF-111A, and a tour at RAF Lakenheath, United Kingdom, as chief of aircrew training in the F-111F. Lieutenant Colonel Glade is a member of the Society of Test Pilots and a member of the Air Force's acquisition corps. A distinguished graduate of the U.S. Air Force Academy, Undergraduate Pilot Training, and the USAF Test Pilot School; he graduated with distinction from the College of Naval Command and Staff, and earned a Bachelor of Science Degree from the U.S. Air Force Academy, a Master of Science Degree from the department of Mechanical and Aerospace Engineering at Princeton University, and a Master of Arts Degree from the U.S. Naval War College. He co-authored a published paper that assesses flying criteria for fighter aircraft.

I. Introduction

The development of uninhabited aerial vehicles (UAVs) raises the possibility that states will be able to conduct military operations in a more efficient and less risky fashion than was the case when aircraft were piloted by humans. While the United States has gained experience in recent military operations with UAVs, notably in Kosovo in 1999, the U.S. defense establishment has not fully explored how this technology will influence the nature and conduct of future military operations. As a result of numerous technological developments, it is possible that the United States will be able to build military systems, including UAVs, which can conduct military operations without human intervention. This prospect raises significant questions about the nature of military operations in the future and how these technologies will influence international security.

When the United States Air Force Scientific Advisory Board (SAB) conducted a study in 1996 on the role of UAV technologies in military operations, its principal conclusion was that UAVs would enhance the ability of the United States to project military power.[1] The equally important conclusion was that these vehicles could perform the tasks that pose increasing difficulties for manned aircraft, of which attacking chemical warfare/biological warfare (CW/BW) facilities and suppressing enemy air defenses are the most important examples. The SAB study concluded that because UAVs are more survivable than manned aircraft, this technological development has profound implications for the military forces that the United States will design and deploy in the future.

The prospect of building unmanned air vehicles is not new by any standard. For most of the twentieth century, states have investigated the feasibility of building unmanned aerial vehicles and their potential value in military operations. A principal reason for the interest in UAVs was the desire to reduce the risk to humans in combat, but it also was to perform military missions in a more efficient and less costly fashion than has historically been the case with manned vehicles. A related reason was that freeing machines from the limitations imposed by humans would increase their performance. From the beginning, the hope has been that unmanned air vehicles would be less expensive to develop and manufacture than manned aircraft, and that UAVs will reduce the demand for the supporting facilities and manpower that modern aircraft require. As a result of technological advances in flight control, data and signal processing, off-board sensors, communications links, and integrated avionics, unmanned aerial vehicles are now a serious option. The hope, as yet unconfirmed, is that uninhabited aerial vehicles may be able to perform the most dangerous military missions, including attacking chemical or biological facilities, fixed and mobile targets, and other aircraft, which would represent a revolution in military capabilities.

There are far more than technological advances that are accelerating the development of UAVs. With the end of the Cold War, the United States spends less on defense, but is more likely to be involved in peacekeeping and humanitarian operations than in major theater wars. In addition, U.S. security will depend on rapidly deploying mobile forces rather than relying on large forces that are based overseas. In all of these operations, the political climate in the United States places great emphasis on minimizing casualties, specifically when U.S. vital interests are not at stake. If the United States can employ technology to minimize the exposure of American military personnel in the lesser contingencies that will dominate American military operations for the foreseeable future, U.S. policymakers will have much more flexibility in responding to crises and challenges.

A number of technological factors suggest that unmanned weapon systems will be important in future military operations. To understand how the technology behind the development of UAVs is changing the nature and conduct of military operations, this paper examines the role of three categories of air vehicles in military operations: aircraft that rely on traditional pilots, vehicles that are operated by pilots at remote locations, and vehicles that operate autonomously. After considering the advantages and disadvantages of these categories of aircraft, the technological implications of using UAVs in military operations will be considered.

II. Defining Aerial Vehicles

As there are several different types of air vehicles, the first step is to define these terms with precision. According to the U.S. Department of Defense, an unmanned aerial vehicle is "a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload."[2] This definition also includes aerodynamic drones and remotely piloted vehicles (RPVs), although RPVs are designed to be recoverable.[3] However, this definition excludes ballistic or semi-ballistic vehicles, artillery, and cruise missiles, the latter of which is viewed as nuclear delivery systems in accordance with various arms control treaties.

Using these terms, UAVs may be manned or unmanned, remotely piloted or operate in an autonomous fashion, and in the case when control is exercised by a remote pilot, control may be continuous or episodic. In some cases, autonomous vehicles follow preprogrammed courses and lack the capacity for re-targeting, while in other cases autonomous UAVs will follow preprogrammed courses and can be rerouted or re-targeted.[4] In military terminology, vehicles are reusable, while weapons are expendable. In addition, UAVs have shorter life spans than manned aircraft, and can suffer attrition in military operations,[5] which means that they will survive for a relatively small number of sorties until failures, accidents, or hostile action destroy them. The loss rate for aircraft and UAVs is an important concept that influences the cost-effectiveness of UAVs and manned vehicles.[6]

Categorizing Air Vehicles

One way to understand the nature of unmanned vehicles, as a military instrument is to develop a framework that traces the development of manned and unmanned air vehicles, assesses the technological state-of-the-art in aircraft and computer technologies, and extrapolates how these developments may influence their use in military operations.

