Unmanned Aerial Vehicles/ Unmanned Combat Aerial Vehicles

Likely Missions and Challenges for the Policy-Relevant Future

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Editorial Abstract: Mr. Pardesi analyzes the strategic implications of unmanned aerial vehicles (UAV) from a Singaporean point of view and concludes that UAVs' lack of situational awareness and need for ever-larger amounts of communication bandwidth are major drawbacks that can be partially compensated for by various means. However, the author concludes that UAVs will complement, but not replace, manned aircraft.

Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.

—Giulio Douhet

THE ABSORPTION OF modern information and communications technologies (ICT) has transformed the US military. Unmanned aerial vehicles (UAV) and unmanned combat aerial vehicles (UCAV) are playing a crucial role in this transformation, as they provide the military with a new platform that exploits the advances in ICTs. At the same time, they are integral to the concept of networkcentric warfare. Although interest in UAVs is as old as the history of manned aviation, UAVs started making news due to their military effectiveness in recent conflicts such as Afghanistan (2001) and Iraq

(2003). The Afghanistan campaign highlighted the growing role of UAVs because it was in Afghanistan that the UAVs actually started attacking targets in addition to performing their primary mission of intelligence gathering and guiding weapons to their target.[1]

This article seeks to answer whether UAVs represent a truly disruptive technology. What will be the impact of UAVs on manned aircraft, and how does the increased use of unmanned platforms alter the strategic landscape? To this end, this article will examine various air operations—intelligence, surveillance, and reconnaissance (ISR); suppression of enemy air defenses (SEAD); and counterair—to establish the disruptive impact of UAVs, if any. This research will also briefly discuss how miniature/micro aerial vehicles (MAV), which are a subset of UAVs, are likely to be deployed on the battlefield.

UAVs, UCAVs, and MAVs

The US Department of Defense (DOD) defines a *UAV* as "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 nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles."[2] While the idea of removing the pilot from the cockpit may be conceptually simple, the UAV presents an operational challenge, as it is a system designed to fly in a hostile environment. Conventional wisdom states that removing the pilot from the aircraft would mean that the extensive and expensive life-support equipment is not needed, thereby making the UAV more cost-effective.

Even though the UAV concept seems somewhat revolutionary in nature, it is not new. The first heavier-than-air, sustained, powered flight was achieved by a pilotless aircraft when Dr. Samuel Pierpoint Langley launched his steam-powered aircraft over the Potomac River on 6 May 1896, for a flight lasting over one minute.[3] After the Wright brothers' first piloted, powered flight on 17 December 1903, unmanned aviation took a backseat to manned aviation. While continuously maintaining a general interest in unmanned technologies, the United States devoted most of its time and resources to developing manned aircraft in the twentieth century. This was primarily a result of the fact that unmanned platforms represented an immature and relatively expensive technology.

Although the United States used UAVs for operational reconnaissance missions in Vietnam, it was Israel's successful use of UAVs during operations in Lebanon in 1982 that ignited American interest in this system.[4] The US Navy acquired the Pioneer UAV from Israel and used it to provide tactical-level intelligence during Operation Desert Storm in 1991.[5] During Operation Enduring Freedom in Afghanistan, the Predator UAV started performing "armed reconnaissance" missions as mentioned earlier, and the Global Hawk UAV made its debut in the skies over Afghanistan in 2001 even though it was an experimental system then.[6] The Predators continued their combat role by attacking high-value targets in Iraq in 2003. Surveillance UAVs also helped US special forces in preventing Iraqis from launching any hidden Scud missiles.[7]

The United States is also heavily investing in a new class of unmanned platforms—MAVs. They are roughly two orders of magnitude smaller than manned systems (some as small as six inches). These compact, lightweight air vehicles carrying miniature sensors are playing a key role in the war against terrorism.[8] While MAVs are more vulnerable to attack and loss due to their low altitude, this is offset by the fact that they are extremely stealthy and very cheap. Their compact size and low weight will allow them to be carried by individual soldiers. The US Air Force is deploying MAVs for force protection in the shape of Lockheed Martin's SentryEye.[9]

