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ENHANCING AIR POWER'S CONTRIBUTION AGAINST LIGHT INFANTRY TARGETS

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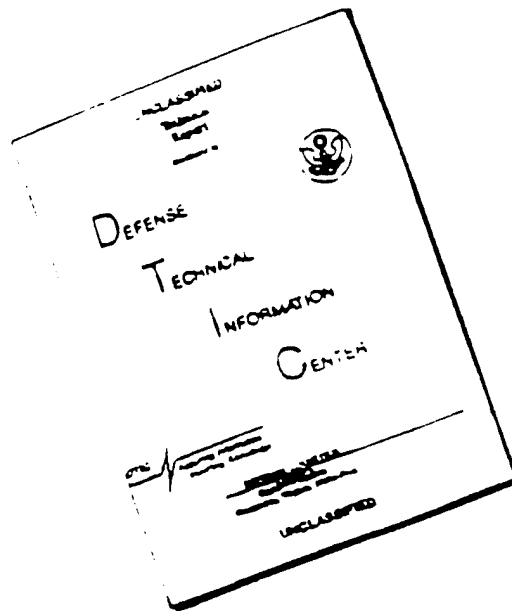
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Abstract: In reviewing the history of the USAF in lesser conflicts, the authors of this report were struck by two facts: (1) The USAF has faced light infantry opponents (or light forces) many times over the years and (2) it is increasingly being called upon to detect and engage such forces (e.g., in Somalia and Bosnia). Despite the salience of this target set, light forces have received little attention from the USAF or aerospace community since the end of the Vietnam War. Although R&D has not been directed at this specific problem, the project team believed that many of the sensor programs designed to detect critical mobile targets or armor could be applied to infantry also. Major advances in detector material design and fabrication, combined with 30 years of progress in the computer field, suggested to the authors that, if it desired, the USAF could make a great leap forward in offensive capabilities against light infantry by applying technologies already developed for these other purposes. The objective of this effort was to explore the signatures and vulnerabilities of adversary light forces, to identify promising sensor and weapon technologies applicable to this target set, and to develop new concepts of operation (OPCONs) that would bring together sensors, weapons, aircraft, and tactics to defeat this opponent. This report presents the results of that effort, including 12 such OPCONs. It should be of interest to USAF personnel in operations, plans, intelligence, and acquisition billets. It also may interest Army, Navy, and Marine aviators, the Special Operations community, and scientists at DoD laboratories.

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PREFACE

In a previous project, Project AIR FORCE investigated the role of the United States Air Force (USAF) in crises and lesser conflicts (see Carl H. Builder and Theodore Karasik, *Organizing, Training, and Equipping the Air Force for Crises and Lesser Conflicts*, Santa Monica, Calif.: RAND, MR-626-AF, 1995). In reviewing that and other work on the history of the USAF in lesser conflicts, the authors of this report were struck by two facts: (1) The USAF has faced light infantry opponents (or light forces) many times over the years and (2) it is increasingly being called upon to detect and engage such forces (e.g., in Somalia and Bosnia). Despite the salience of this target set, light forces have received little attention from the USAF or aerospace community since the end of the Vietnam War. Although R&D has not been directed at this specific problem, the project team believed that many of the sensor programs designed to detect critical mobile targets or armor could be applied to infantry also. Major advances in detector material design and fabrication, combined with 30 years of progress in the computer field, suggested to us that, if it desired, the USAF could make a great leap forward in offensive capabilities against light infantry by applying technologies already developed for these other purposes.

The objective of this effort was to explore the signatures and vulnerabilities of adversary light forces, to identify promising sensor and weapon technologies applicable to this target set, and to develop new concepts of operation that would bring together sensors, weapons, aircraft, and tactics to defeat this opponent. This report presents the results of that effort. It should be of interest to USAF personnel in operations, plans, intelligence, and acquisition billets.

It also may interest Army, Navy, and Marine aviators, the Special Operations community, and scientists at DoD laboratories.

This study was conducted as part of the Strategy, Doctrine, and Force Structure Program of Project AIR FORCE and was sponsored by the Director of Plans, Headquarters, U.S. Air Force (AF/XOX).

PROJECT AIR FORCE

Project AIR FORCE, a division of RAND, is the Air Force federally funded research and development center for studies and analysis. It provides the Air Force with independent analyses of policy alternatives affecting the development, employment, combat readiness, and support of current and future aerospace forces. Research is carried out in three programs: Strategy, Doctrine, and Force Structure; Force Modernization and Employment; and Resource Management and System Acquisition.

In 1996, Project AIR FORCE is celebrating 50 years of service to the United States Air Force. Project AIR FORCE began in March 1946 as Project RAND at Douglas Aircraft Company, under contract to the Army Air Forces. Two years later, the project became the foundation of a new, private nonprofit institution to improve public policy through research and analysis for the public welfare and security of the United States—what is known today as RAND.

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SUMMARY

This report explores the signatures and vulnerabilities of adversary light infantry (or light forces), identifies promising sensor and weapon technologies that could be applied to this target set, and presents 12 new operational concepts that would bring together sensors, weapons, aircraft, and tactics to defeat this opponent.

MAJOR FINDINGS

The report's major findings are as follows:

- Light infantry forces produce signatures that can be detected by airborne and air-implanted ground sensors.¹
- A multiphenomenology approach—combining many different sensor types—offers the highest probability of detecting and identifying enemy light forces.
- Electro-optical sensors on platforms flying at 5,000 feet (ft) above ground level (AGL) and within 2 to 3 kilometers (km) of the target are key to distinguishing between enemy forces and noncombatants and/or friendly forces.

¹Air-implanted ground sensors are dropped by aircraft over areas that friendly forces wish to monitor. Some descend like bombs, implanting themselves in the ground. Others descend by parachute and hang from trees. Using acoustic, video, chemical, magnetic, and seismic sensors, they detect and transmit details of enemy activities.

- The proliferation of advanced manportable surface-to-air missiles (SAMs) will increasingly constrain U.S. Air Force (USAF) operations at these low altitudes.
- Because they can survive at low altitudes, unmanned aerial vehicles (UAVs) will increasingly have to replace manned aircraft as sensor platforms for operations against light infantry.
- Integration of advanced airborne and air-implanted ground sensors, UAVs, and combat aircraft (from all services) can vastly improve air power's contribution against adversary light forces.
- These improvements do not require the development and acquisition of large and extremely expensive or complex surveillance and strike platforms.

NEW CONCEPTS FOR AIR OPERATIONS AGAINST LIGHT INFANTRY FORCES

We developed and evaluated 12 operational concepts (OPCONs) (six near-term [within 5 years] and six far-term [beyond 5 years]) designed to accomplish those combat tasks that the USAF is likely to be called upon to perform in future lesser conflicts (see Table S.1).

Table S.1
Near- and Far-Term Operational Concepts to Accomplish
Six Combat Tasks

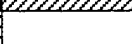
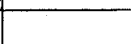
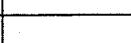
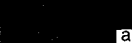
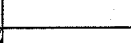
Task	OPCONs	
Locate/destroy light infantry in the open	Near term:	UAV and Tactical Air (TACAIR) team
	Far term:	Ground sensor and TACAIR team
Locate/destroy light infantry in woods	Near term:	Ground forces as sensors
	Far term:	Foliage-penetrating radar on UAV
Locate/destroy heavy weapons in woods	Near term:	Ground counterbattery radar and UAV team
	Far term:	Airborne counterbattery radar
Protect convoy from ambush	Near term:	UAV scouts
	Far term:	Ground sensor monitoring
Locate/destroy urban snipers	Near term:	UAV and Attack Helo team
	Far term:	Acoustic ground sensors
Interdict vehicles re-supplying light forces	Near term:	Joint Surveillance and Target Attack Radar System (JSTARS) and ground force team
	Far term:	Ground sensor array

Near-term OPCONs are limited to systems already deployed, in the acquisition pipeline, or proven in Advanced Concept Technology Demonstration (ACTD) programs. The far-term OPCONs are based on plausible applications of known technologies.²

Our analysis suggests that these OPCONs could significantly enhance air power's ability to detect, identify, and attack light infantry targets. Table S.2 compares the USAF current capability to accomplish the six combat tasks with the capabilities we believe the USAF can achieve

Table S.2
USAF Current Capabilities Compared with Near-Term and Far-Term OPCONs

RANDMR697-T-S.2

Task	Current	Near-Term	Far-Term
Locate/destroy light infantry in the open			
Locate/destroy light infantry in woods			
Locate/destroy heavy weapons in woods			
Protect convoy from ambush			
Locate/destroy urban snipers			
Interdict vehicles resupplying light forces		 ^a	

 Very limited capability  Some capability  Good capability

^aWe rate the USAF capability to interdict vehicles resupplying light forces as very limited, only because we envision the efforts in most lesser conflicts to be more like smuggling (e.g., a relatively small number of commercial vehicles mixed in with civilian traffic) than classic military resupply. If, in contrast, the conflict is akin to Vietnam, with hundreds of enemy trucks traveling down well-defined lines of communication, we would rate the USAF capability to interdict those supply efforts as good.