The simplest approach is to divide aircraft into manned and unmanned vehicles, and then to further sub-divide unmanned vehicles into those that are remotely operated and autonomous. This framework rests explicitly on the human role in perceiving and influencing events during the operation of air vehicles. If manned aircraft use direct human presence to directly perceive events and conditions around the vehicle, remotely operated vehicles keep the human presence at a distance. The critical factor that distinguishes between aircraft and UAVs is the amount of information that is available to the human flying a UAV. The technological and operational communities have invested considerable resources in using visual and data displays to provide information to the human about conditions in and around the vehicle. The problem is that these technologies have been inadequate because the human operator is deprived of significant information about the vehicle's performance, which includes attitude, vibration, and sound, among others. In the case of vehicles that are operated only periodically by a human, such as the Global Hawk UAV, the operator must make decisions with significantly less information about the vehicle than an on-board pilot. The concept of the information that is provided to a remote operator has significant implications for UAVs, principally because it directly increases the combat effectiveness, cost, and complexity of these vehicles.[7]

If we turn to the case of autonomous vehicles, the human presence exists at a distance, is confined to receiving information about the vehicle, and does not exercise direct control over the vehicle. By their nature, humans lose control of autonomous vehicles once it is launched, which implies that human operators do not control the operation of autonomous vehicles, and that available information about the status of the vehicles is quite limited. Once these limitations are understood, autonomous vehicles may be well suited to attacking targets whose location is precisely and accurately known. The value of this assumption diminishes, however, in the case of searching for mobile targets, of which SCUD missiles and command and control centers are prominent examples. One fundamental reason for the development of these vehicles is the desire of the U.S. military to destroy what is known as time critical targets, especially when these vehicles are missiles that may be armed with weapons of mass destruction.

Perhaps the best way to differentiate between aerial vehicles is to consider the role of human presence, which can be immediate or distant, and can involve large or small amounts of information about the vehicle's operation. However, the information provided to the human operator is not the same for all types of piloted aircraft, For example, while the MiG-23 and F-15 are both manned fighter aircraft, F-15 pilots have greater visual perception than MiG-23 pilots as a result of the larger and less restrictive canopy. To cite another example, the F-15 pilot has vastly more tactical information than the pilot of the World War II era P-51 Mustang fighter, principally because the F-15's radar greatly extends the pilot's ability to perceive events in the air and on the ground.

In principle, all unmanned vehicles possess some degree of automation. An interesting problem, however, is that completely autonomous operations create unexpected situations, which was reaffirmed during tests of the Global Hawk UAV.[8] Not surprisingly, the price of automation is to significantly increase the cost of engines, hydraulics and electrical systems, and avionics systems to the point where these are more expensive than the less automated counterparts that are controlled by humans.

Categorizing Military Operations

The roles of UAVs can vary widely based on the difficulty of the military operation that is to be conducted. The simplest military operations involve attacks against fixed ground targets, while the more challenging operations involve attacks against mobile ground targets and other air vehicles. As one would expect, an attack against fixed targets is the simplest because it is relatively easy to find targets whose location does not vary and which can be assessed with great accuracy. However, an attack against air targets is more difficult because the target's mobility makes it more difficult to find and destroy the target, and further because the target's ability to maneuver makes it more difficult to prosecute an attack. Even when an air target has been located, the simplest form of attack is the unobserved attack in which the target is not aware that it is under attack. By contrast, an observed attack against a highly maneuverable target with an experienced pilot is most difficult. Consider, for instance, the case of an unobserved attack from behind a large bomber, which would be simpler to conduct than an attack against an opposing fighter whose experienced and well-trained pilot is aware that an attack is underway and will take active measures to defeat the attack.

Another type of attack are those against enemy targets that are out of contact with friendly forces, which are simpler than attacks in which enemy targets are relatively near friendly forces. The principal reason for the difficulty of conducting this type of attack is the high-level of coordination that is necessary if vehicles are to avoid destroying one another, which is known as fratricide. A basic rule of military operations is that the difficulty of combat situations increases as the number of enemy threats increases, and that this rule has important implications in air-to-air and air-to-ground operations when friendly and enemy targets are interspersed throughout the battlespace. Ideally, all of the aircraft in one area belong to the enemy, while the aircraft in other areas belong to friendly forces, but the reality is that in modern military operations enemy and friendly aircraft will be mixed in the same area. The problem becomes even more complex in operations other than war when friendly, enemy, and neutral combatants are scattered throughout the battlespace.

These concepts have several important implications for UAVs. First, human pilots have a vastly greater ability to understand and respond to the conditions in combat around the vehicle than the human who operates the vehicle from a distance. Second, the number and type of threats, degree of mobility of targets and threats, and the degree of sorting that is necessary to separate arid classify threats directly influences the success with which UAVs can be used in military operations. Third, despite these limitations, technology has matured to the point where it will be possible to gradually shift combat functions from piloted to remotely piloted vehicles and eventually to autonomous vehicles in a migration that may transform the nature of war.

Automation. However, the success of this shift will depend in large measure on the ability to develop technologies that will automate many of the functions that humans perform in military operations. In essence, a vehicle is said to be autonomous when it can conduct operations without human intervention. To cite an example from the current generation of automated fighters, the F-117 can “complete an entire mission, from wheels-up to wheels-down, with no intervention by the pilot except consent to weapons release.”[9] The vehicles that are being conceived by industry will include varying degrees of control, in which the remote operator identifies the target and the UAV plans and executes a coordinated attack. A truly autonomous vehicle would not require any form of human intervention.

The military value of UAVs will depend on the ability to automate many of the functions that have historically been performed by humans, which ranges from guiding a vehicle to delivering ordnance against military targets.[10] The simplest form of automation is the radio-controlled model airplane, while a more complicated autonomous aerial vehicle is the World War II V-1 "Buzz Bomb," which performed tasks in a fixed sequence—as does a modem cruise missile that is guided by GPS. The most complex example of automation is a UAV that relies on a rule-based or expert system to detect, identify, and attack mobile targets.

