Number 3

Defense Horizons

A publication of the
Center for Technology and National Security Policy
National Defense University

OCTOBER 2001

UCAVs—Technological, Policy, and Operational Challenges

by Charles L. Barry and Elihu Zimet

Overview

The Bush administration and Congress are in concert on the goal of developing a fleet of unmanned aircraft that can reduce both defense costs and aircrew losses in combat by taking on at least the most dangerous combat missions. Unmanned combat aerial vehicles (UCAVs) will be neither inexpensive enough to be readily expendable nor—at least in early development—capable of performing every combat mission alongside or in lieu of manned sorties. Yet the tremendous potential of such systems is widely recognized, and allies as well as potential adversaries are moving quickly to mount their own research and development programs. The United States is committed to fielding UCAV capabilities by 2010, principally for the missions of suppression of enemy air defense and deep strike, which are among the highest risk tasks for the Air Force and naval aviation.

Currently, UCAVs are unproven, infant technologies just being designed, simulated, and demonstrated. Enthusiasts must be aware that significant technological, policy, and operational challenges must be met. An operational UCAV capability is not expected to be available to U.S. field and fleet commanders for 10 years. Yet a nexus of mature technologies, policy support, and operational needs has been reached, and it is both possible and necessary to accelerate development of UCAVs. Their potential is apparent, and there is sustained momentum behind programs for all the services.

Promise and Challenges

Unmanned combat aerial vehicles (UCAVs) have the earmarks of becoming one of the disruptive technologies that transform conventional military operations across the full spectrum of combat scenarios from peacekeeping to regional wars. In battle, forces engage an adversary by either direct combat or indirect fires. Indirect fires, or standoff engagements, preserve forces and are preferred whenever available and effective. UCAVs promise to carry the concept of indirect fires to a new level. They will be more flexible than missiles in time-sensitive target selection and more readily expendable in high-risk environments than manned systems, and they will have a greater sustained battle presence than either missiles or manned systems. In time, UCAVs may liberate manned systems (such as airborne warning and control systems [AWACS] or joint surveillance and target attack radar systems [JSTARS]) from such routine missions as command, control, and communications protection or carrier battle group air cover. They may also perform a majority of the sorties for long endurance operations, such as *Northern Watch* and *Southern Watch* over Iraq. Eventually UCAVs may be so sophisticated that they will be safer than manned systems for close support of ground forces and more successful than manned aircraft in air-to-air combat. They could someday join the air defense arsenal against either strategic ballistic missiles or cruise missiles.

The intersection of technology advances, national security policy, and operational requirements has led to the commitment to

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
OCT 2001	**N/A**	**-**

4. TITLE AND SUBTITLE
UCAVs-Technological, Policy, and Operational Challenges

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Defense University Center for Technology and National Security Policy Fort McNair Washington, DC 20319

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**UU**	**8**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

near-term UCAV deployment. However, an array of technological, policy, and operational challenges must first be overcome:

Technology

- On-board signal processing, decision aids, and wideband data network links must afford a satisfactory mix of autonomous operation and man-in-the-loop (MITL) decisionmaking.
- Advanced electro-optical, infrared, and radio frequency (EO/IR/RF) passive and active sensors must provide for accurate target detection, designation, and engagement for both moving and stationary targets.
- Airframes and systems must be survivable against more capable air- and ground-based countermeasures, including missiles, gunfire, or energy-based weapons. Stealth technologies will be crucial.
- Automatic flight controllability will have to extend to a broader range of fight profiles, including hypersonic speed and evasive maneuvers in excess of human tolerances (9 times the force of gravity).
- New airspace/air traffic aids must network UCAVs into the broader airspace system without degrading other airspace users in terms of flexibility, responsiveness, and proximate engagement. These technologies must include automated landing and ground/deck operating systems.
- Propulsion systems must be developed that match desired efficiencies in terms of aircraft size, fuel duration, reliability, and survivability.

Policy

- Conventional arms controllers eventually will have to decide whether to classify UCAVs as systems to be counted under existing definitions of combat aircraft or to amend the Conventional Forces in Europe (CFE) Treaty to count a new category of weapon systems.
- The degree of autonomy to be built into unmanned vehicles will be a policy issue as well as a technical question. At least for the near term, an MITL decisionmaker will have to be included.
- Service cultural issues related to investing in unmanned capabilities at the expense of manned systems raise a host of secondary policy issues as budgetary realities require program decisions to be made.
- If coalition partners are to bring modern forces to operations, technology must be transferred to allies willing to purchase or be licensed to build UCAV systems using American technologies.