²The study team did a preliminary feasibility analysis of these technologies, based on our technology survey, interviews, gaming, and some basic calculations. Much more detailed engineering studies and tests would be necessary to determine which, if any, of these OPCONs are both technically feasible and effective under actual operational conditions.

in the near and far term. The technical feasibility of several of the long-term concepts remains to be demonstrated; we have tried, therefore, to be conservative in our assessments. Nonetheless, we believe that both the near-term and far-term OPCODEs are sufficiently promising that the USAF could have a good capability to conduct four of the six combat tasks within a decade if it chooses to pursue these programs.

NEXT STEPS

We recommend that the USAF convene a Light Adversaries Concoivers' Action Group (CAG)³ to address the problem of detecting, identifying, and defeating adversary light forces. The CAG is a team of operators, planners, scientists, engineers, and acquisition specialists who develop and evaluate new operational concepts. The Director of Requirements (AF/XOR) on the Air Staff and the Director of Requirements for Air Combat Command (ACC/DR) are two possible sponsors for this Light Adversaries CAG.

The CAG could use the operational concepts in this report as a starting point. After identifying a set of promising OPCODEs, the CAG would then propose additional tests, exercises, and evaluations. The CAG would also identify doctrinal and command-control-communication issues raised by these new OPCODEs. It is our hope that the CAG report, tests, and exercises would convince a major user—such as the Air Combat Command—to take the next steps to turn these concepts into fielded capabilities.

PUTTING THE LIGHT INFANTRY CHALLENGE IN PERSPECTIVE

It is unlikely that, in future lesser conflicts, the USAF will ever deploy an array of sensors so extensive and integrated that local commanders would have a complete view of enemy activities. Nothing equivalent to the Advanced Warning and Control System (AWACS) for air threats or the JSTARS for armored threats is likely to exist in

³See Glenn A. Kent and William E. Simon, *A Framework for Enhancing Operational Capabilities*, Santa Monica, Calif.: RAND, R-4043-AF, 1991.

the world of light infantry. Even if the USAF deployed *all* the sensors described here, along with a large UAV force, some enemy infantry activities would go undetected or unidentified. That is the case for all sensors, including patrols by friendly ground forces. Thus, the question is not whether a multiphenomenology sensor array on UAVs, manned platforms, and ground sensors will give a 90-percent probability of detecting and identifying adversary light forces—which is unlikely. Rather, it is: Can these new technologies be integrated in a way that significantly improves USAF capabilities against light infantry forces at an acceptable cost?

Some conflicts—because of terrain, rules of engagement (ROE), weather, and other factors—will be more amenable to air-only options than others. In some situations (e.g., small units in triple-canopy jungle), enemy ground forces cannot be effectively detected, identified, and attacked from the air; so friendly infantry would be required to accomplish one or all of these tasks. Although overlaps with Army tactical surveillance assets would have to be worked out, most of the sensors and concepts discussed in this report could be applied to close support and other air operations supporting friendly ground forces.

One thing is certain. The role of air power against light forces is likely to remain small if current USAF sensor deficiencies are not corrected. Conversely, the USAF could make a significant contribution in virtually all scenarios if it embraces this mission area and pursues the possibilities described in this report.

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ACRONYMS AND ABBREVIATIONS

AAA	Anti-aircraft artillery
ABCCC	Airborne Command and Control Center
ACC	Air Combat Command
ACTD	Advanced Concept Technology Demonstration
ADAD	Air Defense Alerting Device
AFB	Air Force Base
AGL	Above ground level
AIL	Airborne Instruments Laboratories
AMRAAM	Advanced Medium-Range Air-to-Air Missile
ARPA	Advanced Research Projects Agency
ASARS	Advanced Strategic Airborne Radar System
ATCCS	Air Traffic Control Compliance System
ATR	Automatic target recognition
AWACS	Airborne Warning and Control System
C2	Command and control
C3	Command, control, and communications
CAG	Conceivers' Action Group
CB	Counterbattery
CCD	Charge-coupled device
CM	Countermeasure
DARO	Defense Airborne Reconnaissance Office
DIADS	Distributed Integrated Air Defense System
DoD	Department of Defense
EO	Electro-optical
FAC	Forward Air Controller
FLIR	Forward-looking infrared

FM	Frequency modulated
FMLN	Farabundo Marti National Liberation Front (El Salvador)
FolPen	Foliage-penetrating [radar]
FPA	Focal Plane Arrays
GPS	Global Positioning System
HF	High frequency
HSI	Hyperspectral Imaging
HUMINT	Human intelligence
IADS	Integrated Air Defense System
InSb	Indium antimonide
IR	Infrared
IRCM	Infrared countermeasure
IRLS	Infrared Line Scanners
ISC	Infiltration Surveillance Center
IUGS	Internetted Unattended Ground Sensor
JSTARS	Joint Surveillance and Target Attack Radar System
LADAR	Laser Radar
LGB	Laser-guided bomb
LLTV	Low-light television
LOC	Line of contact
LOCUSP	Low-Cost Uncooled Sensor Prototype
LRF	Laser range finder
LTLW	Less-than-lethal weapons
LWIR	Long-wavelength infrared
MANPADS	Manportable air defense systems
MCT	Mercury cadmium telluride
MLRS	Multiple-Launch Rocket System
MSI	Multispectral imaging
MTI	Moving Target Indicator [radar mode]
NVA	North Vietnamese Army
NVG	Night vision goggles
NIIRS	National Imagery Interpretability Rating Scale
OPCON	Operational concept
PSSM	Precision Standoff Support Munition
PtSi	Platinum silicide
RCS	Radar cross section

R&D	Research and development
RMP	Reprogrammable microprocessor
ROE	Rules of engagement
SACLOS	Semiautomatic command to line of sight
SAM	Surface-to-air missile
SAR	Synthetic aperture radar
SATCOM	Satellite communications
SEAD	Suppression of enemy air defenses
SIGINT	Signals intelligence
SOUTHCOM	Southern Command
SWIR	Short-wavelength infrared
TACAIR	Tactical Air
U.N.	United Nations
UAV	Unmanned aerial vehicle
UGS	Unattended Ground Sensors or Sensor
USAF	United States Air Force
UV	Ultraviolet
UWB	Ultra wide band
VHF	Very high frequency

BACKGROUND

U.S. military forces, doctrine, and strategy are oriented toward the detection, attack, and defeat of relatively large formations of conventional land, air, and sea forces. This orientation is, in part, the legacy of the Cold War, but it also reflects the nature of the threat U.S. forces have previously encountered and could face again in Southwest Asia and Korea. As demonstrated during *Operation Desert Storm*, U.S. air power has proven particularly adept at destroying mechanized ground forces and their related command-and-control, logistics, and industrial infrastructure. In contrast, the U.S. military has found that lighter forces in complex terrain (e.g., urban areas, triple-canopy jungle) are much more difficult to detect and engage.

The U.S. military has fought adversary light infantry forces in many theaters and conflicts.¹ Examples include the Pacific and Italian campaigns in World War II, and the Korean and Vietnam wars, as well as the U.S. interventions in Grenada, Panama, and Somalia. Generally, U.S. light infantry forces, both Army and Marines, did the brunt of the work, often in costly close-in fighting.² Air power played

¹Throughout this chapter, *light infantry forces* and *light forces* are used interchangeably.