Fundamentally, the essence of automation is to use rules to guide decision-making, but this is a highly complex problem in war. This complexity is illustrated by the air campaign during the Persian Gulf War, which involved roughly 2,600 allied aircraft of at least 41 different types and 950 opposing enemy aircraft of 17 types, of which at least 6 types of aircraft shared common features with allied aircraft. All of these aircraft could be attacked by various air-to-air weapons, 16,000 surface-to-air missiles in 10 types, and 7,000 anti-aircraft guns.[11] For automation to succeed in military operations, a computer must be able to sort though large numbers of choices and make good decisions about the use of lethal force in a reliable and timely fashion.[12] At present, the problem is that rule-based decision-making has not reached a sufficient level of reliability to permit autonomous vehicles to make the kinds of decisions in war in which humans could have high confidence, especially when failure can result in the deaths of hundreds or thousands of innocent civilians.

III. Evaluating Aerial Vehicles

This paper thus far has focused on understanding the differences between piloted, unmanned, remotely piloted, and autonomous vehicles. This discussion now turns to a consideration of the advantages and disadvantages of these vehicles in the context of how technological advances are altering the role of air vehicles in military operations.

Characteristics of Piloted Vehicles

While there are many ways to characterize modem piloted aircraft, speed, range, altitude, and payload are among the more important when examining the differences between piloted and unpiloted vehicles. Beyond that, however, the most fundamental characteristic is that piloted vehicles rely on the presence of humans to detect and respond to changes in the vehicle's operation. While human sensors have their own limitations and shortcomings, it is still true that the current state of non-human sensors is not sufficiently developed to replace their human counterparts. Aircraft have historically relied on pilots because technology has not been able to assess the operation of the aircraft without the presence of a human. The human can deal with the condition of the aircraft, including unusual vibration that may indicate structural damage or impending engine failure. The value of humans, which technology has not yet replaced, is the ability to absorb and analyze larger volumes of more diverse and ambiguous information than any machine. A related characteristic is that piloted aircraft are designed for longer lifetimes than their unpiloted counterparts, principally because the human payload is considered to be intrinsically valuable.

Perhaps the most important characteristic of piloted aircraft is their ability to deliver weapons that can be used to attack a wide array of targets. In terms of targeting, modern tactical aircraft can carry a number of munitions that can produce wide-area as well as precise effects, and do so at standoff distances that range from thousands of meters to thousands of kilometers. The trend in recent years has been to increase the accuracy of munitions, which permits designers to reduce the size of the warhead.

Finally, while conventional aircraft require long runways and large numbers of supporting personnel, facilities, and supplies, the shift toward weapon systems that employ some degree of automation will reduce our reliance on the infrastructure that is commonly associated with military organizations.

Advantages. The most significant advantage of piloted vehicles is their ability to use humans to sense events within and outside the vehicle, which is known in military jargon as "situational awareness." A related advantage of the reliance of humans is that no two pilots react the same in every situation, which in military operations involves how humans identify threats and targets, make decisions in unfamiliar and ambiguous situations, and function in an analytic and creative fashion. The advantage of human pilots is that they are able to adapt to new and different circumstances, make decisions on the basis of incomplete or ambiguous information, and deal with unexpected situations, such as damage or malfunction. One condition that distinguishes piloted vehicles from their automated counterparts is that the latter cannot possess these human qualities. While piloted vehicles use electronic devices, such as radio, radar, radar warning, and electronic countermeasures, to supplement the pilot's senses, the most fundamental characteristic of piloted vehicles is that the human makes critical decisions about the use of lethal force.

The principal advantage of piloted vehicles is that people are able to solve problems that machines cannot, and further humans can tolerate greater confusion than machines and make decisions that computers cannot. Even in the first decade of the twenty-first century, we have not reached the stage where humans are freed from the responsibilities of supervising machines in war.[13]

For the U.S. Air Force Scientific Advisory Board, the concept of human control over the critical functions that are executed during combat operations is the most important of piloted vehicles. The SAB argues that human controllers have unique abilities that we have yet to replicate in machines, and which will represent a decisive advantage in combat as long as humans can think, synthesize, and comprehend faster than machines.[14] While unmanned vehicles can conduct military operations with minimal risk to humans, the tradeoff is a reduction in the ability of such vehicles to make decisions in military operations. Until UAVs can perform this function, their role in military operations will remain quite limited.

Disadvantages. The principal disadvantage with piloted aircraft is that the human physiology imposes fundamental limits on the performance of the aircraft. At the same time, the presence of humans in aircraft increases their complexity and cost, and piloted vehicles are more vulnerable because they are larger than most UAVs, and hence more susceptible to attack than the smaller UAVs. A final disadvantage is that piloted aircraft are vulnerable to political exploitation. There are several recent cases in which the loss of an aircraft created political difficulties for the United States, including the loss of aircraft in the raid against Libya in 1986 (Operation Eldorado Canyon), Bosnia in 1995, and the loss of an F-117 over Serbia in March l999.

Characteristics of Unmanned Vehicles

UAVs fall into two distinct groups of remotely piloted and autonomous vehicles. This section examines the general characteristics of UAVs, while the subsequent discussion focuses on the unique characteristics of autonomous vehicles. A useful concept for distinguishing between these types of vehicles is to remember that remotely operated vehicles remove the operator from the vehicle, while autonomous vehicles remove the operation of the vehicle from the control of the human operator.