Roles and Missions

While there is a good deal of confidence in the underpinning technology of unmanned platforms, there is a great deal less certainty surrounding their roles and missions. UAVs/UCAVs are likely to play a key role in mission areas commonly categorized as "the dull, the dirty, and the dangerous."[10] This section discusses some of the more important air missions (ISR, strike/SEAD, and counterair) to determine if UAVs/UCAVs can replace manned platforms in some or all of these roles. This will also include a short analysis of the role of MAVs on the battlefield. It must be pointed out that the move towards unmanned platforms is not necessarily due to the inadequacy of manned aircraft. Rapid technological advancement over the past decade has led to a "technological push" in this direction. Moreover, since the end of the Cold War, the United States has been attempting to replace manpower with technology, mostly because it retains strategic interests in every corner of the globe but is increasingly hesitant to commit its military personnel for many of these missions. The move towards the unmanned platform is a result of all these developments.

Intelligence, Surveillance, and Reconnaissance

UAVs have been traditionally used as ISR assets, and their ability to do so is being boosted by advances in sensors and modern ICTs. For the United States, ISR collection is a critical factor in achieving the *Joint Vision 2020* operational concept of "precision engagement."[11]

During the Vietnam War, the photos provided by the Ryan 147 Lightning Bug—a reconnaissance UAV—revealed precise locations of surface-to-air missile (SAM) sites, enemy airfields, ship activity in Haiphong Harbor, and battle damage assessment (BDA), intelligence that otherwise would have been obtained only if manned aircraft were sent in harm's way.[12] In Desert Storm, the Pioneer UAV contributed to the tactical successes of the US Navy and Army by playing an important role in target designation, damage assessment, and reconnaissance.[13]

In Afghanistan, Global Hawk was used for reconnaissance prior to strikes and for post-strike BDA.[14] The Predator was used in Afghanistan to feed imagery to AC-130 special operations gunships and special operations teams on the ground.[15] Global Hawk accounted for only 5 percent of intelligence sorties during Operation Iraqi Freedom but produced 50 percent of the information on time-sensitive targets.[16] UAVs retreated to their traditional role of reconnaissance in Iraq in spite of some successes in combat roles in Afghanistan. A dozen UAVs launched 115 Hellfire missiles and laser-designated 525 targets in Afghanistan. In Iraq, where more than 56 larger UAVs and more than 60 smaller portable ones were used, UAVs launched only 62 Hellfires and laser-designated only 146 targets. The main reasons for this disparity were Iraqi winds and sandstorms—these aircraft are much lighter than their manned counterparts—and the increased need for intelligence in the Iraqi campaign.[17]

UAVs face two competing systems for performing ISR missions: manned platforms and satellites. While providing a significant improvement in information-collection capability over these systems, UAVs also pose some serious limitations.

Large and manned aircraft, capable of carrying Airborne Warning and Control Systems (AWACS) and Joint Surveillance Target Attack Radar Systems (JSTARS), have limited maneuverability and self-defense. Unlike the loss of UAVs, loss of these expensive manned systems is likely to cause severe domestic political repercussions for the United States. However, given the current state of technology, UAVs cannot completely replace AWACS and JSTARS manned aircraft in ISR missions. The military is seeking sensors with high-definition television standards, foliage-penetration radar with hyperspectral imagery, synthetic-aperture radar, and moving-target indication mode to track targets in all types of terrain throughout the spectrum of military operations.[18] Advanced sensor technology is still under development, and it is not sufficiently developed to perform the complex battle management and command and control functions handled by AWACS and JSTARS personnel. Due to their inability to absorb data and reason (at least for the foreseeable future), UAVs cannot process and relay the same amount of data as a pilot in the cockpit (who can do so by learning, experiencing, and intuition) and cannot maintain a 360-degree situational awareness (SA).

Manned missions provide high-resolution data and are extremely flexible at adapting to multiple-mission scenarios; however, their main limitation is their loiter time. UAVs, on the other hand, are capable of long loiter times; are smaller and hence stealthier than manned platforms; are much less costly to procure, operate, and support; and avoid putting pilots at risk. However, fast jet-based tactical reconnaissance remains a much sought after, but scarce, capability for UAVs.[19] The use of Global Hawk, Predator, and JSTARS systems (i.e., both manned and unmanned platforms) was the key factor behind the shattering of the Republican Guard and the success of the Scud-suppression campaign in western Iraq during Iraqi Freedom.[20] It is possible that in the future, UAVs will be faster and more maneuverable; however, there are trade-offs as higher speed creates penalties for loiter time, one of the biggest assets of unmanned platforms.