²For example, U.S. soldiers participating in infantry combat during *Operation Just Cause* were three times more likely to be wounded or killed than soldiers fighting in the longer-range armored combat of *Desert Storm*. See Kenneth Watman and Daniel Raymer, *Airpower in U.S. Light Combat Operations*, Santa Monica, Calif.: RAND, MR-457-AF, 1994, p. 3.

an important and, at times, decisive, supporting role.³ During the Vietnam War, for example, air power was often the key supporting element: At the tactical level, air power (both rotary and fixed wing) saved small units from annihilation on hundreds of occasions. It also proved decisive at the operational level, saving outnumbered friendly ground forces from defeat at Khe Sanh in 1968 and at Kontum and An Loc during the 1972 Easter Offensive.⁴

In most of these cases, friendly ground forces—or air liaison officers located with them—detected and identified ground targets for attacking aircraft. During the Vietnam War in particular, the airborne Forward Air Controller (FAC), flying low and slow in vulnerable propeller aircraft, also played a vital role, serving as an airborne traffic cop, liaison to ground forces, and independent set of eyes. Airborne FACs, however, had no sensors beyond their own eyes and a set of binoculars. Consequently, while they were able to detect enemy personnel in open areas, they were dependent on ground observers to detect and identify targets in thick woods.

In contrast to the successful operations in support of engaged ground forces, *independent* air operations against non-engaged enemy light forces were hampered by a variety of factors. Primary among those factors were sensor limitations that prevented light infantry forces from being detected and identified in foliage and at night.⁵

³The first known decisive application of air power in support of friendly ground forces was on July 17, 1927, when a garrison of U.S. Marines and Nicaraguan national guardsmen numbering less than 100 men was attacked by an 800-man Sandinista force. U.S. aircraft, strafing and bombing, broke the back of the attack. See Richard Hallion, *Strike from the Sky: The History of Battlefield Air Attack 1911–1945*, Washington, D.C.: Smithsonian Institution Press, 1989, p. 73.

⁴United States Air Force (USAF), *Khe Sanh 22 January–31 March 1968: Project CHECO Report*, Hickam AFB, Hawaii: Headquarters, Pacific Air Forces, 1968; *The Battle for An Loc, 5 April–26 June 1972: Project CHECO Report*, Hickam AFB, Hawaii: Headquarters, Pacific Air Forces, 1973; and *Kontum: Battle for the Central Highlands 30 March–10 June 1972: Project CHECO Report*, Hickam AFB, Hawaii: Headquarters, Pacific Air Forces, 1973.

⁵Independent air interdiction operations against enemy lines of communication were conducted during World War II, Korea, and Vietnam. Considerable controversy remains about the ultimate effectiveness of those campaigns, particularly against light forces. Furthermore, the issue may be moot; recent combat against light forces has offered few opportunities for classic interdiction campaigns. See F. Sallagar, *Operation Strangle (Italy Spring 1944): A Case Study of Tactical Air Interdiction*, Santa Monica,

This challenge is particularly salient today, because U.S. forces are increasingly facing light adversaries in peacekeeping and enforcement operations.⁶ It is likely to continue for three reasons. First, there is little evidence that ongoing ethnic, religious, and separatist conflicts—in which light forces are prominent—will lessen in the near future. Second, the information revolution is undermining elite control in traditional societies, empowering those who would challenge those societies and increasing the possibility for internal unrest and conflict. Third, rapid population growth in the developing world is severely straining resources and leading to disease, famine, and violence. These disparate trends are often mutually reinforcing—as when preexisting tribal conflicts are exacerbated by fighting over scarce food supplies. It appears likely that the international community will continue to selectively intervene in many of these situations to restore order and provide humanitarian assistance. Because of its unique skills in transportation, organization, and combat, the U.S. military can expect to be involved in many such operations.

The United States may also intervene unilaterally to shore up the governments of key allies threatened by insurgent movements. Expanded counterdrug operations, hostage rescue, counterterrorism, and other special operations could all require that the USAF neutralize enemy light forces. Finally, the USAF could face enemy light infantry forces during major regional conflicts in Korea or Iran.

PURPOSE

As U.S. involvement in lesser conflicts has increased, light forces have become the most common opponent force. Yet, the USAF's ability to detect, identify, and attack light infantry forces in dense foliage, rugged terrain, and urban areas is not significantly better than it was during the Vietnam War. This deficiency is in stark contrast to the quantum improvements in USAF combat capabilities against other target sets.

Calif.: RAND, R-0851, 1972, and Eduard Mark, *Aerial Interdiction in Three Wars*, Washington, D.C.: Center for Air Force History, 1994.

⁶See Carl H. Builder and Theodore W. Karasik, *Organizing, Training, and Equipping the Air Force for Crises and Lesser Conflicts*, Santa Monica, Calif.: RAND, MR-626-AF, 1995.

This report is offered as a modest first step toward correcting this deficiency. It is organized around the following questions:

- What are the characteristics of typical adversary light infantry forces and how do they operate?
- What signatures are associated with light infantry forces and operations?
- What sensors—both deployed and in R&D programs—can detect such signatures?
- What airborne platforms are best suited to carry these sensor suites?
- What air defenses will USAF aircraft face in operations against light forces?
- What weapons are most appropriate for light infantry targets?
- How might the identified sensors, platforms, and weapons be combined into concepts of operation?
- What steps can the USAF take to turn the promising technologies and ideas into deployed capabilities?

ORGANIZATION

This report is organized into six chapters and three appendices. This first chapter has presented an overview of the problem. Chapter Two discusses light infantry operations, capabilities, and typical signatures. Chapter Three describes and analyzes sensor technologies most applicable to this target set. Chapter Four describes platforms, weapons, and related devices that can be combined with those sensor technologies. Chapter Five brings the preceding technologies together; it details and evaluates 12 operational concepts (OPCONs) that integrate sensors, platforms, weapons, and tactics to accomplish six combat tasks against light forces. Chapter Six recommends next steps for the USAF to take to turn these promising technologies into field capabilities. The appendices provide additional details on U.S. UAV programs, light infantry air defenses, and UAV coverage potential.

INFANTRY OPERATIONS AND SIGNATURES

INTRODUCTION

Light infantry forces vary greatly in their quality of leadership, organization, training, and equipment. They can be classified into three tiers. At one extreme, the high tier, there are the light infantry forces of the United States, other NATO nations, and Israel. The mainstay of these nations' ground forces is heavy mechanized forces. Light forces are relatively few and are found primarily in elite formations, such as the British Royal Marines, U.S. Army Rangers, German mountain troops, and Israeli paratroopers. These units are well-equipped, well-led, and well-trained. They are backed up by large and sophisticated intelligence, communications, transportation, and fire-support capabilities in their own and sister services. Outside of NATO and Israel, less generously equipped but well-trained and well-led infantry units (the medium tier) are found in countries such as Vietnam. Although lacking the equipment and air support of their U.S. counterparts, these forces have shown that they can, nevertheless, be formidable opponents. Finally, at the lowest tier are the lightly armed fighters of insurgent, terrorist, and militia groups, which are capable of performing only a limited repertoire of missions and are often poorly led, trained, and equipped. However, at close range, even the most ragged force can inflict unacceptably high casualties—as U.S. forces discovered in Somalia on October 3, 1993.

In short, light infantry is the most common type of ground force, found in both regular army and elite formations, national police, and internal security and paramilitary units, as well as in insurgent and

terrorist organizations. This report focuses on the capabilities and operations of the medium- and low-tier infantry forces. It is such forces—exemplified in past conflicts by the Viet Cong, the North Vietnamese Army (NVA), Panamanian Defense Forces, Bosnian Serbs, and Somalia militias—that the United States is most likely to face in future conflicts.

EQUIPMENT

By definition, *light infantry units* travel on foot and are equipped only with manportable weapons such as those listed in Table 2.1. In actual practice, however, “light” forces often make selective use of much heavier equipment.¹ Table 2.2 shows some of the additional equipment that light forces have used in past conflicts or might use in the future.