By virtue of their range, persistence, and altitude capabilities, UAVs enhance the ability to project military power, as demonstrated by the Predator and Global Hawk UAVs, whose endurance is far greater than that of piloted vehicles. For these reasons, UAVs can accomplish tasks that are increasingly difficult for manned aircraft, of which attacking chemical and biological warfare facilities and suppressing enemy air defenses are emerging as critical problems. At the same time, UAV technologies are Teaching the level of technological maturity where they are able to inflict devastating damage on many targets.

In historical terms, extending the range or distance between the target and the person who is responsible for using the weapon were significant factors in the development of UAVs. The use of UAVs began with

German experiments with guided weapons in WWII including the V-1 Buzz Bomb. This approach parallels the modern tactic of using high-altitude piloted aircraft or low-altitude cruise missiles to deliver ordnance. The development of UAVs for photo reconnaissance was spurred in the early 1960s by the downing of the U-2 aircraft that was piloted by Francis Gary Powers in May 1960 and the downing of a U-2 during the Cuban Missile Crisis. Furthermore, UAVs were used for photographic, communications, and electronics reconnaissance, surveillance, and electronic combat in the Vietnam War, and by Israel for photographic and electronic reconnaissance as well as decoys during the 1973 Yom Kippur War and 1982 Lebanon operation.[15] More recently, the U.S. Army, Navy, and Marine Corps used the Pioneer UAV for tactical reconnaissance, surveillance, and target acquisition during the Persian Gulf War.[16]

In operational terms, UAVs can operate at altitudes that exceed 70,000 feet and can carry optical sensors and radar.[17] The development of new warhead technologies allows UAVs to deliver compact weapons that can inflict significant damage against fixed and moving targets. While these technologies can be used with manned aircraft, the interesting possibility is that UAVs could be used to locate and destroy mobile targets, in particular because of recent successes with the development of automatic target recognition software.[18]

Advantages. The principal advantage of UAVs is their ability to reduce the risk to humans, and thus to provide cost-effective military options that can be used when political or environmental conditions prohibit the use of manned systems. The other advantages of UAVs are the ability to free the aircraft from the human's inability to withstand acceleration, (g) forces, and fatigue, and to eliminate the myriad systems that sustain human life in the cockpit, and that increase the weight, complexity, and cost of piloted aircraft. Once freed from these limitations, UAVs can be more maneuverable, enjoy longer endurance or loiter times, and be less observable than their piloted counterparts. The principal operational advantage of UAVs is their ability to fly close to highly defended targets, which in the case of nuclear, biological, and chemical (NBC) targets, creates significant risk for pilots.

Disadvantages. The primary disadvantages of UAVs are their need for large bandwidth communications, vulnerability to jamming, and low survivability in military operations. While it is commonly assumed that UAVs are relatively inexpensive in comparison with manned aircraft, the current generation of UAVs is relatively expensive to develop and build. However, this cost advantage may be overstated if the expected operating costs of the Global Hawk UAV are roughly half the operating cost of U-2 aircraft. While the Global Hawk cannot perform all of the U-2's missions, it is interesting if UAVs are less expensive to operate.[19] For now, the production costs for UAVs are relatively high because these systems typically involve small production runs, and the avionics and weapons used by UAVs are quite sophisticated and expensive. An important concern is that the losses of UAVs could be prohibitively expensive if large numbers were lost in military operations. A second problem with UAVs is their need for sufficient bandwidth to permit the remote operator to maintain an adequate data link with the vehicle. And the need for large bandwidth increases their vulnerability to jamming.

A third problem is that UAVs have unique survivability problems. The most notable are that UAVs are not technologically sophisticated enough to warn the operator that the vehicle is under attack, cannot operate in adverse weather, and have a low level of reliability, which reduces the role of UAVs in military operations.[20]

Characteristics of Remotely Operated Vehicles

Since RPVs have a remote operator, these vehicles are smaller, have greater operational endurance, are less expensive than piloted vehicles with comparable capabilities, and rely on sensors and communication links to inform the operator of the condition of the vehicle. The current approach is to use RPVs for intelligence, surveillance, and reconnaissance missions, and some thought has been given to using RPVs in air combat missions to protect other fighter aircraft or high-value assets, such as the Airborne Warning and Control System (AWACS). However, the ability of RPVs to perform these missions will require these vehicles to have the autonomous functions that typically increase their development and acquisition costs.

Advantages. The principal advantage of remotely operated vehicles is their ability to use human reasoning, and that the vehicle is less expensive than its piloted counterpart. RPVs can be smaller, lighter, have greater endurance than piloted vehicles, and can be stealthy depending on the design of the aircraft and its communication system. However, while RPVs enjoy many of the advantages that are associated with human decision-making, these vehicles are limited by the fact that aircraft must rely on the sensors and time delays that exist when the aircraft and the operator are in different locations.

The operational advantage of RPVs is their ability to maneuver more adeptly than piloted vehicles. In addition, the rule is that RPVs are less detectable than aircraft because their smaller size makes them less observable. The roles of the remote operator are similar to the ability of the pilot, which is to make decisions in the presence of incomplete or unambiguous information, deal with unexpected circumstances, and take measures to protect the vehicle. To be successful, however, the operator must have access to timely information about threats to the vehicle, be able to identify that an attack is contemplated or in progress, and take measures to protect the vehicle. The problem is that the current generation of RPVs, as exemplified by the Predator UAV, does not have the technological sophistication to perform these measures.