Operational Concepts

- Unmanned combat aircraft will have to be at least as effective as manned aircraft in terms of availability, ease of integration into the overall battle plan, and mission success rates, as well as being cost effective.
- As operational airspace users, UCAVs must be responsive to a continuously changing airspace management picture and must not restrict other users critical to successful prosecution of the battle.
- UCAVs must feature handoff capability to a central air battle operations center capable of controlling the full array of unmanned systems with a single architecture.
- Roles and missions for UCAVs must be determined and prioritized. Particular high-risk missions that UCAVs might take on are suppression of enemy air defense (SEAD) and deep strike against some stationary targets, especially targets that may be rapidly relocatable.

Lieutenant Colonel Charles L. Barry, USA (Ret.), is a Washington-based defense consultant; he may be contacted at (410) 827–5048 or via e-mail at cbarryusa@aol.com. Elihu Zimet is the head of naval expeditionary warfare science and technology in the Office of Naval Research; he may be contacted at (703) 696–4773 or via e-mail at zimete@onr.navy.mil

Nexus of Technology and Political Support

The U.S. military has experimented with unmanned aircraft for half a century and has resolved a host of technological obstacles to military employment. The right mix of operational requirements and available technology presented itself in 1999 over Kosovo, where U.S. and NATO forces used unmanned aerial vehicles (UAVs) extensively to collect intelligence on Serb forces and targets. The Kosovo operation was a benchmark, demonstrating that UAVs had an important place on future battlefields in the missions of intelligence, surveillance, and reconnaissance (ISR).

Since Operation *Allied Force*, many countries have taken the next logical step in the application of unmanned or robotic aircraft: the missions of target acquisition and engagement. Many countries have initiated UCAV programs, including France, Israel, Italy, and the United Kingdom. Nowhere has UCAV development achieved greater momentum than in the United States. President George Bush and Secretary of Defense Donald Rumsfeld have made it a highlight of their visions of defense transformation. In 2000, Congress added a provision to the 2001 Defense Authorization Act specifying that, within a decade, one-third of all U.S. deep-strike aircraft should be UCAVs. In 2001, Congress provided additional funding to the Department of Defense budget to show that it wants to move forward without delay.

Defense planners see an operational need for a system that can assume some of the current demands on manned systems, especially high-risk and long-term patrolling missions. Americans are averse to needless casualties if a better solution exists, notwithstanding a resolve to defend their homeland at any price if threatened. U.S. forces often face missions where few or no casualties are a proviso for sustaining public support at home and abroad. Other missions consist of continuous defensive patrolling or the monitoring of regions against violations of international agreements, as in the case of Iraq.

Leverage from UAV Operations

The interest in UCAVs flows from the operational success of UAVs. The U.S. fleet of UAVs has amassed more than 50,000 flight hours and considerable operational experience. UAV technology continues to improve in terms of platforms, flight control systems, autonomy, and sensors. UAVs are proceeding to the next stages of research and development and will integrate with UCAVs on the future battlefield to accomplish such missions as target identification and handoff. UCAVs may operate as armed UAVs for some missions or as UAV protection. Some UAV and UCAV subsystems probably will use synchronous technologies and even interchangeable components.

Unmanned aerial technology gained momentum from the quest for battlespace information dominance. Commanders in all battle mediums—land, sea, and air—have ever-increasing demands for streaming, real-time, full situational awareness of the battlespace. Continuous information flows provide details of enemy forces, terrain/sea conditions, and weather, as well as friendly force locations. More sophisticated, all-weather UAVs give commanders a unique perspective and enable them to dominate adversary decision cycles. UAV platforms, and the proposed man-portable organic air vehicles (OAVs), will be able to operate from as far away as inner space or as near as city rooftops. Unmanned platforms under development operate either at high altitudes (for example, Global Hawk at 60,000–70,000 feet) or in close proximity to the ground (for example, hovering UAVs and OAVs). That flexibility reduces UAV operations in the congested battlespace of manned combat aircraft. Still, UCAVs must be able to operate—even continuously—alongside manned systems, which will create different demands on the autonomous operating capabilities and positive control of UAVs and UCAVs.

Unmanned systems such as Global Hawk are poised to enter production and fielding with an initial operational capability in 2003, years ahead of the first projected UCAVs. UAV experience will inform the development of UCAVs, perhaps most notably in the area of networked systems and airspace management. From a systems design perspective, UCAV development may borrow more technologies from manned platforms.