Light infantry forces may be transported to combat by ship, plane, or truck. Marines routinely arrive by amphibious transport, paratroopers by plane, and airmobile forces by helicopter. During the Falklands War, British light forces were resupplied by helicopter and

Table 2.1

Typical Equipment in a Light Infantry Company

Assault rifles (e.g., M-16s, AK-47s)
Light (5.56mm) and medium (7.62mm) machine guns
60mm or 81mm mortars
Grenades (hand thrown)
Grenade launchers
FM radios (short range, line of sight)
Light antitank weapons or 90mm recoilless rifles
Mines
Night vision goggles

¹In Bosnia, for example, Serb forces were composed of a mix of light, motorized, and heavy forces. In some engagements, a light infantry force would be supported by a few tanks and artillery.

Table 2.2
Supplemental Equipment for Selected Light
Infantry Operations

Heavy machine guns (.50 caliber and larger)
Manportable surface-to-air missiles
Trucks with heavy machine guns or anti-tank weapons
Heavy mortars (120mm)
Towed artillery (105mm or larger)
Towed anti-aircraft artillery
Light to heavy tanks
Armored personnel carriers
Small radars (both ground and air surveillance radars can be carried in a pickup truck)

a few small tracked vehicles.² During the Vietnam War, almost all U.S. operations were resupplied by helicopter. Less-sophisticated forces are likely to use pickup trucks, jeeps, and other vehicles for resupply and other functions. For example, North Vietnamese and Viet Cong forces were supported by a large logistics system comprising hundreds of trucks.

OPERATIONS

Light infantry forces are typically confronted in contingencies (e.g., counterinsurgency or peace operations) in which the rules of engagement are strict, noncombatants and combatants intermingle, and U.S. vital interests are not threatened. Under these conditions, U.S. leaders are generally unwilling to commit large numbers of troops or risk substantial casualties. Operations under these conditions require that casualties—enemy, noncombatant, and friendly—be minimized.

²These Volvo BV202s—essentially large snowmobiles designed to support Royal Marine operations in arctic settings—proved equally effective crossing the Falklands' bogs and soggy peat. See Nick Vaux, *Take That Hill: Royal Marines in the Falklands War*, Washington, D.C.: Pergamon-Brassey's International Defense Publishers, 1986, p. 128.

To illustrate the kind of operations that the USAF might be asked to counter in a future conflict, let us consider the activities of a notional insurgent force. The insurgent force might conduct the following operations:

- Sabotage
- Assassinations
- Patrols
- Ambushes
- Harassment
- Raids
- Major offensives.

Insurgent forces typically operate as small units. Sabotage, assassinations, patrols, ambushes, and harassment operations are all typically done with squad-to-platoon-sized units. Conversely, raids and major offensive operations often require battalion-, regiment-, and even division-sized formations.

Sabotage is most often directed at bridges, power and phone lines, and other economic targets. More-capable insurgents conduct sabotage operations against military targets as well. Assassinations of key political and military leaders are common in insurgencies. Both sabotage and assassinations can be conducted by individuals or by very small units. Patrolling is done to collect intelligence on enemy operations, to protect supply lines and base camps, and in conjunction with political activities (e.g., recruiting, tax collection, propaganda efforts). Ambushes are conducted to maintain the initiative, control territory, demoralize enemy forces, and collect intelligence. Harassment operations use sniper rifles, mortars, recoilless rifles, rockets, and artillery to inflict casualties and to damage facilities; their underlying goal is to undermine the adversary's morale and willingness to fight. Raids are hit-and-run operations conducted against villages, military installations, and economic targets. Their purpose may be to terrorize, collect intelligence, destroy a high-value asset, or capture weapons. They are not intended for holding terrain. Raiding force size is determined by the mission's objectives, terrain, and the capabilities of both attacking and defending forces. Raiding

force sizes typically range from platoon to battalion. Classic Maoist guerrilla doctrine called for major offensives in the final, "conventional" phase of insurgencies. In actual insurgencies, major offensives have occurred at various times, but much less frequently than in conventional warfare.

Virtually all light infantry operations exploit darkness, terrain, and foliage for protection from both air attack and more heavily armed ground forces. Table 2.3 illustrates the distribution of adversary operations in five recent conflicts.

When they are not conducting operations, light forces rest in base camps, villages, and even urban locations. A base camp could be as simple as a few tents or as elaborate as a building and/or tunnel complex complete with major food and weapons caches and a small hospital. Alternatively, light insurgent forces might operate out of villages or urban settings. The traditional model for guerrilla forces is working at a job during the day and slipping out at night to conduct operations. The village model works for slow-paced insurgencies but cannot sustain larger, more-ambitious operations. Larger operations require full-time soldiers, and more equipment and supplies. As the forces become more like regular army units, villages and other civilian locations become less attractive.

SIGNATURES

A typical infantry force produces signatures that can be detected by a variety of sensors. (Table 2.4 lists some of these signatures.) The

Table 2.3
Infantry Operations in Recent Conflicts

Operation	Vietnam	El Salvador	Grenada	Somalia	Bosnia
Sabotage	X	X			
Assassination	X	X			
Patrol	X	X			X
Ambush	X	X	X	X	X
Harassment	X	X	X	X	X
Raid	X	X		X	X
Major offensives	X	X			X

Table 2.4
Signatures Associated with Infantry Forces

Object	Visual	Chemical	Infrared	Electromagnetic	Radar	Acoustic
Personnel	X	X	X		X	X
Radios	X		X	X		X
Vehicles	X	X	X	X	X	X
Weapons	X	X	X		X	X
Structures	X		X		X	
Fires	X	X	X			

most simple visual signature is the infantryman himself. Other visual signatures associated with infantry include trails, disturbed foliage, lights, weapons, equipment, structures, vehicles, smoke, and dust. Chemical signatures include odors produced by people, cooking,³ weapons, explosives, fires, and vehicle exhausts. Infrared signatures include body heat, lights, vehicle engines, generators, laser designators and aimers, fires, structures, dead foliage, trails, and places where vehicles have recently been parked. Infantry radios and man-portable radar transmissions can be detected, and communications can be intercepted. Personnel have low radar cross sections and, therefore, are not ideal targets for radar. Their movement, however, can sometimes be picked up by radars with Moving Target Indicator (MTI) modes. Buildings, equipment, large weapons, and vehicles can produce significant radar returns, even in wooded areas. Finally, voices, motors, radios, gunshots, and construction activity produce noises that can carry significant distances and stand out against the backdrop of natural noises in wild areas.

Clever adversaries will find ways to minimize their signatures and will learn to spoof and defeat some sensors. They cannot, however, hide all their signatures. To some extent, light forces will have to choose between achieving operational objectives and minimizing the risk of exposure. Typically, the more ambitious the operational and strategic objectives, the greater the operational tempo required.

³During the Vietnam War, U.S. reconnaissance patrols detected enemy encampments from the pungent smell of *nuoc-mam*, an oily fish sauce used widely in Vietnamese cooking. See Donald Duncan, *The New Legions*, New York: Pocket Books, 1967, p. 14.

More forces, more operations, more movement, more equipment—all translate into *more* signatures.

In Chapter Three we discuss sensor technologies that can detect these signatures.

INTRODUCTION

Advances in detector technologies and data processing during the past 10 years have combined to make new sensors vastly more capable than those of the past. New detectors, such as infrared focal plane arrays made from gallium arsenide and other exotic materials, offer longer ranges and clearer images. The combination of target recognition algorithms and the enormous computational power found in today's microprocessors make it possible for modern sensors to detect low-contrast targets and handle high data flows that previously were missed by or were overwhelming to human operators. These sensor advances have come primarily from DoD programs designed to detect and identify adversary armored vehicles. Many of the technologies have great potential against infantry targets as well.

In Chapter Two we introduced the visual, electromagnetic, acoustic, and chemical signatures associated with light infantry forces. In this chapter we discuss sensor phenomenologies and technologies that have the potential to detect these signatures. Specifically, we

- present a brief tutorial on applicable sensor technologies
- describe a multistep process in which multiple sensors are employed to detect and identify a potential target
- discuss the optimal use of the various sensors.