Desert Storm highlighted the pivotal role that satellites will have in future conflicts. However, UAVs have a major advantage over satellites in addition to being cheaper, as it is easier to alter their flight paths and coverage. Moreover, they provide a comparatively cost-effective method of collecting ISR. UAVs have an additional advantage of being able to fly closer to the target.[21] However, the major drawback with UAVs, as mentioned previously, is their lack of SA. This weakness can be overcome by integrating UAVs with reconnaissance satellites, but this creates an additional problem. High data rates (bandwidths) are essential for real-time interactive command and control systems like flight controls, video reception, and transmissions. UAVs are major consumers of bandwidth.[22] Since 11 September 2001, the US bandwidth requirement has increased eightfold due to the war in Afghanistan and the pursuit of terrorists in the region.[23] Stationing the mission control on a standoff aircraft (within line of sight) would decrease the dependency on satellites generated by stationing the mission control on the ground thousands of miles away. Autonomous UAVs will also require less bandwidth as more data will be processed on board.[24] Moreover, since UAVs fly in close proximity to the target, they would need to have a high signal-to-noise ratio (especially if they are flying far from their control station), thus increasing their possibility of detection.

MAVs have tremendous potential for ISR operations. In the battlefield, they are likely to be operated by individual soldiers for local reconnaissance. MAVs integrated with a high-flying UAV will circumvent the need to develop foliage-penetration sensors. They will also play an important role in urban operations, which may require stealthy airborne assets closer to the ground. At sea, MAVs can also be deployed from ships to gather intelligence to prevent acts of maritime terrorism. They may also be fielded in a hostile environment to detect people equipped with shoulder-fired missiles to attack aircraft. MAVs shall play an important role in real-time detection and analysis of a biological or a chemical agent in an infected environment. They are also likely to play an important role in humanitarian missions (e.g., searching for survivors amidst rubble from earthquakes).

The way forward is to integrate manned, unmanned, and satellite-based sensors to create a common operational picture of the battlefield. Development of ICTs and software algorithms to integrate the data provided by the three platforms will be crucial to ISR operations in the future. The information-collection system of the future is likely to be based on space assets providing wide-area surveillance at a low level of resolution, but looking for cues that require detailed monitoring. Manned and unmanned vehicles will perform this detailed monitoring.

Armed Reconnaissance and Suppression of Enemy Air Defenses

US military strategy following the embassy bombings in Africa focused on targeting Osama bin Laden and his training camps with Tomahawk land attack missiles (TLAM). This strategy did keep US troops out of harm, but it suffered from many operational limitations. The most important of these was the long delay between acquiring reliable intelligence on the precise location of time-sensitive targets (from the skies over Afghanistan) and the execution of an actual cruise missile attack (from ships in the Arabian Sea). The United States was looking for an "armed reconnaissance" platform to strike time-sensitive targets. Technological momentum led the US Air Force to fit two 45-kilogram (kg), laser-guided Hellfire-C missiles to a Predator UAV.[25] On 15 November 2001, two Hellfire missiles launched from a Predator, killing Muhammad Atef, al-Qaeda's chief of military operations.[26] This was the first use of the Predator as a weapons platform. On 3 November 2002, almost a year later, a CIA-operated armed Predator flying over Yemen, with Yemen's approval, killed a top al-Qaeda operative, Ali Qaed Sinan al-Harthi, and his five companions traveling in the same car.[27] By performing successful "strike" missions, these incidents demonstrated the usefulness of armed UAVs in the global war against terrorism. These strike missions opened up a debate on a possible new role for the armed UAVs—SEAD.

The US DOD defines the term *SEAD* as an "activity which neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means."[28] The Predator UAV was credited with two strikes in Iraqi Freedom in March 2003—one strike was against an antiaircraft vehicle while the other was against a television satellite dish in Baghdad.[29] The United States is currently developing a new version of the armed Predator UAV, called Predator B, which will have the capability to carry eight Hellfire missiles instead of two.[30] The United States is also developing newer platforms—UCAVs—with a primary offensive mission of strike and SEAD. To determine the efficacy of the unmanned platform in a SEAD role, the United States will need to consider two rival challenges: the adoption of new countertactics by its opponents and the development of new antiair systems.