Cost

Most experts agree that building UCAVs in projected quantities will cost less per unit to acquire, operate, and maintain than manned aircraft. However, they will still require significant research and development (R&D) investment to bring them to the point of production. UCAVs are expected to cost in the millions of dollars, though an approximate unit cost is hard to define without knowing the platform numbers and identifying the suite of onboard systems, data links, and ground control stations. The unarmed Global Hawk UAV just coming into production is estimated to cost approximately $50 million, roughly the same as the vintage U–2 that it is designed to replace. However, once R&D costs are amortized across a larger fleet, the UCAV unit cost is anticipated to drop to around $30 million or less—about half that of a manned system.

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More important than acquisition cost savings will be lower UCAV operating costs. Unlike pilots, UCAV controllers (who probably will be recruited from military pilots or navigators) will train almost solely in simulators, and their UCAVs will be maintained in ready storage, perhaps for years. Hence the operating and support (O&S) costs should afford even greater life cycle cost savings than initial procurement. UAVs, because of their peacetime ISR missions, will not achieve the same level of O&S savings as UCAVs. Before O&S savings are calculated with any certainty, however, further study will be required on the ground support investment that UCAVs generate. UCAVs should suffer far lower accident rates than either manned aircraft or UAVs because they will be stored and used only for limited training during peacetime, when manned combat aircraft fly the majority of their sorties (95 percent) and incur their highest losses (261 of the 265 F–16 losses as of 2000 occurred during training).

The other side of the cost equation is deciding whether to engage targets with long-range (ballistic or cruise) missiles or with UCAVs, which would be the more expensive choice but would offer a multiple-mission platform. On the other hand, missiles, such as the conventional Tomahawk, are less costly (albeit still expensive) but are one-time-use munitions. Both cruise missiles and UCAVs offer the same unmanned standoff engagement with regard to concerns about combat casualties; therefore, the decision variables will be cost and assurance of target destruction. If the target is mobile or fleeting, UCAVs may offer greater assurance of target engagement, and cost concerns would be secondary. Conversely, using Tomahawks against known but well-defended fixed targets, such as the attack against Iraqi weapons of mass destruction (WMD) sites in early 2001, avoids unnecessary loss of UCAVs while offering a high degree of assurance of target destruction.

Converting obsolete aircraft to UCAVs—the so-called scrapyard option—has surfaced as both more cost effective and available much sooner than the option to research and develop new aircraft. Commercial companies such as Lockheed Martin and Texas-based Mission Technologies have proposed using F–16s and A–10s as UCAVs. Members of Congress and the Air Force also have voiced support for this approach to UCAV fielding.

Nonetheless, as the battlefield becomes more sophisticated and counter-UCAV systems proliferate, antiquated systems will become more vulnerable and ultimately will have to be replaced by high-tech UCAVs if they are to take on essential operational roles.

UCAV Systems

A UCAV is actually a system of systems requiring full operational support services. A single aerial vehicle consists of an advanced airframe and its onboard suite of flight controls, weapons, guidance packages (including multiple target sensors, designators, and handoff data links), survivability features, perhaps an aerial refueling system, and a propulsion system. Each UCAV system is composed of a number of aerial vehicles and a ground control station (GCS).

Like manned aircraft, UCAVs will be formed into squadrons of several systems and accompanied by ground support equipment, spare parts/supply, and maintenance personnel. Unmanned craft will have to be supported by planners for deployments and routine services, such as fuel/ordnance resupply and weather information. Operating bases with UCAVs will require facilities and special mapping plans for UCAV ground operations.

As UCAVs grow in sophistication, so will their cost and operational value. Neither UCAVs, UAVs, nor any other unmanned system will be low-cost and readily expendable. Using unmanned systems for only a single sortie, or even for a limited number of sorties, would be short-sighted. Commanders can be expected to husband UCAVs on the battlefield as they would any other limited, hard-to-replace resource.

Because UCAVs will not fly extensively in peacetime, they should actually have more combat potential than manned systems in terms of sortie generation rates. Unmanned systems should be designed to the same standards of reliability, survivability, and autonomy as manned systems. The magnitude of this challenge is reflected in a 2000 Department of Defense study that noted UAVs have experienced mishaps at 10 to 100 times the rate of manned aircraft.