SENSOR PHENOMENOLOGIES

The ideal sensor would have long range, fast coverage rates, and high resolution. It would operate from high altitude 24 hours a day under all weather conditions and would penetrate foliage, dust, smoke, and structures. Unfortunately, no such sensor exists. Indeed, these characteristics often conflict with one another. For example, fast coverage rates and long range must often be traded off against high resolution. Thus, different sensor phenomenologies on board separate platforms must be integrated to approach the full coverage desired in operational settings. Our survey of available technologies suggests that radar, thermal imagers, and low-light television (LLTV) are the most promising airborne sensor technologies. Seismic, magnetic, acoustic, and LLTV appear to have the most potential for ground sensors.¹

Airborne Radars: General

Following its introduction at the beginning of World War II, radar quickly became the sensor of choice for countless airborne, naval, and ground applications. As an airborne ground-surveillance sensor, radar provides long-range, all-weather, wide-area coverage around the clock. It gives both range and angular information about the scene; some processing algorithms can produce photolike images as well.

Radar can detect both fixed and moving targets. The probability of detection of a target is a function of the radar cross section (RCS) of the target and the background clutter environment. For example, a large airplane at high altitude is an ideal target for a ground radar, because it combines a large RCS and a clean background (the sky). Conversely, a small aircraft flying at low altitudes is a demanding target for an airborne radar because of the confusing returns the radar gets from the ground. Basic airborne radars can detect crude topographic features (e.g., mountains and coastlines), and are often used for navigation.

¹Spaced-based reconnaissance assets may provide cueing under some conditions. There are several promising space sensor technologies, including synthetic aperture radar (SAR), optical Moving Target Indicators, and synthetic aperture optics.

To detect ground vehicles and other smaller targets requires high-resolution radar. *Radar resolution* is defined as the smallest distance between two objects in which the objects can be distinguished as being separate. For example, a radar with a resolution of 1 foot (ft) can distinguish between two objects separated by at least 1 ft. Resolution has both range and angular components. *Range resolution* measures the distance between objects in line with the radar beam; *angular resolution* measures the distance between objects perpendicular to the radar beam (see Figure 3.1). Good range resolution can be obtained from any wide-bandwidth radar.² The best angular resolution is produced by using a technique called synthetic aperture radar (SAR).

Airborne Radars: Synthetic Aperture

Synthetic aperture radar has the capability to provide photograph-like imagery at long ranges. SAR provides day-night, all-weather,

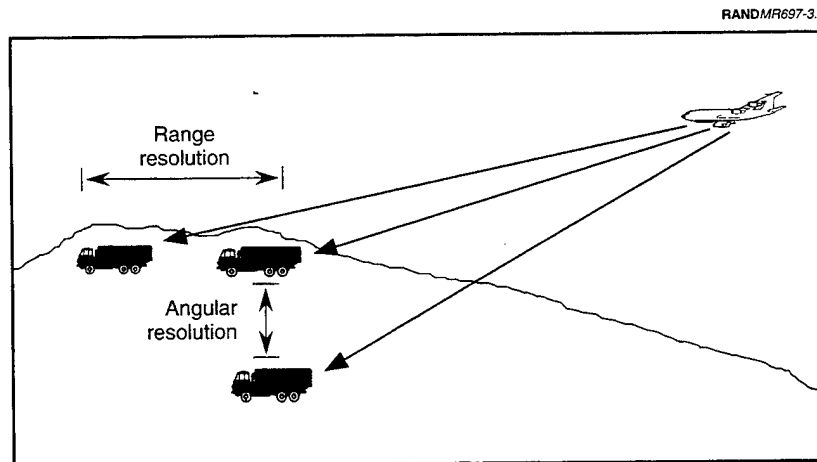


Figure 3.1—Range and Angular Resolution for Radars

²See J. C. Toomay, *Radar Principles for the Non-Specialist*, Belmont, Calif.: Lifetime Learning Publications, 1982, p. 120.

long-range surveillance of selected areas. An airborne SAR uses its own movement to simulate a large radar aperture, producing better angular resolution than would be obtained from a stationary antenna of the same size. A major drawback of SAR is the relatively slow ground-coverage rate resulting from the additional signal collection and image processing required. As processing capability inevitably increases, signal-collection time will become the dominant factor limiting ground-coverage rates.

Synthetic aperture radars are currently employed on AC-130U, F-15E, B-1, B-2, U-2R, and E-8 aircraft and Predator³ UAVs. The U-2R ASARS-2 (Advanced Strategic Airborne Radar System) and E-8 JSTARS (Joint Surveillance and Target Attack Radar System) are reconnaissance and surveillance aircraft and could be deployed in lesser conflicts to provide broad-area coverage against ground and/or maritime targets and imagery of large ground/maritime targets.

SAR imagery is most useful against fixed and other large targets (e.g., tanks, trucks, ships). In general, personnel lack a sufficient RCS to be detectable by SAR.

Airborne Radars: Moving Target Indicator

Radars with MTI modes offer an effective means of detecting moving vehicles over large areas. They can cover many times the area that an airborne SAR can on a similar-length mission.⁴ The MTI mode uses the Doppler effect⁵ to detect objects moving toward or away from the radar. The greater the velocity is relative to echoes from the

³Predator is a Defense Airborne Reconnaissance Office (DARO) Advanced Concept Technology Demonstration (ACTD) program. The Tier II aircraft are to be transferred to the USAF 11th Reconnaissance Squadron sometime after June 30, 1996. See Appendix A for more specifications of UAVs.

⁴A typical X-band radar has a coverage rate of about 10,000 square kilometers per hour (3-meter resolution) in SAR mode and about 3 million square kilometers per hour in MTI mode.

⁵The effect upon the apparent frequency of a wave train produced (1) by motion of the source toward or away from the stationary observer and (2) by motion of the observer toward or away from the stationary source. See *The International Dictionary of Physics and Electronics*, Princeton, N.J.: D. Van Nostrand Company, 1956, p. 258.

ground (i.e., clutter), the easier the target will be to detect. Stationary objects are not detected because they have no velocity relative to the clutter.

Radar systems with an MTI mode are currently employed on several Air Force systems, including the AC-130U, U-2R equipped with an ASARS-2 radar, and the E-8 JSTARS. In MTI mode, the AC-130U can detect vehicles moving as slowly as 6 knots. The U-2 and E-8 provide long-range broad-area coverage,⁶ but the U-2 with ASARS-2 cannot detect slow-moving vehicles.⁷ Data from the ASARS-2 are transmitted by a real-time data link to a ground station for analysis. JSTARS has the processing and real-time display capability on board the aircraft. The wide-area/MTI search mode can be used to identify potential targets for more-detailed inspection with SAR. MTI radar systems are also being developed for small aircraft and UAVs; power and antenna limitations on these smaller platforms reduce the effective range of these systems.

Some airborne MTI radars can also detect personnel in the open.⁸ This capability would be valuable for monitoring foot traffic on roads, open trails, and across cultivated areas.

Airborne Radars: Foliage Penetrating (FolPen)

Ultra-wide-band (UWB) radars operating in the high-frequency (HF) and very-high-frequency (VHF) portions of the spectrum have the capability to penetrate foliage and soil. These FolPen radars could be used to detect structures, vehicles, and equipment in forested areas, as well as shallowly buried objects such as bunkers and landmines.

⁶JSTARS and ASARS-2 have MTI ranges of 225 and 160 km, respectively. See E. R. Hooton and Kenneth Munson, eds., *Jane's Battlefield Surveillance Systems*, Surrey, United Kingdom: Jane's Publishing, 1994, p. 179.

⁷The fast MTI mode on the baseline ASARS-2 is primitive; it can detect only vehicles moving fast enough to fall outside the clutter Doppler spectrum. Hughes has developed an enhanced version of the ASARS-2 that can detect slow-moving vehicles. It has been installed on at least one aircraft.

⁸For example, the AN/TPS-74 produced by AIL Systems has an MTI mode and is designed to be carried by light aircraft or UAVs. See Hooton and Munson, 1994, pp. 66-67.

Experimental systems are currently being developed by the USAF Wright-Patterson Laboratories, the Swedish National Defense Research Establishment,⁹ and SRI International.

The SRI system appears to be the furthest along in development, having successfully detected structures and equipment hidden in tropical forests during SOUTHCOM (Southern Command) tests in Panama. The system has been installed on a DeHavilland DASH 7 turboprop. It is flown at 6,000 ft above ground level (AGL), with the system looking down 45 degrees (deg) on either side, scanning 1 km in each direction.