Today, the United States relies exclusively on the F-16 and the Navy's EA-6B for defense-suppression missions. The loss of a modern, expensive platform like the F-16 (and its pilot) will be a major political embarrassment for the United States, in addition to being an economic loss. SEAD is an important mission as it helps in attaining "air superiority." The air forces can attack the heart of the enemy (i.e., perform the "interdiction" mission) only after gaining command of the air. However, during Desert Storm, the superstealthy F-117 allowed the United States to hit the enemy's key nodes within the opening minutes of the conflict.[31] In order to avoid a similar fate during the air war over Serbia, the Serbs chose not to deploy a determined air defense system. This enabled them to launch 700 missiles in the course of the 78-day conflict and cause enormous frustration to US Airmen.[32] It was recently reported that the United States was using its drones to scan Iran for nuclear weapons. It is likely that the Iranian authorities did not activate their air defense systems out of the fear of revealing their positions.[33]

In addition to such tactics, the United States is also likely to face "antiaccess-threat systems" like cruise missiles, theater ballistic missiles, and advanced air defense systems. The range of modern SAMs (estimated to be between 50 and 250 miles) is forcing the United States to develop strategies and systems to reduce the risk to its Airmen.[34] Missiles launched from a distance from mobile SAM sites are difficult to detect, and the high speed of newer missiles makes them more maneuverable. This means that the friendly aircraft/UAVs will have a very narrow "escape zone" to avoid the SAMs. Unmanned jet engine *g-forces* (g) limitations ($\pm 12\ g$) do not significantly exceed those of the human pilot (between $-3\ g$ and $+9\ g$) and hence do not substantially increase defensive capability against missiles.[35] The cost arithmetic further complicates the analysis and is not useful in determining the efficacy of UCAVs over current standoff systems like cruise missiles. Joint Direct Attack Munitions employed by UCAVs may be cheap compared to the Tomahawk, but the UCAV, which is an expensive recoverable platform, is likely to suffer considerable attrition due to its proximity to the target.[36] Unmanned systems are "attritionable" but not expendable (i.e., it is fine to lose them only when the alternative to their loss is manned aircraft). Moreover, on an average, unmanned platforms are lost at a much higher rate than manned aircraft.[37]

It makes sense to use low-cost UAVs and/or decoys to locate the positions of enemy SAM sites, which may then be attacked as a part of a "reactive" SEAD strategy.[38] This, together with UCAVs equipped with passive sensors (an extremely stealthy platform), represents an effective counter to mobile defenses. There are, however, several constraints here that must be kept in mind: (1) the primitive nature of current target-recognition programs means that a human operator must be kept in the loop to authorize the "kill," thereby increasing the bandwidth requirements, and (2) integration with other ISR platforms is necessary to locate time-sensitive targets.[39] These constraints put serious limitations on the use of unmanned combat platforms in reactive SEAD missions.

UCAVs are more likely to play an important role in "preemptive" SEAD missions (where the exact locations of enemy SAM sites are known) as opposed to reactive SEAD missions. UCAVs, integrated with manned and unmanned assets like AWACS aircraft, F-16s, F-117s, Global Hawks, and communications satellites, will play a role in future SEAD missions (reducing some risk to manned assets in this high-threat environment); however, they will be only one of many platforms used for this mission. UAVs/UCAVs are nevertheless very suitable for strike missions, especially against a very heavily defended target due to their high level of stealth.

UAVs/UCAVs will also play an important role in electronic-attack missions. However, they will play only a limited role at best, as the future use of electromagnetic-pulse weapons and directed-energy weapons will increase the risk of self-jamming for the unmanned platform itself.

Swarms of MAVs equipped with sensors and miniaturized warheads are theoretically capable of attacking high-value targets such as radars and launchers of SAM sites; that is, they are likely to play an important role in SEAD missions in the future.[40] The global positioning system allows precise autonomous navigation and position reporting for MAVs, which are critical to the military application of these technologies. Some of the limitations of this technology are its short-range and high-damage potential (especially due to the prevailing weather). Microelectromechanical systems, micromanufacturing, and nanotechnology could provide an exponential leap in microminiaturization for weapons, sensors and platforms.[41] However, for operational success, MAVs would have to be integrated with other UAVs or manned aircraft to address the complete operational scenario.