U.S. Programs

The Predator-Hellfire UCAV demonstration. In early 2001, the Air Force conducted the only successful UCAV demonstration to date when it engaged a stationary tank by firing Hellfire laser-guided missiles from a modified Predator UAV platform that both lased and engaged the target. The Predator is the best known UAV, with combat experience in Kosovo. The Predator is not being developed as a future UCAV, but serves as a UCAV concept demonstrator, and could fulfill an interim operational UCAV role.

The Defense Advanced Research Projects Agency (DARPA)/Boeing/Air Force X–45 program. The X–45 system is being designed as a pure UCAV vehicle optimized for the missions of hunter-killer SEAD and precision air-to-ground strike. It will be autonomous, rather than remote-controlled, able to operate if controller communications are jammed. Two X–45As are undergoing engine and flight-testing this year. An X–45B is under design and will be a higher fidelity version for evaluation of the ultimate UCAV platform and systems, including off-the-shelf weapon systems. Production versions will be low-observable, almost all-composite aircraft and will incorporate electronic surveillance measures and satellite link data/communications equipment. The program plans to move from technical testing to mission testing in 2003 and start engineering and manufacturing development (EMD) in 2008.

the technology for unmanned aerial vehicles is widespread, with 55 countries operating almost 80 types of UAVs

The DARPA/Navy UCAV–N program. The UCAV–N program is only in the preliminary design phase but is expected to reach EMD by 2008, with Boeing and Northrop Grumman competing in the program. The UCAV–N will be a dual-role reconnaissance UAV and attack UCAV aircraft. It is expected to be larger than the X–45 and have greater range and payload. The Navy is asking for a UCAV with a 4,000-pound payload, a 650-nautical-mile radius, and a 12-hour surveillance duration. The UCAV–N must be capable of carrier operations integrated with manned systems, which may require remote-controlled arresting gear and steering. A key capability for UCAV–N will be shipboard takeoff and landing guidance systems. An experimental technology, the shipboard relative global positioning system (SRGPS), converts the absolute positioning of a global positioning system (GPS) into positioning relative to a ship's deck, taking into account the ship's forward motion, heave, and sway. Accuracies for the SRGPS are expected to be 40 centimeters. The reconnaissance mission of the UCAV–N will put it in the maintenance profile of other UAVs—that is, it will not be stored in peacetime (like UCAVs) but will operate routinely and require more robust maintenance and support. Northrop Grumman has invested in Pegasus, a scale-model, kite-shaped UCAV–N that is due to fly in late 2001.

The DARPA/Army/Boeing UCAV program. The Army is considering a rotary-wing UCAV concept proposed by Boeing. The Canard Rotor-Wing concept lands and takes off like a helicopter, but the rotor stops and converts to a jet-powered wing in flight. The concept to date is simulation-based; however, a test flight model has been developed and is expected to fly later this year. The project is a part of the Army's overall Future Combat Systems initiative and may be either a UAV or UCAV.

Foreign Programs

The technology for unmanned aerial vehicles is widespread, with 55 countries operating almost 80 types of UAVs. The following are indications of international developments moving toward UCAV technology.

France. Dassault Aviation flew a small stealth UCAV demonstrator called *Petit Duc* in July 2000. Dassault is now working on a larger demonstrator with greater autonomy and range called *Moyen Duc* that could be flying in 2002. These early demonstrators are intended to lead to a full-size stealth UCAV somewhat smaller than a manned fighter and capable of carrying standard fighter weapons. The French concept is to control the UCAV from an airborne station in the backseat of a manned fighter several hundred miles away.

Germany and the United Kingdom. Both are studying the use of a UCAV capability to pick up some of their manned air-to-ground fighter missions.

Israel. Israel has logged more UAV hours than the United States and is reported to be pursuing an active UCAV program.

Italy. Italy has indicated interest in buying the Predator as a UAV, which may afford the Italian military with a ready-made UCAV capability should recent U.S. tests result in an operational variant of the Predator. Italy is also considering the conversion of obsolete F–104s to unmanned use.

Russia. Indications are that Russia may not be actively engaged in a UCAV program. However, it operates several UAVs, including the 800-kilometer-per-hour Reis and the slower, tactical Pchela series of UAVs. The maker of the Pchela, Kulon Scientific Research Institute, and the Yakovlev Design Bureau, a major Russian military aircraft manufacturer, have been urged to take the next logical step and develop a larger UAV that can carry bombs and missiles.