Although foliage is transparent to these radars, tree trunks are not; a typical forest will produce returns throughout the area of interest. Small targets could easily be lost in the "noise" from the forest. In contrast, structures, vehicles, and large equipment would produce large linear returns when viewed from certain angles. For example, the return from the bed of a pickup truck could produce a very strong return (much like a corner reflector) under the correct angles of incidence. A vertical plate, present on most vehicles and buildings, could also produce a dihedral effect with the ground. When viewed from the side, a flatbed truck will produce two returns—one off the bed and another off the side of the truck. These linear returns are distinct and unlike most background clutter from trees and other natural objects.

Figure 3.2 illustrates (from the left) a single dihedral return from the side of an enclosed truck and (on the right) the double dihedral from the side and the bed of a flatbed truck. Under the vehicles is an illustration of a representative FolPen SAR display, showing the typical inkblot returns from trees, the single linear return for the enclosed truck, and the distinctive double linear return of a flatbed truck.

FolPen radars would probably be best suited for surveillance of dense forests impenetrable to electro-optical (EO) sensors and conventional radar. For example, FolPen SARs can detect roads and trails underneath forest canopy, a capability that would have been useful in Vietnam, where it was difficult to detect the myriad jungle

⁹Hans Hellsten, "CARABAS—An UWB Low Frequency SAR," *Military Technology*, May 1994, pp. 63–67.

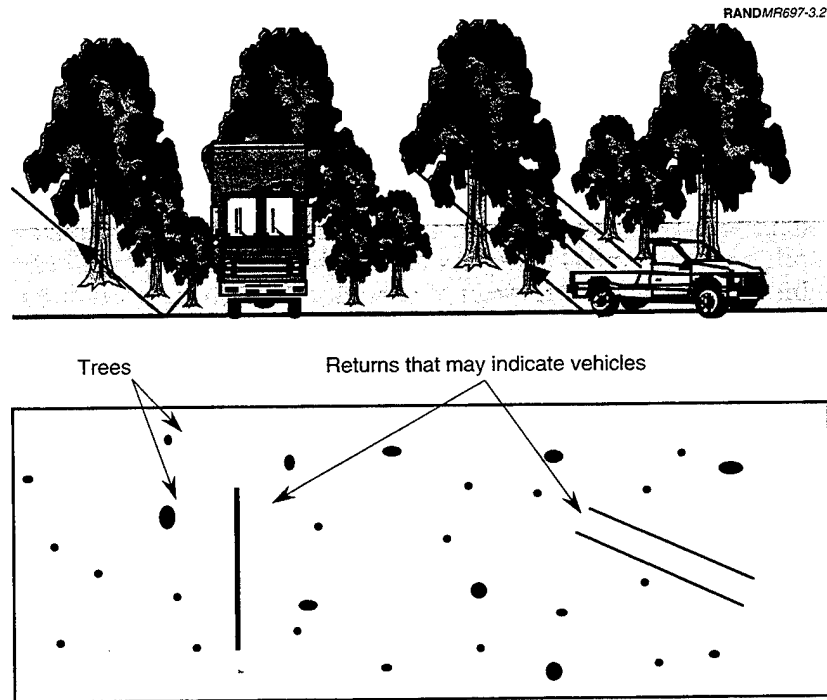


Figure 3.2—Common Dihedral Radar Returns from Vehicles and Representative FolPen SAR Display

trails and roads. This mapping feature could assist in direct interdiction of the roads, as well as leading to vehicle parks, marshaling areas, and munition dumps. In many situations, once FolPen has detected a target, other airborne sensors, ground sensors, or a ground patrol would have to investigate further.¹⁰ Alternatively, FolPen could be cued by another sensor to search a small area.¹¹ For example, if signals intelligence (SIGINT) had detected transmissions

¹⁰In 1996, the Predator UAV will be upgraded with a FolPen radar and a hyperspectral imaging (HSI) processor. Thus, Predator will be able to self-cue with the FolPen, then take a closer look with its HSI sensor.

¹¹*Cueing* is the process whereby one sensor or intelligence source alerts another, typically higher-resolution, sensor to take a closer look.

from an enemy base camp, FolPen could be used to look for structures at the camp. Under less-strict rules of engagement (ROE), FolPen detection of structures in the suspect area might be sufficient to call in air strikes.

One intriguing combination of radar technologies would add an MTI mode to a FolPen radar so that vehicles moving in forests could be detected. We know of no technical reason why this combining cannot be done. An MTI FolPen radar might also have a limited capability against concentrations of personnel, particularly if they were wearing helmets and carrying weapons.

Airborne Passive Sensors: General

Electro-optical sensors use optical components to collect and focus electromagnetic energy and convert it into electrical signals. These signals can then be transmitted to a visual display. Most EO sensors operate in the long-wave infrared (LWIR) through the ultraviolet (UV) region of the spectrum. Sensors that operate in this region have an inherent advantage dictated by physics—the fundamental diffraction-limited resolution of a sensor is proportional to the wavelength. Therefore, EO sensors are capable of better resolution than real aperture radars, because UV, visual, and IR wavelengths are shorter than those used by radar systems.¹² However, physics works against shorter-wavelength sensors, because this is the regime that is most effectively scattered by atmospheric particulates and water vapor.¹³ Such conditions limit the range of visual, UV, and IR sensors—even on clear days. Haze defeats shorter-wavelength sensors, and rain blinds all but long-wavelength radar systems.

The detection wavelength chosen for EO sensors is influenced by the transmission properties of the atmosphere and the reflected or emit-

¹²Laser Radar (LADAR) is the exception. Operating at 10.4 μm , it provides better resolution than radar.

¹³A beam is most effectively scattered by objects with dimensions on the order of its wavelength. The degree of scattering is also related to the density of the suspended particles.

ted energy of the target. Water vapor, oxygen, ozone, and carbon dioxide absorb many wavelengths across the spectrum.¹⁴

Electro-optical sensors are the most common type of airborne passive sensor and the most relevant to our work.¹⁵ EO sensors can be used to detect, classify, and identify targets. Their potentially high resolution makes these sensors particularly valuable for target identification. EO sensors may be called upon for extremely demanding identification missions such as distinguishing between

- a pickup truck with a 2×4 board in the bed and one with .50-caliber machine gun
- a farmer with a hoe and a guerrilla with a rifle
- a soldier with an AK-47 and one with an M-16
- a soldier with an American helmet and web gear and a soldier with other equipment.

To make such subtle distinctions under operational conditions now requires National Imagery Interpretability Rating Scale (NIIRS) 9¹⁶ imagery and a highly skilled sensor operator. Although the specifics will vary with light, weather, foliage, and other local conditions, our review of current systems suggests that most EO sensors will have to be within 3 km of the target and at or below 5,000 ft AGL to obtain such exceptionally detailed images.

¹⁴EO detectors must operate in six specific windows between 0.3 and 14 μm . The six windows are ultraviolet (0.3–0.4 μm), visual (0.4–0.7 μm), near IR (0.7–1.0 μm), short-wave IR (1.0–2.5 μm), mid-wave IR (3–5 μm), and long-wave IR (8–14 μm).

¹⁵Strictly speaking, the pilot's naked eye is the most common airborne passive sensor. Although unassisted vision has been used by pilots in past conflicts to detect, identify, and attack light forces, the proliferation of manportable air defense systems (MANPADS) has forced pilots to fly at higher altitudes where the naked eye cannot see small ground targets.

¹⁶A variety of metrics is used to measure the quality of an image (e.g., ground-resolved distance). The National Imagery Interpretability Rating Scale, developed by professional photo interpreters, is the standard used in the intelligence community. It takes into account image sharpness, contrast, and other factors, rating images on a scale from 0 to 9. For example, an image of an enemy airfield in which taxiways and runways could be distinguished would be NIIRS 1. At the other end of the scale, an image in which vehicle registration numbers (i.e., license plates) on a truck could be read would receive an NIIRS 9 rating.

Airborne Passive Sensors: Low-Light Television

Television is a basic, but very useful, sensor for airborne reconnaissance and surveillance. Stabilized TV cameras with zoom lenses enable real-time monitoring of activities on the ground at distances over 10 km.¹⁷ Television is the ideal sensor for daylight surveillance of personnel in the open and plays a critical role in identifying personnel as friend, foe, or noncombatant. It has been used successfully on AC-130s and other platforms in several conflicts, including current operations in Bosnia. Low-light television intensifies the incident radiation, enhancing operators' ability to work in overcast conditions and at night, but it will not work in total darkness.