Counterair

In March 2003, a Predator launched a Stinger air-to-air missile at an Iraqi MiG before the Iraqi aircraft shot it down.[42] This has led to the speculation that armed UAVs/UCAVs will play a role in counterair operations (and by extension as air superiority fighters in the future). The US DOD defines the term *counterair* as "a mission that integrates offensive and defensive operations to attain and maintain a desired degree of air superiority. Counterair missions are designed to destroy or negate enemy aircraft and missiles, both before and after launch."[43]

The USAF F-15C, USN F-14A/D, and USN and USMC F/A-18 aircraft were the platforms instrumental in the command of the skies over Iraq during Desert Storm.[44] The same air assets were available during Operation Allied Force for the function of counterair. Lockheed Martin's F-22 Raptor is likely to play the key role in America's air superiority efforts in the years ahead.[45] Stealth, maneuverability, and cost are the most important design prerequisites for air superiority fighters of the future.[46] Whether or not a UCAV will replace the F-22 fighter (a manned platform) is a crucial question as American air superiority in a future conflict depends on the answer to this question. This is also a timely question since the decisions taken today will guide the research, development, production, and training of the new system (manned or unmanned replacement of the F-22 fighter) over the next two decades. Aerial combat is the most challenging mission for manned aircraft to perform, and it is believed that missiles do not always kill the adversary (especially one equipped with significant counterair assets and capabilities like the MiG-29 Fulcrum and the Su-27 Flanker)[47], so close engagements are necessary. Combat survivability remains the most significant limitation to UAV employment.[48] As previously mentioned, limitations imposed by line-of-sight data-transfer requirements will enhance the role of satellite communications. However, the current American and allied satellite communications infrastructure is incapable of supporting any sizable number of UAVs or UCAVs. Global Hawk consumed five times the total bandwidth used by the entire US military in the Gulf.[49] Autonomous systems will reduce bandwidth requirements. However, it is unlikely that the UCAV will replace the manned aircraft in all operations as some politically sensitive targets will still need a human operator to make the "kill decision." Moreover, systems based on artificial intelligence are unlikely to replace the human completely, even though significant developments are likely to occur over the next two decades.

Stealth requirements dictate that the UCAV weapons be small and precise. The weaponization of the unmanned platform for air superiority missions is not likely to happen over the next two decades.[50] In the near future, the UCAV is not likely to have its own air-to-air weapons; that is, no air-to-air weapons are being designed or produced at the moment with the UCAV as the launch platform. For the foreseeable future, the UCAV is going to carry air-to-air weapons like the Sidewinder missile and advanced medium-range air-to-air missile that already exist.[51] UAVs/UCAVs will be used predominantly to provide active sensors against highly lethal antiaircraft weapons in support of inhabited vehicles.[52] UCAVs are unlikely to replace the manned aircraft for air combat missions in the policy-relevant future. The future will see a mix of manned and unmanned platforms together with space weapons in counterair operations.

Conclusions

On the one hand, UAVs enhance the ability of the United States to intervene militarily anywhere in the world whenever its interests are threatened (whether through ISR missions or in a combat capacity through surgical strikes, preemptive SEAD missions, etc.) without putting its forces in harm's way. On the other hand, this possibility will drive certain nations to acquire armed UAVs and/or weapons of mass destruction to oppose a US-led intervention.[53] It must be emphasized that the greatest risk is posed by terrorists' use of armed UAVs. UAVs will also enable regional powers to bolster their power-projection capabilities. India has raised its profile in the Indian Ocean region by operationalizing its first full-fledged UAV base in Kochi where its Southern Naval Command is based.[54]

The UAV is an innovative weapon system that avoids placing a pilot in harm's way, but it is not a truly disruptive technology as there will always be missions that will require the manned aircraft. Likewise, the unmanned platform has less flexibility and greater vulnerability; moreover, it cannot analyze its environment. Furthermore, many advanced unmanned platforms are as expensive as manned aircraft, and their high cost makes them attritionable, not expendable. Their software complexity, automation, and communications architecture make them operationally unreliable for many missions. Thus far, communications technology has limited the effectiveness of the unmanned platform, especially its armed version.