Technology Status and Challenges

The introduction of a new operational military system generally follows the intersection of a recognized operational need and the maturation of enabling technologies. The successful utilization of UAVs in combat has provided the U.S. military with a nascent concept for other unmanned systems. The post-Kosovo development of UAVs has enhanced the technology base in autonomous control, MITL guidance, and ground station displays and control.

Perhaps counter-intuitively, the principal technology enablers for UCAVs come from technology developments in manned aircraft, advanced sensors, high-speed processing, and networking rather than from UAV developments. Hence, UCAV performance requirements are more aligned with those of the manned aircraft. Current requirements for manned aircraft have led to the need to apply computer-aided dynamic flight control for stable flight (the plane is not stable if the flight controls are locked down). In addition, the shaping of the airframe to reduce radar signature has led to aerodynamic compromises and thus to more computer control. In parallel with aircraft development has been the development of advanced sensors, including imaging radars, hyperspectral infrared sensors, and passive and active millimeter wave radar. These and other sensors, coupled with high-speed signal processing hardware and algorithms, provide far more information than the unaided human eye. With the computer operating the aircraft and the primary information coming from sensors, taking the pilot out of the aircraft and providing remote oversight is not inconceivable.

expanding the mission set will require more endurance, greater maneuverability, increased weapon payloads, and faster target acquisition

Basic technologies are in place to build a prototype UCAV with a limited mission set. Yet significant technology challenges await if UCAV is to develop a multimission capability in a complex battlespace environment. These challenges include the following:

Intelligent autonomy. The level of autonomy allowed a UCAV is both a great technical challenge and the most contentious issue in terms of capability, weapon release authority, and deconfliction with other platforms. The tremendous increase in processing speeds and software development has enabled significant advances in autonomous control and decision aids. Major advances in autonomy are still required, even with offboard oversight, before UCAVs will be operational with weapon release authority in unrestricted airspace. Required technology development includes the development of fault-tolerant, behavior-based intelligence and adaptive reasoning systems (such as neural networks). Fusion of information from multiple diverse sensors and the processing of data will be required to form a real-time situational assessment. Automated detection and combat identification need to be significantly enhanced. The technology for real-time, on-the-fly mission-management and route planning needs development. Other technologies include autonomous sensor management and operator decision aids and displays. The systems developed must be fault tolerant, highly reliable and maintainable, and should incorporate modular low-cost electronic and micro-electrical-mechanical systems.

Network connectivity. Equal in importance is the need to network UCAVs with manned aircraft, other UAVs, offboard sensors, and ground stations for overall battle management. The cooperative engagement capability and development of the single integrated air picture have demonstrated the value of cooperative, inter-platform operations. Further technology development is required for responsive command, control, and communications (C^3) battle management. These technologies include wideband, secure, and all-weather data links. Also required are distributed, high-speed processing and video/data compression techniques to reduce the demand for bandwidth. Digital "software" radios are another new technology. High-data-rate transmission radios are needed to handle the proliferation of dedicated data links for new weapon and communication systems, including UCAVs, which may lead to dynamic wireless networking.

Airspace management. Unmanned aircraft will bring a new dimension to airspace management. The solution to management problems must include rule-based operational procedures and protocols for deconfliction of assets coupled with the technology to realize the concept. In addition to the need for robust, wideband data links and a single, integrated air picture, airspace management requires significant advances in precision navigation and in space/time positioning (GPS and inertial measurement unit [IMU] development have significantly increased this capability). A specific concern is the return of UCAVs to base with live munitions. If the base is an aircraft carrier, the problem is even more complex. Technology challenges include the development of an anti-jam GPS system, very-low-drift-rate IMUs, collision detection and avoidance systems, air-traffic control and mission management algorithm development, precision landing aids such as the SRGPS for carrier-based UCAVs/UAVs, and the influence of the weather on the operational environment.

Platform and platform components. Few of the components of the actual UCAV platform (outside of the flight management system) are unique to the vehicle. However, the expectation for expanding the mission set from SEAD and deep air interdiction to battlefield air interdiction, air superiority (including missile defense), and close air support will require more endurance, greater maneuverability, increased weapon payloads, and faster target acquisition. During the past 10 years, turbine engine development has increased the thrust-to-weight ratio by about 80 percent for manned aircraft, with more increase feasible. Engine development for a UCAV would be sized to a smaller vehicle, with cost and signature as significant drivers. Because a UCAV is not constrained in maneuverability by human tolerance for acceleration, its propulsion and airframe could be designed for higher maneuver capability. A more immediate goal for the UCAV is to develop propulsion and airframe for endurance and stealth. The elimination of the cockpit gives the UCAV significant signature advantages. Stealth design and materials have matured considerably since the F–117. A UCAV will depend on robust data links and operate in a netted environment, so its onboard sensor suite may not need to be comprehensive. Specialized sensors may be required for unique attributes of the UCAV involved in collision avoidance, landing, and perhaps mid-air refueling.