Airborne Passive Sensors: Thermal Imagers

Thermal imagers detect the difference in surface temperature of objects. They are currently used in many airborne applications and are often referred to as FLIRs (forward-looking infrared). Thermal imagery systems operate at longer ranges than those in the visual, near-infrared, or short-wave infrared (SWIR) portion of the spectrum, require no ambient light source, and have the added advantage of operating better in poor weather, smoke, and dust.¹⁸ Two types of thermal imagers are currently operational: Infrared Line Scanners (IRLSs) and Focal Plane Arrays (FPAs).¹⁹ IRLSs consist of a single row of detectors and form an image one line at a time. Advances in manufacturing technology have allowed the production of FPAs that detect radiation from an entire image simultaneously. Absorption of the infrared radiation causes these photon detectors to produce an

¹⁷As discussed earlier in this chapter, under most conditions TV and IR sensors must be within 3 km of personnel to have a high probability of identifying them as friend or foe.

¹⁸They can, however, be blinded by phosphorous smoke or large amounts of battle-field dust. See F. Niles et al., "Propagation Environments, Effects and Decision Aids," in *Atmospheric Propagation in the UV, Visible, IR and MM Wave Region and Related Systems Aspects*, Neully Sur Seine, France: Advisory Group for Aerospace Research and Development, Report CP-454, 1989.

¹⁹Several types of detector material are used in FPAs, notably mercury cadmium telluride (MCT), extrinsic silicon, indium antimonide (InSb), and platinum silicide (PtSi). Materials vary in their sensitivity to different wavelengths of radiation, in their cooling requirements, and in the efficiency with which they convert incident radiation into an electrical signal.

electrical current. Today's photon detectors are very sensitive but must be kept extremely cold.²⁰

The main disadvantage of photon detectors is the size, weight, and power requirements of their associated cooling equipment—requirements that have restricted deployment of thermal imagers to aircraft, ground vehicles, and fixed sites.²¹ An Advanced Research Projects Agency (ARPA) program, the Low-Cost Uncooled Sensor Prototype (LOCUSP), is developing thermal detectors that will operate at room temperature in the 8–12- μm range. One of these sensors weighs 6 kilograms (kg) and has a range greater than 3 km, which should allow the deployment of thermal imagers on air-implanted ground sensors.²²

Thermal imagers have several advantages over visual sensors: They can be used at night and in haze, and they are less easily fooled by camouflage. For example, personnel, vehicles, and buildings in woods can be easily hidden from visual observation by the use of various paint schemes, foliage, or camouflage nets. In contrast, neither paint nor standard camouflage nets can hide these targets from thermal imagers. Cut or live foliage can be used to obscure an object in the mid- to long-wave-IR range. If cut, the foliage will lose its thermal camouflage value as it dries out; in hot, dry weather, it will need to be replaced often.²³ Since metal heats and cools differently than natural backgrounds, vehicles can often be detected by thermal imagers. Insulating covers can make the vehicle look more like the background in a thermal image—but only if the engine has cooled

²⁰For example, a detector designed for a peak response around 10–12 μm must operate at approximately -193°C . See Charles M. Hanson, Kevin N. Sweetser, and Steven N. Frank, "Uncooled Thermal Imaging," *Texas Instruments Technical Journal*, September–October 1994, pp. 2–10.

²¹A number of programs have attempted to produce sensitive detectors that can operate at room temperature. See Henry W. Neal and Robert J. S. Kyle, "Texas Instruments Uncooled Infrared Systems," *Texas Instruments Technical Journal*, September–October 1994, pp. 11–18.

²²Air-implanted ground sensors are dropped by aircraft over areas that friendly forces wish to monitor. Some descend like bombs, implanting themselves in the ground. Others descend by parachute and hang from trees. Using acoustic, video, chemical, magnetic, and seismic sensors, they detect and transmit details of enemy activities.

²³This is also true when cut foliage is used to defeat simple visual observation: Piles of dead, brown foliage can be spotted at considerable distances against a green background.

down; otherwise, the diffusing thermal energy produces an observable aura around the insulated vehicle. A more ambitious scheme uses an insulating tent to hide the vehicle. To avoid producing an aura, air from around the still-warm vehicle is mixed with ambient air and pumped out.

Airborne Passive Sensors: Multispectral Approaches

Radar and thermal imagers can detect targets under many conditions, but they generally lack the resolution to identify those targets as hostile. Visual sensors, while better at target identification, are limited by range, weather, and darkness. One approach to circumventing this problem uses inputs from a variety of sensors (a *suite*) to form a "picture" of the operational situation. Alternatively, a single sensor suite can simultaneously sample across the electromagnetic spectrum. This multispectral approach shows great promise for detecting and identifying objects that are indistinguishable using only a portion of the spectrum. For example, standard camouflage nets can easily be picked out of the background vegetation using the UV (0.3–0.4 μm) and the red-through-SWIR (0.6–2.5 μm) portion of the spectrum.

An extension of the multispectral concept, referred to as *hyperspectral*, samples across hundreds of bands in the ultraviolet-to-LWIR spectrum to arrive at a very detailed description of the incident radiation on a detector element. Since every object has a unique signature across the wavelength spectrum, this technique can be used to automatically identify objects that are contained within one detector element or across several. Algorithms are used to process this information and cue the operator to objects that have particular spectral and spatial characteristics.²⁴

²⁴The current generation of multispectral imaging (MSI)/HSI sensors is coarse in spatial resolution, although it may be fine in spectral resolution. For most target detections, clever processing techniques must be relied on to amplify target spectrum admixtures at the subpixel level. Detecting the presence of a target occupying as little as 5 percent of the pixel may be possible. Spatial characteristics will not usually be exploitable against small, light infantry targets unless the MSI/HSI sensor is used to cue or is fused with a fine-resolution EO/IR sensor.

Hyperspectral imaging sensors are currently being developed by several companies. For example, TRW's Hyperspectral Imager (HSI) operates in the visual-to-SWIR bands (0.4–2.5 μm). It has undergone flight tests in Panama, successfully detecting a variety of targets that were not visible to single-spectrum sensors.

Airborne Passive Sensors: Ignition and Magnetic Detectors

During the Vietnam War, some AC-130A gunships were equipped with the AN/ASD-5 direction finder, a sensor that detected electrical signals produced by gasoline-engine ignitions.²⁵ Named Black Crow, it also reportedly was used to detect surface-to-air missile (SAM) launches.²⁶ A 1972 RAND report concluded that "Black Crow proved to be an exceptionally effective cueing sensor by virtue of its ability to identify ignition signals at average ranges of 5 to 6 mi in all terrain and foliage environments in Southeast Asia. In combination with the infrared sensor it was highly useful in pinpointing the location of activity in truck parks and storage sites largely obscured by foliage."²⁷ We were unable to find any examples of modern ignition sensors. This may be an area worth additional investigation.

Another approach to detecting vehicles and other large masses of metal is with magnetic sensors. Since the intensity of a magnetic field is inversely proportional to the cube of range, magnetic sensors have quite limited range (e.g., 100–200 m for vehicle-sized targets). Magnetic sensors may have potential as ground sensors or on very-low-flying UAVs.²⁸

²⁵Diesel vehicles—lacking electrical ignitions—could not be detected.

²⁶See Jack S. Ballard, *Development and Employment of Fixed-Wing Gunships, 1962–1972*, Washington, D.C.: Office of Air Force History, 1982, pp. 130–131, 134–135, 138, 139, 155, 156, 173. See also USAF, *Combat Introduction/Evaluation (Coronet Surprise): December 12, 1969–January 18, 1970*, Wright Patterson AFB, Ohio: USAF Aeronautical Systems Division, 1970, pp. 17–18; USAF, *The Air Force in Southeast Asia: Tactics and Techniques of Night Operations: 1961–1970*, Washington, D.C.: Office of Air History, 1973, pp. 164–173; and USAF, *U.S. Air Force Oral History Program Interview of Lt Col Stephen J. Opitz*, Maxwell AFB, Ala.: USAF History Office, 1972, pp. 12, 14.