UAVs also face considerable challenge from competing systems like satellites and TLAMs. Satellites not only provide better situational awareness, but also avoid international norms for violating national/sovereign airspace and are thus far invulnerable to shootdown. TLAMs have proven superior in weapon-delivery roles. However, many dull, dirty, and dangerous missions will see an increased role for the unmanned platform.

UAVs are going to perform the critical ISR mission in future military operations where they are likely to fly tactical missions together with their manned counterparts upon obtaining cues from satellites. MAVs with their potential to substantially transform urban operations and special operations missions will see their role enhanced in future conflicts. UCAVs and armed UAVs shall also perform strike and preemptive SEAD missions in the future but are not likely to perform reactive SEAD missions due to the proliferation of sophisticated air defense systems worldwide. They are also likely to play an important, but limited, role in electronic-attack missions. The proliferation of sophisticated counterair assets makes UAVs unsuitable for counterair missions, and communications and automation technology limitations, together with political ones (the authorization to fire), reduce their usefulness for combat missions. It is unlikely that the unmanned platform will make significant inroads into the force-application role in the policy-relevant future.[55]

However, their potential for homeland security and commercial applications will give unmanned platforms prominence in the years ahead. The defense-industrial sector is likely to see an influx of new players from the commercial sector, as advances in unmanned technologies are likely to have important commercial applications. However, unmanned platforms can never replace the manned aircraft, as the unmanned platform is just a machine that takes cues from the environment and follows a predefined set of instructions to react (i.e., it cannot analyze its environment). Even artificial-intelligence systems can at best only improve existing technology; they can never supplant humans because of the uncertainties and rapid changes of war. ❑

Notes

1. Keith Somerville, *US Drone Takes Combat Role*, BBC News Online, 5 November 2002, http://news.bbc.co.uk/1/hi/world/2404425.stm.

2. Joint Publication (JP) 1-02, *DOD Dictionary of Military and Associated Terms*, 30 November 2004, http://www.dtic.mil/doctrine/jel/doddict/data/u/05601.html. Unless stated otherwise, this article uses the phrase "unmanned platform" to refer to UAVs and/or UCAVs.

3. Maj Thomas G. O'Reilly, "Uninhabited Air Vehicle: Critical Leverage System for our Nation's Defense in 2025" (master's thesis, Air Command and Staff College, Air University, Maxwell AFB, AL, 1999), 9–10.

4. Elizabeth Bone and Christopher Bolkcom, *Unmanned Aerial Vehicles: Background and Issues for Congress*, 25 April 2003, 2, www.fas.org/irp/crs/RL31872.pdf.

5. Ibid.

6. John McWethy, "Robo-Planes: Unmanned Aircraft Redefines How Military Wages War," http://abcnews.go.com/sections/wnt/dailynews/roboplane020501.html.

7. Andrew Krepinevich, *Operation Iraqi Freedom: A First Blush Assessment* (Washington, DC: Center for Strategic and Budgetary Assessments, 16 September 2003), http://www.csbaonline.org/4Publications/Archive/R.20030916.Operation_Iraqi_Fr/R.20030916.Operation_Iraqi_Fr.htm.

8. Michael A. Dornheim and Michael A. Taverna, "War on Terrorism Boosts Deployment of Mini-UAVs," *Aviation Week and Space Technology* 157, no. 2 (8 July 2002): 48; and Mark Hewish, "Small, but Well Equipped," *Jane's International Defense Review* 35 (October 2002): 53–62.

9. Hewish, "Small, but Well Equipped," 53–62.

10. Office of the Secretary of Defense, *Unmanned Aerial Vehicles Roadmap, 2002–2027*, December 2002, iv, http://www.acq.osd.mil/usd/uav_roadmap.pdf. Dull missions include missions requiring coverage time beyond the capability of manned sorties. Dirty missions include reconnoitering areas contaminated with radiological, chemical, or biological agents. Dangerous missions include high-risk missions like SEAD with less need for supporting aircraft.

11. Chairman of the Joint Chiefs of Staff, *Joint Vision 2020* (Washington, DC: Government Printing Office, June 2000), 12, http://www.dtic.mil/jointvision/jv2020.doc.