Weapons and targeting. The utility of a UCAV would not be enhanced if it required unique weapons. Fortunately, the direction of developments in current air-launched weapons from low-signature aircraft is supportive of the UCAV concept. A significant attribute of a UCAV-launched weapon would be a fire-and-forget capability. Internal carriage and aircraft survivability have driven the next generation of missile seekers in this direction and away from the current paradigm of laser or optically guided weapons requiring human intervention. These new weapons will require low-cost imaging infrared or millimeter-wave seekers that have become available. A UCAV will be required to provide targeting coordinates and target identification information to a weapon prior to release. The degree of autonomy built into the targeting and weapon release will impact the MITL degree of involvement.

Policy Issues

Training, exercising, and operating with coalition partners (inside or outside NATO) will require new agreements to cover UCAV integration. UCAV operations may be forced to rely on procedural separation when links with allies are less reliable, leading to information voids or slow information processing updates. Allies should be encouraged to embrace the technologies required for closely integrated coalition operations, including UCAVs from multiple nations. In each case, the challenge will be to make an informed decision about how closely U.S. forces can operate with each ally and how to integrate their capabilities.

some technology transfer will be necessary if allied UCAV programs are to keep pace with U.S. programs

Arms control. In late 2000, an American interagency legal team concluded that UCAVs, which do not use launchers and are designed to return to base, do not meet the definition of a cruise missile under the 1987 Intermediate-Range Nuclear Forces (INF) Treaty, and thus are not subject to its provisions. Russia, the other party to the INF treaty, has not responded to this position. The United States sees UCAVs as a type of conventional aircraft and therefore potentially subject to the 1990 Conventional Forces in Europe Treaty. As UCAVs become more common, some parties may desire to control their numbers under CFE. Some UCAV designs include tilt-rotor or helicopter technologies; however, most are of a fighter aircraft design. Both attack helicopters and fighter aircraft are CFE-controlled weapon systems. UCAVs could be subjected to the treaty, either inclusively as part of a nation's fighter aircraft holdings or as a new category of systems. Treaty limits on fighter aircraft holdings are well above current inventories of almost all signatories. Therefore, if UCAVs were declared fighters under the treaty definition, there would be little concern that they would displace manned systems. More likely, as UCAV employment becomes more proximate, there will be sentiment to amend the treaty to track them under a new definition. Except in Europe, no conventional forces treaties would limit UCAVs.

Technology transfer. Some technology transfer will be necessary if allied UCAV programs are to keep pace with U.S. programs. Technologies subject to export controls and limitations on foreign military sales, including some components and complete systems packages, are annually reviewed under the Defense Technologies Support Initiative of 2000. Industry will seek overseas sales within the law, and allied access to UCAVs will improve their capability to close the UCAV technology gap. The main concern is to guard against risks to national security through technology transfers that end up in the hands of adversaries.

NATO UCAV capability, standards, and interoperability. The Alliance might be moved to invest in UCAVs as a NATO rather than member-owned resource. However, NATO is more prone to negotiate a common standard and encourage its members to design their national systems to Alliance specifications to achieve interoperability. Unless NATO can set and adhere to standards for essential functions, such as secure data transfer and discreet target designation, national systems would not be interoperable in a military operation.

Levels of UCAV autonomy. Autonomy is a policy issue and an operational factor as well as a technological challenge. On the policy level, there are concerns about "robotic warfare": warfare conducted by machines that seek, locate, identify, and attack targets without a person in the loop for decisionmaking. Therefore, a key policy issue to consider as UCAVs are designed and tested is balance between autonomy and MITL control. Scenarios could arise in which one target must be distinguished from another. Policymakers have become more sensitive to these issues than in the past. During the Vietnam War, engagement with unobserved fires (such as artillery or bombs) was routine when unattended ground sensors activated deep in enemy territory. UCAVs should reach a higher level of target assurance than these older systems and methods. The incorporation of decision aids for information synthesis and decision support will be essential to rapid identification of targets and options. Policymakers have a strong bias to build a minimum MITL component into all UCAV systems.