Disadvantages. The principal disadvantage is that the operator is fundamentally unaware of the tactical situation around the vehicle, which translates into a greater probability that the mission will fail or the vehicle will be lost. At present, RPVs are susceptible to the loss of the electronic link with the human operator, which has catastrophic implications for failure of the mission or the loss of the vehicle. A general rule is that military systems that rely on distributed sensors are quite vulnerable to failures of the communication links. Another important disadvantage with RPVs, which tends to be ignored or diminished, is that the distance between the vehicle and the operator causes a time delay, which makes RPVS less responsive in combat. Finally, the RPV operator often does not have the same degree of situational awareness as the pilots in manned vehicles.

Characteristics of Autonomous Vehicles

As noted earlier, autonomous vehicles can perform their functions without a human operator, and as a result tend to be smaller and less costly than piloted vehicles. The fact that autonomous vehicles are smaller than remotely operated vehicles reflects the absence of communications systems and their relatively simple guidance systems, and gives autonomous vehicles significantly greater operational endurance. While the current generation of autonomous vehicles is limited to performing intelligence and surveillance missions and attacking fixed targets, the expectation is that technological advances will reach the point where autonomous vehicles will be able to attack mobile targets, such as missile launchers or command and control vehicles.

Advantages. The primary advantage of autonomous vehicles is their ability to work faster, more precisely, and more reliably than human operators. While the value of autonomous vehicles increases as the complexity of the task increases, the performance of autonomous vehicles depends fundamentally on artificial intelligence. However, the present generation of computers does not have sufficient reasoning power to make the right targeting decisions in military operations.[21]

The cost of autonomous vehicles relates directly to their capabilities. For now, autonomous vehicles with simple guidance systems cannot adapt to changing conditions on the battlefield as it flies toward the target. Military commanders, however, will want relatively inexpensive vehicles in the arsenal that are equipped with complex sensors, can interact with other systems, and are able to react to rapidly changing situations. At present, the United States does not have the technological capability to build autonomous vehicles that can perform even relatively simple missions.

Autonomous vehicles have an advantage in terms of their endurance or when they are operating in the presence of nuclear, chemical, or biological weapons.[22] Mother advantage with autonomous vehicles is derived from the fact that these vehicles are freed from the constraints that we imposed by the need for long runways or large fuel supplies, and thus can be dispersed to a large number of small airfields. Finally, autonomous vehicles can be sufficiently small that they are difficult to observe and destroy.

Disadvantages. The primary disadvantage with autonomous vehicle is that human controllers have very little information about how the mission is succeeding or how the vehicle is performing. While autonomous vehicles could be used to provide bomb damage assessment in much the same fashion as weapons that are guided with electro-optical sensors, the current state of the technology does not permit the present generation of autonomous vehicle to provide this information.

A significant disadvantage with autonomous vehicles is that the system may be susceptible to ambiguities or simple programming errors that cause it to attack friendly forces and cause collateral damage in areas that contain civilian non-combatants. The broader disadvantage with purely autonomous systems is that computers cannot make decisions without humans to supervise their behavior.[23] In terms of cost, autonomous vehicles that possess sophisticated artificial intelligence or expert systems will be expensive, complex, and prone to behave in ways that an adversary could recognize and exploit. In general, these machines cannot adapt to or exploit the factors that are essential to success in combat.

A reasonable assumption is that autonomous vehicles are not able to analyze the events or display the freedom of action that is essential for success in military operations. Autonomous vehicles cannot replicate the human ability to understand the nuances that make the difference between success and failure in war.[24] Autonomous vehicles cannot demonstrate initiative, but must rely on the expert systems or artificial intelligence that in itself is a product of lists of explicit rules and contingencies. These systems will lack the human ability to adapt and behave in unpredictable ways, which will increase their vulnerability to enemy actions. One reason for this limitation is that expert systems do not react well to information that operates at the edge of their "knowledge," known as "brittleness," which increases their vulnerability to enemies who can use deception or ambiguity to confuse the autonomous vehicle.[25] Given the sheer number of objects that highly automated systems may encounter and number of decisions that must be made correctly and rapidly, the problem is the relative ease with which an adversary could exploit autonomous vehicles

IV. Military Roles for Unmanned Aerial Vehicles

Manned aircraft has dominated the twentieth century, but technological advances are leading to the development of UAVs that will be able to perform military missions that once were reserved for piloted aircraft. There are a number of roles that UAVS could perform in future military operations.

Transportation. While it is very unlikely that UAVs will transport passengers in the near future, a more realistic possibility is that UAVs could transport cargo, especially in the relatively small quantities that would apply in tactical situations. The current state of technology may be sufficient to create remotely piloted or autonomous helicopters that are capable of delivering supplies and ammunition to troops in the field, as long as specific instructions and restrictions guide these UAVs.

Intelligence, Surveillance and Reconnaissance. A more practical is to use UAVs for intelligence, reconnaissance and surveillance option missions, which would take advantage of the fact that UAVs have long loiter times, can be positioned flexibly near potential targets, and are small and relatively difficult to detect. The long endurance of UAVs is particularly important for surveillance when these operations could be conducted over days. In this sense, UAVs could relieve manned platforms of the need to maintain the high operational tempo for the extended periods that are the norm in modern military contingencies.