12. Lt Col Richard M. Clark, *Uninhabited Combat Aerial Vehicles: Airpower By the People, For the People, but Not With the People*, CADRE Paper no. 8, College of Aerospace Doctrine, Research and Education (Maxwell AFB, AL: 2000), 15–16.

13. Ibid., 34–35.

14. John Persinos, "Unmanned Aerial Vehicles: On the Rise," *Aviation Today*, 1 February 2002, http://www.aviationtoday.com/cgi/rw/show_mag.cgi?pub=rw&mon=0202&file=0202rorep.htm.

15. Bone and Bolkcom, *Unmanned Aerial Vehicles*, 14.

16. Thomas Donnelly and Michael Vickers, *Iraq: Lessons Learned*, American Enterprise Institute, 8 December 2003, http://www.aei.org/events/filter.,eventID.337/summary.asp.

17. Gail Kaufman, "UAVs Shifted Role in Iraq Operations—Shot Fewer Missiles Than in Afghanistan," *Defense News*, 8 December 2003, http://www.defensenews.com/sgmlparse2.php?F=archive2/20031208/atpc8593809.sgml.

18. Mark Hewish, "Unmanned, Unblinking, Undeterred," *Jane's International Defense Review* 35 (September 2002): 47–55.

19. A Predator is a slow platform that takes 30 minutes to travel 50 nautical miles.

20. Donnelly and Vickers, *Iraq: Lessons Learned*.

21. UAVs within 10 kilometers (km) of an object can resolve to 10 centimeters (cm), and those within one km to just one cm. See Michael O'Hanlon, *Technological Change and the Future of Warfare* (Washington, DC: Brookings Institution Press, 2000), 34.

22. Currently satellites offer low data-transfer rates. For a brief technical description of bandwidth requirements, see Maj William K. Lewis, "UCAV—The Next Generation Air Superiority Fighter?" (master's thesis, School of Advanced Air Power Studies, Air University, Maxwell AFB, AL, 2002), 44–46.

23. Bone and Bolkcom, *Unmanned Aerial Vehicles*, 17–18.

24. Ibid. The Global Hawk is an autonomously, rather than a remotely, piloted vehicle. In spite of this, it still requires multiple-satellite and line-of-sight links for control, in-flight mission reroutings, and the relay-of-sensor data.

25. Dennis M. Gormley, "New Developments in Unmanned Air Vehicles and Land-Attack Cruise Missiles," in *SIPRI Yearbook 2003—Armaments, Disarmament and International Security* (Oxford: Oxford University Press, 2003), 416–17.

26. Ibid., 417.

27. Ibid.

28. JP 1-02, *DOD Dictionary*, http://www.dtic.mil/doctrine/jel/doddict/data/s/05165.html.

29. Bone and Bolkcom, *Unmanned Aerial Vehicles*, 14.

30. Ibid.

31. The F-117, which flew only 2 percent of the total attack sorties, struck nearly 40 percent of the strategic targets. See Thomas A. Keaney and Eliot A. Cohen, *Revolution in Warfare? Air Power in the Persian Gulf* (Annapolis: Naval Institute Press, 1995), 189–93.

32. See Gen John Jumper, "Global Strike Task Force: A Transforming Concept, Forged by Experience," *Aerospace Power Journal* 15, no. 1 (Spring 2001): 27.

33. Nazila Fathi, "Iran Says Pilotless US Planes Are Spying on Nuclear Sites," *New York Times*, 17 February 2005, A-16.

34. Countering "antiaccess" threats implies a capability to operate from well outside an enemy's defenses. See John A. Tirpak, "The Double Digit SAMs," *Air Force Magazine* 84, no. 6 (June 2001): http://www.afa.org/magazine/june2001/.

35. Airframes and mechanical components can be designed to operate out to the ±20 *g* envelope. See Lt David Bookstaber, USAF, "Unmanned Aerial Combat Vehicles—What Men Do in Aircraft and Why Machines Can Do It Better," *Air and Space Power Chronicles*, June 2000, www.airpower.maxwell.af.mil/airchronicles/cc/ucav.pdf. However, designing jet engines that could withstand ±20 *g* would require billions of dollars in development or would produce limited thrust-to-weight ratios (speed). Moreover, sensor-technology limitations are unlikely to allow the vehicle to maneuver in the proper direction at the proper time. See Thomas P. Ehrhard, "Unmanned Aerial Vehicles in the United States Armed Services: A Comparative Study of Weapon System Innovation" (PhD diss., Johns Hopkins University, 2000), 574.