Acquisition strategy. The debate over UCAV cost remains unsettled, yet the context for near-term investment under the Quadrennial Defense Review 2001 is becoming more definitive. The present issue is development and procurement, and these are the arenas in which UCAV investments must compete head-on with such systems as the V–22, Joint Strike Fighter, F–22, and Comanche. The defense budget has increased for 2001 and is forecast to increase further in the next two budget years. However, the highest priorities are for personnel-related investment, homeland security, and missile defense, with fewer increases for development and procurement. This means that the services will face tough choices in supporting UCAVs in spite of their potential to revolutionize warfare. Strategies devised to pursue UCAV development and acquisition in this environment may include limited-mission technology demonstrators and the use of manned/unmanned aircraft to test subsystems and concept integration methodologies. However, initiatives for promising future technologies should not be cancelled.

Civil airspace safety and control. A more pressing challenge is to integrate unmanned aircraft into U.S. and international civil airspace in a way that does not degrade the safety of civil aviation. So

Priority Technologies

■ *Intelligent autonomy* to accomplish complex missions with minimal continuous human intervention. Technologies include behavior-based intelligence, pattern recognition algorithms for combat identification, real-time mission and route planning, decision aids, and operator displays.

■ *Network connectivity* for dynamically managed, interoperable, high-capacity connectivity between UCAVs, manned aircraft, UAVs, off-board sensors, and ground stations. Technologies include broadband all-weather secure data links, distributed high-speed processing, and data compression algorithms.

■ *Airspace management* for operation in a civilian airspace environment. Technologies include precision navigation and space/time positioning, anti-jam GPS, collision avoidance sensors and controls, and precision all-weather landing aids.

■ *Platform and platform components* to enhance maneuverability, endurance, payload, and survivability beyond the capability of manned aircraft. Technologies include power and propulsion, signature reduction, vehicle management, and fault-tolerant flight and systems control.

■ *Weapons and targeting* that are compatible with an unmanned aircraft. Technologies include fire-and-forget weapons and human-computer interfaces to support MITL decision authority.

far, UCAVs and UAVs have operated solely in airspace restricted from civil use with significant advanced written notification that can be widely disseminated. The FAA and its international counterpart, the International Civil Aviation Organization (ICAO), have safety as their primary concern. All military aircraft, including unmanned, must adhere to the fundamental rule of "see and avoid" when the aircraft is clear of clouds. Deployment of UCAVs to exercises or actual operations would require coordination with the FAA and ICAO, and it poses significant technology challenges.

Operational Issues and Challenges

UAV missions. UAV missions have developed through operational experience to include:

- Crisis monitoring in nonpermissive environments
- Pre-air-superiority situations
- Peace operations surveillance, intelligence, operational, and strategic reconnaissance
- Target acquisition and designation
- Real-time operational and tactical battlefield decision support nodes.

UCAV Air Force/Navy missions. SEAD missions in support of manned aircraft strikes against operational or strategic targets are the most apparent UCAV mission for first-generation platforms. These missions are high risk but essential for penetration air attacks. UCAVs could also be used for deep strikes themselves, including reconnaissance-strike missions and strikes against fixed or mobile (versus moving) targets, such as enemy C^3I or logistics nodes. UCAVs might be employed for strategic strike missions, such as the 1986 raid on Tripoli, Libya. They could be used with cruise missiles for greater assurance of target destruction in preemptive strikes or for counterstrikes.

Unique Navy UCAV missions. The Navy has special UCAV design and mission requirements because of the need to operate from aircraft carriers. UCAV–Ns will have to be multimission assets, capable of both UCAV and UAV missions to conserve limited deck and hold space aboard ships. They will need the rugged launch and recovery, electromagnetic pulse shielding, and greater corrosion protection characteristics of other carrier aircraft designed into all systems. The Navy may push faster than other services to employ UCAVs in routine patrolling missions with long loiter times, such as antisubmarine warfare, electronic warfare, or carrier air cover. That use could free up manned systems and increase the offensive capabilities of aircraft carriers.