The U.S. military in surveillance missions uses a number of UAVs. The U.S. Air Force has used the Global Hawk for surveillance missions, and the U.S. Army and Navy developed the *Outrider* UAV for tactical reconnaissance.[26] The Congressional Budget Office recommended that UAVs should be bought in order to reduce the Army's purchase of Comanche reconnaissance helicopters, which would save several billion dollars.[27] Meanwhile, the U.S. military is developing UAVs that can fly autonomously and broadcast real-time information, which the U.S. Army will use for reconnaissance, jamming, chemical or biological detection, and placing remote sensors on the battlefield.[28]

Attack Fixed Targets. The U.S. military has developed UAVs that demonstrated the ability to launch weapons against air defense sites. As early as 1972 a Ryan Lightning Bug drone successfully launched an AGM-65 Maverick electro-optical missile against a radar control van.[29] It is conceivable that UAVs could detect whether states are involved in manufacturing or storing weapons of mass destruction, and attack those facilities. The U.S. Air Force Scientific Advisory Board suggested that to attack these facilities, the United States should develop "dual-equipped" UAVs with multi-spectral sensors and weapons. This surveillance UAV would fly in concert with UAVs that are armed with precision, guided penetrating weapons or weapons, which employ kill mechanisms that prevent the spread of these materials. UAVs can be used to attack high-value, fixed ground targets in military operations. Once military commanders give the location, type of target, and desired weapons effects to the UAV, it would determine the proper way to attack the targets with a remote operator or some form of automation.

Attack Mobile Targets. The concept of attacking mobile targets with UAVs is quite popular, and involves using sensors on high-altitude, long-endurance UAVs in conjunction with aircraft. The fundamental problem with using UAVs is the difficulties of detecting and identifying targets in modem combat operations. For now, the problems of finding and destroying the right targets in combat operations mitigate against using UAVs for attacking mobile targets. If equipped with surveillance and reconnaissance sensors as well as munitions, low observable UAVs that operate at high-altitudes for long periods could be used to detect theater and cruise missiles. The relatively long endurance of these vehicles, when coupled with the ability to detect and identify targets, could make remotely operated UAVs a viable option for this mission.

Air-to-Air Combat. In the foreseeable future, technology will permit UAVs to conduct offensive and defensive combat operations against aircraft, cruise missiles, and ballistic missiles. If military commanders could use advanced UAVs to intercept aircraft, they would be able to shift manned aircraft to other combat missions. If we look to the longer term, it may be technologically feasible to develop UAVs that can replace the current generation of combat aircraft with vehicles whose performance and survivability exceeds that of piloted vehicles. Furthermore, UAVs could be used to attack facilities that produce or store weapons of mass destruction as well as attack critical fixed and moving targets.[30] While some form of remotely piloted vehicle may be valuable in air combat, many concepts that rely on degrees of automation, exceed current technological capabilities.

Combat Support Missions. A related idea is to use UAVs for the electronic support operations that are performed by strike aircraft and bombers, which involves using UAVs in conjunction with aircraft to target and jam fire-control radars. This category of UAV could function as a decoy that duplicates the radar, infrared, and radio signatures of fighter aircraft to increase their survivability. Once UAVs detect the location of enemy air defenses and transmit that data to manned attack aircraft, these or other UAVs could deliver weapons to destroy enemy air defenses, as noted earlier.

Summary. It is inevitable that technological developments will permit UAVs to assume many military roles. For this reason, it is essential for the United States to use the investment in UAV technology to increase the cost effectiveness of weapon systems while reducing the risk to humans in combat. However, the prudent option for the United States is to maintain significant capabilities in manned aircraft until computers and sensors have reached the point where they are capable of making the decisions in war that historically were controlled by humans.

V. Conclusions

The U.S. military faces numerous concepts for how UAVs should be used in military operations, but the fact is that many of these concepts rest on speculation about how UAV technologies might work. Given the present state of technology, there are significant problems that limit our ability to use unmanned vehicles, especially those that rely on automation to make decisions in combat. By most standards, automation is the critical technology that will determine whether UAVs will be able to function effectively in military operations. It is not enough to say that because the current generation of cruise missiles use inertial navigation systems, automated terrain-comparison, or Global Positioning System (GPS) technologies, that the U.S. military has reached the point where UAVs can assume a dominant role in military operations?[31] The reality is that the development of UAVs has been slowed by the problems associated with building autonomous machines that can perform human functions, of which making decisions in combat about the use of lethal force are probably the most difficult.

There is no doubt that recent technological advances have increased the military value of UAVs. For example, control systems have been perfected to the point where the operator needs far less experience with operating vehicles, and can focus on delivering weapons. Nor is it clear that UAVs will be less expensive to operate than their manned counterparts. While one study suggested that the Global Hawk UAV may be less expensive to operate than the U-2 aircraft, there are considerable uncertainties about how much it will cost to operate UAVs. For example, the U.S. Air Force discovered during the 1999 Balkans campaign that it was more expensive to operate the Predator UAV than it had anticipated.[32]

Finally, the military must understand that there will always be cases in which unmanned vehicles cannot fulfill the missions performed by manned aircraf.[33] The fundamental technological problem with UAVs is their limited ability to deal with ambiguity in military operations. Whether in major wars or peace enforcement operations, military commanders routinely make mistakes when identifying friendly and enemy forces as well as civilians. A notable example was the failure to realize that civilians were crossing a bridge in Kosovo at the same time as military forces, which were attacked by NATO aircraft.[34] The problem is that command and control bunkers may shelter civilians or surface-to-air missile systems may be located in urban areas, which if attacked by mistake will kill innocent civilians. To pass the threshold where UAVs can be used extensively in military operations, UAVs must demonstrate a level of automation that can deal with this ambiguity, but this standard still exceeds our technological capabilities. Until remotely operated UAVs have the sensors and computers that can resolve the ambiguities that exist in combat, the U.S. military will not be able to rely on automated systems. This is not to say that technology will never create automated systems that can guide UAVs on military missions. But the danger is that as the volume of information grows which increases the pressure to make decisions more quickly, human operators may become so overloaded that they willingly abdicate control to automated systems.