36. Joint Direct Attack Munitions employed by UCAVs have a unit cost of $21,000 compared to $600,000 for a Tomahawk cruise missile. See Col Robert E. Chapman II, "Unmanned Combat Aerial Vehicles: Dawn of a New Age?" *Aerospace Power Journal* 16, no. 2 (Summer 2002): 60–73. However, UCAVs will need to fly closer to the target and are not inexpensive. The Joint Strike Fighter will have a flyaway cost of $35 million, and it is estimated that the Defense Advanced Research Projects Agency/Boeing X-45 UCAV will cost about $25 million. See Bill Sweetman, "UCAVs Grow Fat on Requirements," *Jane's International Defense Review* 36 (1 May 2003): 44–47.

37. The crash rate of a Predator is an order of magnitude higher than that of the F-16. Moreover, a large number of crashes are due to human-operator error. See Sweetman, *UCAVs Grow Fat on Requirements*, 44–47.

38. There are two categories of SEAD missions—reactive and preemptive. For a detailed analysis of the usefulness of UCAVs for SEAD missions, see Lt Col Robert E. Suminsby Jr., "Fear No Evil: Unmanned Combat Air Vehicles for Suppression of Enemy Air Defenses" (master's thesis, Air War College, Air University, Maxwell AFB, AL, 2000).

39. It is unlikely that political and military authorities would leave the "kill" decision to automated systems, for such a move would empower a machine to autonomously make the decision to kill a human. Moreover, there would be significant political backlash if autonomous machines hit innocent civilians by mistake, for example, during an operation in an urban area. The time for imagery transmission will depend on the bandwidth. Moreover, the time for human decision making is a major unknown. These delays can prove fatal under the high-threat SEAD environment. Also, the size of a deployed UCAV fleet is a major concern as it increases bandwidth requirements. Integration with satellites for data transmission will be essential for UCAV command and control.

40. Hewish, "Small, but Well Equipped," 53–62.

41. For the potential military applications of MAVs, see Timothy Coffey and John A. Montgomery, "The Emergence of Mini UAVs for Military Applications," *Defense Horizons*, December 2002.

42. David A. Fulgham, "Predator's Progress," *Aviation Week and Space Technology* 158, no. 9 (3 March 2003): 48. See also David A. Fulgham, "Stinger Eyed for UAV Role," *Aviation Week and Space Technology* 156, no. 9 (4 March 2002): 44.

43. JP 1-02, *DOD Dictionary*, http://www.dtic.mil/doctrine/jel/doddict/data/c/01329.html.

44. Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report* (Washington, DC: Government Printing Office, 1993), 56.

45. See *F-22 Raptor*, http://www.fas.org/man/dod-101/sys/ac/f-22.htm.

46. Stealth enhances survivability before engagement, and maneuverability enhances survival while engaged.

47. The proliferation of advanced S-300 and S-400 integrated air defense systems is also a serious concern for Americans.

48. The low altitude of tactical UAVs makes them susceptible to small-arms fire. Strategic UAVs fly higher but at speeds observable by radar. Moreover, they may be within the range of modern SAMs. See Maj Ronald L. Banks, "The Integration of Unmanned Aerial Vehicles into the Function of Counterair" (master's thesis, Air Command and Staff College, Air University, Maxwell AFB, AL, 2000), 18.

49. See Lt Col Kurt A. Klausner, "Command and Control of the Air and Space Forces Requires Significant Attention to Bandwidth," *Air and Space Power Journal* 16, no. 4 (Winter 2002).

50. Lewis, "UCAV—The Next Generation," 50.

51. Ibid., 52.

52. Manned platforms will mostly rely on passive sensors.

53. At least 40 countries have produced more than 600 different types of UAVs, many with ranges in excess of 300 km. See Gormley, "New Developments," 410.

54. Josy Joseph, *Navy to Use UAVs to Spy on Sea-Lanes*, 29 December 2003, http://www.rediff.com/news/2003/jan/31uav.htm.

55. However, advances in nanotechnology have the potential to boost the role of the unmanned platform (MAVs) in a combat mission.