Army UCAV missions. The augmentation of Army aviation (attack helicopters) with Army-owned and -operated UCAVs will be less immediate because Army missions will require more advanced capabilities than envisioned for first-generation UCAVs. The Army employs armed aircraft (helicopters and other service high performance aircraft) for close air support of ground troops or for relatively close-in armed reconnaissance intended to develop the immediate situation. Using unmanned aircraft for either mission would require close coordination under rapidly changing combat situations. Although such capabilities eventually will come, they are not entry-level UCAV missions. One near-term mission worthy of study is UCAV employment in nonpermissive tactical scenarios where ground troops are not present, such as the 1999 situation in Kosovo that prevented the commitment of AH–64 Apache helicopters.

Airspace coordination. A combination of procedures and technologies will have to be assembled to allow UCAVs to operate in the same airspace as manned systems and other systems, such as cruise missiles, artillery and naval gunfire, bombs, laser designators, helicopters, and even weather balloons. Other coordination challenges include ingress and egress across friendly lines where air defenders track and engage unidentified targets, overflight of firing batteries, mortars, helicopter refuel/rearm points, and a host of other danger points that are constantly relocating on the battlefield. Continuous availability of accurate information is key, as is the use of coded on-board interrogation equipment such as identification, friend or foe (IFF) systems.

UCAV command and control (C^2). All resources should be coordinated at the air operations center, even if different members of a joint or multinational task force deploy several different UCAV and UAV systems. UCAVs should be integrated into the air tasking order like any other strike or support air asset. However, that integration will be complicated if each system is designed to respond to its own discrete controller, unable to accept hand-off to a single integrator at the air operations center. Discrete controllers might mean deploying

Policy Issues

■ *Research and testing* must be a joint service effort with key program leads for both the Air Force and unique Navy applications. The Army and Marine Corps should be involved throughout as supported services, at least for initial investment programs.

■ *Interoperability with NATO and other allies* will be crucial to UCAV employment in combined operations. However, UCAVs and other new systems should seek interoperability in new ways: through incorporation of interface software that allows them to exchange secure data from other systems, similar to Apple Computer interface software that allows its computers to use PC programs and files.

■ *Monitoring arms control implications* should be based on the premise that UCAV design has evolved sufficiently to conclude that these systems are aligned with fighter aircraft and not cruise missiles for the purposes of arms control. UCAVs may eventually be subject to the CFE Treaty but should not be subject to the INF Treaty. Whether UCAVs would be considered fighter aircraft or a new category of weapon is still undetermined.

■ *U.S. export controls* that restrict the dissemination of UCAV technologies will work against allied forces acquiring UCAV capabilities but may be required in some instances for national security reasons. Export controls that apply to emerging UCAV technologies will have to be studied and modified where possible to accommodate technology sharing.

■ *UCAV technology investments* must be prioritized to align with roles and missions evolution, both within programs for UCAV development and within the broader context of overall science and technology investments. Cost savings for UCAVs are less likely in the areas of development and procurement but increase significantly in the area of operation and support.

Operational Considerations

■ *Mission capability, force integration, and base logistics requirements must be clarified*.

■ *UCAVs must be integrated into operational command and control and air tasking orders*, including the optimum control architecture and methods for mission changes.

■ *UCAVs must be integrated into joint and combined airspace management doctrine/systems* without degradation to other users: manned aircraft, helicopters, artillery and missiles, and UAVs.

■ *An operational concept for employing UCAVs in combined operations with allies must be agreed upon*, including common operational doctrines, combat identification systems, and procedures.

■ *UCAV impacts on deployment and sustainment systems must be defined*, from global to tactical support.

■ *UCAV mission planning requirements must be determined*, such as key mission profiles, information requirements, response times, and onboard/offboard reprogramming requirements.

a host of UCAV/UAV controller facilities with each air operations center, burdening theater (and strategic) logistics as well as slowing command and control. UCAVs should be capable of rapid mission change, from mission abort orders to redirection to more urgent targets. To do that, they need to incorporate links that can accept mission changes from the central air operations center, AWACS, or other controlling agency, not solely from system-discrete protocols.

Unmanned combat aerial vehicles are new technologies currently being designed, simulated, and demonstrated. Each of the services has its own program, as do several U.S. allies and other countries. In order for the United States to achieve its goal of fielding UCAVs within a decade, significant technical issues must be solved; for example, the situational awareness picture presented by current "soda straw" optical systems must be expanded, and the reliability of propulsion and flight control systems must be improved. Policy questions—such as how UCAVs should be classified under arms control agreements—and operational challenges—such as UCAV integration into the overall battle plan—need to be resolved. Yet sufficient progress is being made in all of these areas, and meeting the goal of UCAV deployment within the decade seems feasible.

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