A related question is whether the development of UAVs will lead the technological obsolescence or extinction of piloted aircraft, and hence of the U.S. Air Force. The counter argument however, is that if the U.S. Air Force fails to adapt to rapid technological change, its role will diminish in any case.[35] Nevertheless, it is conceivable that the reliance on machines could accelerate the demise of an era in which humans play a decisive role in the use of air power.

These technological developments should not obscure the fact that piloted, remotely piloted, and autonomous aerospace vehicles can make significant contributions to military operations, and that military organizations must consider how these technologies will change the doctrinal foundations of military power. The U.S. military must adapt to technological change if it is to preserve its ability to prevail in military operations. And this, rather than the presence of human operators, is the ultimate military and technological test of success.

As technological advances increase the lethality of weapons on the modern battlefield, it is inevitable that UAVs will reduce the risks to humans in combat. It is illusory, however, to believe that technological progress will completely erase the need for placing humans in harm’s way. If there is a fundamental constraint on the development of UAVs, it is that technology promises to find purely unmanned solutions to combat but cannot deliver on that promise. Political and military authorities should approach with caution the prospect of a world in which automated systems select military targets and employ lethal ordnance. Let us imagine the dangers of a situation in which an autonomous vehicle that is armed with missiles mistakenly attacks a school bus, which is filled with children because the automatic target recognition software concluded that the "target" was the transported-erector launcher that carried a SCUD missile. This problem can be compounded if one considers that the automatic target recognition system might fail to "realize" that the mobile missile is parked in a schoolyard.

While automation can assist humans, we have not reached the point where technology will allow automated systems to make decisions about the use of lethal military force. If the objective behind the development of UAVs is find technological solutions for saving human lives in combat, it should not divert the technological community from finding better ways to integrate humans and machines into the most effective system for making the best possible decisions in war

Notes

1. United States Air Force Scientific Advisory Board, Report on UAV Technologies and Combat Operations (Volume 1: Summary), SAB-TR-96-01. November 1996.

2. Joint Publication 1-20, Department of Defense Dictionary of Military and Associated Terms, March 23, 1994, as amended through April 15, 1998, pp. 138, 369, and 459.

3. Author interview with Edward E. Huling, III, and Major James D. McCormick, Reconnaissance Systems Program Office, Aeronautical Systems Center, November 24, 1998.

4. Brian T. Kehl and Michael D. Wilson, Manned Versus Unmanned Reconnaissance Air Vehicles: A Quantitative Comparison of the U-2 and Global Hawk Operating and Support Costs, AFIT/GCA/LAS/98S-7 (Wright-Patterson Air Force Base, OH: Air Force Institute of Technology Thesis, 1998).

5. United States Air Force Scientific Advisory Board, Report on UAV Technologies and Combat Operations (Volume 1: Summary), SAB-TR-96-01, November 1996, pp. 4-6.

6. See William Wagner, Lightning Bugs and Other Reconnaissance Drones (Fallbrook, CA: Aero Publishers, 1982). See also Christopher A. Jones, Unmanned Aerial Vehicles (UAVs): An Assessment of Historical Operations and Future Possibilities (Maxwell AFB, AL: Air Command and Staff College, March 1997), p. 11,

7. In terms of cost, the least expensive weapon is a dumb bomb, the next more expensive option is an expendable cruise missile or a precision standoff weapon that is delivered from manned platform, and the most expensive option is a precision weapon that is delivered by a reusable vehicle that is remotely piloted or autonomous.

8. "Global Hawk 2 Flight Sets Stage For Airborne Sensor Tests," Aviation Week & Space Technology, November 30, 1998, p. 32. "Operators had one unexpected event. While on approach, the Global Hawk was told by the Edwards [Air Force Base] tower that heavy traffic required it to hold. The aircraft's flight plan was suspended, and the UAV

was put into a holding pattern [by the remote operator] at 5,000 ft. until it was permitted to land. It then conducted an autonomous landing."

9. Bill Sweetman, "Pilotless Fighters: Has Their Time Come?" Jane's International Defense Review, June 1997, pp. 57-61.

10. Stan Gibilisco, ed., The McGraw-Hill Illustrated Encyclopedia of Robotics & Artificial Intelligence (New York, NY: McGraw-Hill, Inc., 1994), p. 406. For reference, there are at least eight levels of automation, ranging from manually operated tools and manipulators, machines that perform a series of tasks in a fixed sequence, programmable manipulators, numerically controlled robots, sensate robots or robots that incorporate any type of sensor, adaptive robots that compensate for changes in their environment, smart robots with artificial intelligence, and smart "mechatronic" or mechanical-electronic systems that can control a fleet of robots or robotic devices.

11. James P. Coyne, Airpower in the Gulf (Arlington, VA: Air Force Association, 1992), pp. 19-35.

12. Gibilisco, p. 62.

13. Ibid., p.23.

14. See United States Air Force Scientific Advisory Board, Report on UAV Technologies and Combat Operations (Volume 1: Summary), SAB-TR-96-01, November 1996, pp. 4-3, which noted that, "Humans can learn to perform control functions and can thus adapt to unexpected inputs and demands. Humans can also reason effectively under conditions of uncertainty and perform higher order integration tasks." See John R. Boyd, Patterns of Conflict, December 1986 briefing, who argued that "to win, we should operate at a faster tempo or rhythm than our adversaries—or, better yet, get inside adversary's Observation-Orientation-Decision-Action time cycle or loop."

15. Dana Longino, Role of Unmanned Aerial Vehicles in Future Armed Conflict Scenarios (Maxwell Air Force Base, AL: Air University Press, 1994), pp. 1-6.

16. Christopher A. Jones, Unmanned Aerial Vehicles (UAVs): An Assessment of Historical Operations and Future Possibilities, AU/ACSC/0230D/97-03 (Maxwell AFB, AL: Air Command and Staff College, March 1997), p. 5.

17. Report on UAV Technologies and Combat Operations, op. cit., pp. 4-1, 4-2.

18. Ibid., pp. 2, 3-2 to 3-4.

19. See Kehl and Wilson, pp. 51, 81, 88.

20. Report on UAV Technologies and Combat Operations, p. 4-2.
21. Gibilisco, pp. 23, 25, 81.
22. Report on (UAV Technologies and Combat Operations, pp. 3-2, 4-2.
23. Gibilisco, p. 23.
24. Boyd, Patterns of Conflict
25. Daniel Crevier, AI: The Tumultuous History of the Search for Artificial Intelligence (New York: Basic Books, 1993), p. 207.
26. Author interview with Lieutenant Colonel Paul Geier, U.S. Air Force UAV Battlelab, November 17, 1998.
27. David A. Fulghum, "U.S. Army Debates Tactical UAV Requirements," Aviation Week & Space Technology, November 23, 1998, p. 50.
28. David A. Fulghum, "Miniature Air Vehicles Fly Into Army's Future," Aviation Week & Space Technology, November 9, 1998, p. 37
29. Jones, Unmanned Aerial Vehicles, p. 13.
30. Report on UAV Technologies and Combat Operations, p. 4-3
31. See "Gallery of USAF Weapons," Air Force Magazine Vol. 81, No. 5 (May l998), p. 155.
32. David A. Fulghum and Robert Wall, "Pentagon Budget Up, But Research Withers," Aviation Week & Space Technology, February 8, 1999, p. 28,
33. See Kehl and Wilson, pp. 51, 81-88.
34. ABC News, June 1, 1999.
35. See Carl H. Builder, The Masks of War: American Military Styles in Strategy and Analysis (Baltimore, MD: Johns Hopkins University Press, 1989); Carl H. Builder, The Icarus Syndrome: The Role of Air Power Theory in the Evolution and Fate of the U.S. Air Force (New Brunswick, NJ: Transaction Publishers, 1994).

Center for Strategy and Technology

The Center for Strategy and Technology was established at the Air War College in 1996. Its purpose is to engage in long-term strategic thinking about technology and its implications for U.S. national security.

The Center focuses on education, research, and publications that support the integration of technology into national strategy and policy. Its charter is to support faculty and student research, publish research through books, articles, and occasional papers, fund a regular program fo guest speakers, host conferences and symposia on these issues, and engage in collaborative research with U.S. and international academic institutions. As an outside funded activity, the Center enjoys the support of institutions in the strategic, scientific, and technological worlds.

An essential part of this program is to establish relationships with organizations in the Air Force as well as other Department of Defense agencies, and identify potential topics for research projects. Research conducted under the auspices of the Center is published as Occasional papers and disseminated to senior military and political officials, think tanks, educational institutions, and other interested parties. Through these publications, the Center hopes to promote the integration of technology and strategy in support of U.S. national security objectives.

For further information on the Center for Strategy and Technology, please contact:

Grant T. Hammond, Director
Theodore C. Hailes, Deputy Director
John P. Geis II, Director of Operations

Air War College
325 Chennault Circle
Maxwell Air Force Base, Alabama 36112
(334) 953-6996/2985/5579
(DSN 493-6996/2985/5579)

Email: Grant.Hammond@maxwell.af.mil
Ted.Hailes@maxwell.af.mil
John.Geis@maxwell.af.mil

Titles in the Occasional Papers Series

1
Reachback Operations for Air Campaign Planning and Execution
Scott M. Britten, September 1997

2
Lasers in Space: Technological Options for Enhancing U.S. Military Capabilities
Mark E. Rogers, November 1997

3
Non-Lethal Technologies: Implications for Military Strategy
Joseph Siniscalchi, March 1998

4
Perils of Reasoning by Historical Analogy: Munich, Vietnam, and the American Use of Force Since 1945
Jeffrey Record, March 1998

5
Lasers and Missile Defense: New Concepts for Space-Based and Ground-Based Laser Weapons
William H. Possel, July 1998

6
Weaponization of Space: Understanding Strategic and Technological Inevitables
Thomas D. Bell, January 1999

7
Legal Constraints or Information Warfare
Mark Russell Shulmann, March 1999

8
Serbia and Vietnam: A Preliminary Comparison of U.S. Decisions to Use Force
Jeffrey Record, May 1999

9
Airborne and Space-Based Lasers: An Analysis of Technological and Operational Compatibility
Kenneth W. Barker, June 1999

10
Directed Energy and Fleet Defense: Implications for Naval Warfare
William J. McCarthy, February 2000

11
High Power Microwaves: Strategic and Operational Implications for Warfare
Eileen M. Walling, March 2000

12
Reusable Launch Vehicles and Space Operations
John E. Ward, Jr., March 2000

13
Cruise Missiles and Modern War: Strategic and Technological Implications
David J. Nicholls, March 2000

14
Deeply Buried Facilities: Implications for Military Operations
Eric M. Sepp, March 2000

15
Technology and Command: Implications for Military Operations in the Twenty-First Century
William B. McClure, July 2000