²⁷R. B. Murrow, *Gunship Truck Interdiction Results: AC-130A Surprise Package Initial Operations*, Santa Monica, Calif.: RAND, R-0963-PR, 1972, p. vi.

²⁸U.S. Navy P-3 Orion Anti-Submarine Warfare aircraft use a magnetic-anomaly detector on a tailboom to precisely locate enemy submarines detected by sonobuoys. The P-3 flies at low altitudes over the area where the last sonar contact was made—

Unattended Ground Sensors

Although, strictly speaking, unattended ground sensors (UGS) are not airborne sensors, they are an important tool for supporting air power in anti-infantry operations. They could be used to monitor suspected infiltration routes, to help protect friendly facilities, to monitor convoy routes, or to assist in the identification of suspicious personnel. Sensor phenomenologies appropriate for UGS application include acoustic, seismic, magnetic, radio-frequency, electro-optical (visual and IR), and chemical.

The USAF developed, deployed, and operated UGS during the Vietnam War. *Igloo White*, the major UGS program of the war, used seismic, acoustic, and ignition sensors to detect the movement of vehicles and men down the Ho Chi Minh Trail.²⁹ Most of those sensors were implanted by aircraft. Seismic detectors were spike-shaped penetrators that buried themselves on impact, then measured the vertical motion of the ground caused by vehicle or personnel movement. Acoustic sensors were dropped by parachute into the jungle canopy. The parachute would get tangled in the branches, and the sensor would hang free underneath. Ignition sensors detected the "pulsed radio frequency energy" from gasoline-powered engines.³⁰ Maximum sensor ranges varied from 50 m (for a seismic sensor detecting personnel) to 1,500 m (for an acoustic sensor detecting vehicles).³¹

When a sensor detected movement, it transmitted its basic identity code to an orbiting EC-121. The EC-121 relayed the data to the Infiltration Surveillance Center (ISC). The ISC used the identity code to plot the location of the movement, then contacted the Airborne

usually the last step before the P-3 attacks the submarine with a torpedo. This application of magnetic sensors is effective for several reasons: Submarines have huge magnetic signatures; the P-3 can safely fly at low altitudes over the flat "terrain" of the ocean; and there are no air defenses to threaten the P-3.

²⁹The program was first known as *Practice Nine*. It was followed by *Illinois City*, *Dyemarker*, *Muscle Shoals*, and, finally, *Igloo White*. The entire program is now generally referred to as *Igloo White*. See Jacob Van Staaveren, *Interdiction in Southern Laos, 1960–1968*, Washington, D.C.: Center for Air Force History, 1993, pp. 255–283.

³⁰USAF, *Igloo White January 1970–September 1971: Project CHECO Southeast Asia Report*, Hickam AFB, Hawaii: Headquarters, Pacific Air Forces, 1971, p. 53.

³¹USAF, *Igloo White*, 1971, p. 6.

Command and Control Center (ABCCC) to request an air strike. Finally, an airborne FAC would drop a radar beacon or would fire smoke rockets at the target for fighters or bombers to guide on when they attacked.

Many of these sensors were damaged on impact or landed far from planned locations. Of those that landed close to their intended targets and functioned, many sent spurious signals, were disabled by the NVA, or suffered premature power failures. Despite these frustrations, *Igloo White* made significant contributions to the interdiction campaign and was credited with assisting "in the real time location of more than 20 percent of the targets attacked." Furthermore, "nearly all the targeting of LOCs [lines of contact], about 38 percent of the truck parks, and 15 percent of the trucks struck were located using *Igloo White* inputs."³²

Many of the technical problems encountered by *Igloo White* are being corrected in ARPA's Internetted Unattended Ground Sensor (IUGS) program. IUGS is an air-delivered, Global Positioning System (GPS)-guided spike with magnetic, seismic, acoustic, chemical, and environmental sensors. The IUGS looks very much like a laser-guided bomb. Several can be carried by a single tactical aircraft. Once the sensor is dropped, the GPS guidance system sends signals to aerodynamic surfaces on the spike, causing it to fly a precise course to the intended impact point. Flight tests are scheduled for fiscal year 1997; 10-m accuracy is expected. Thus, in contrast to *Igloo White*, future USAF operators should be able to put sensors exactly where they want them and receive their precise coordinates once the sensors are planted. Another major improvement of IUGS over its predecessors is its advanced microprocessor, which enables onboard feature extraction, classification, and data fusion. These capabilities will simultaneously reduce false alarms and minimize the amount of data that will have to be uplinked and analyzed offboard. Finally, advanced batteries will give IUGS a several-month operational endurance.

³²USAF, *Igloo White: July 1968-December 1969: Project CHECO Southeast Asia Report*, Hickam AFB, Hawaii: Headquarters, Pacific Air Forces, 1970, p. 12.

GETTING THE RIGHT SENSOR FOR THE RIGHT JOB

To better understand how these sensors might be used together, consider a notional mission by a broad-area surveillance asset such as a JSTARS with MTI. This surveillance mission takes place within a mosaic of other intelligence and combat operations. Intelligence drawn from national-level resources, defectors, local villagers, friendly ground patrols, and other sources provides a background for the mission. Indeed, many missions would be planned to follow up on intelligence from one of these other sources. Thus, one could argue that almost all missions are cued in some sense.

In this example, let us assume that human intelligence sources have reported guerrilla movement of heavy weapons by vehicle. The JSTARS crew are directed to look for vehicle traffic along several roads. During its mission, the JSTARS' MTI radar detects suspicious vehicle traffic in the area of concern. This information is used to cue a UAV equipped with a FolPen radar and EO/IR sensors. The UAV—using its thermal imager—detects and follows several trucks that appear to be carrying weapons. The trucks disappear into a wooded area. The UAV then uses its FolPen radar to follow the vehicles down the hidden road to an assembly area. Ground sensors are then dropped. Using acoustic and thermal imagers, remote operators are able to identify the personnel and vehicles as hostile. Tactical Air (TACAIR) is called in to destroy the site.

The Detection and Identification Process

In most cases, initial cueing and detection are best done by sensors that can cover broad areas fairly quickly (e.g., MTI, SIGINT). These relatively low-resolution sensors generally cannot classify, recognize, and identify light infantry targets. Higher-resolution sensors—usually fine-resolution SAR, or visual or IR sensors—are required for these final steps.

The identification step in particular requires a very high confidence level, given the strict ROE typically associated with lesser conflicts. In some situations, the identity of ground targets will remain ambiguous, even after multiple sensors have been employed. If so, commanders may authorize the use of lethal weapons only after ground forces have positively identified the targets.

Describing these steps is useful for analytical purposes, but it should be pointed out that the process is rarely simple. Each step may involve branches, whereby one sensor detects a target and immediately cues another sensor, which goes through its own steps and may cue yet another asset. Furthermore, these steps may occur nearly simultaneously, as is often the case when a surveillance/strike platform detects, classifies, recognizes, identifies, and attacks hostile forces within seconds. (Imagine a fighter pilot spotting and attacking an anti-aircraft artillery [AAA] site, an air-to-air combat engagement, or an infantry ambush: All are characterized by abbreviated detect-identify-attack processes.)

The Complete Process

Our notional JSTARS mission has a more leisurely but nonetheless complex process, beginning with three *cueing* steps. The JSTARS was cued to do the mission; it then cued the FolPen/thermal imaging UAV, which cued the ground sensors. *Detection* simply means that a potential target has been observed. In this example, detection occurred three times as the JSTARS, the UAV, and the ground sensors each picked up the target. *Classification* occurred once, when the UAV operators, using the thermal imagers, were able to identify the targets as trucks. The UAV operators were, however, unable to conclusively *identify* the trucks as hostile under the strict rules of engagement in this hypothetical conflict; they had to use air-implanted ground sensors to make the final determination.

CONCLUSIONS

No single sensor can detect all infantry signatures under all operational conditions. Furthermore, distance between sensor and target, ambient light, weather conditions, terrain masking, foliage, buildings, intermingling of combatants and noncombatants, and camouflage all can limit the effectiveness of any single sensor. A multiphenomenology approach will, therefore, be necessary to achieve robust performance and have acceptable probabilities of detection and identification against infantry adversaries under varied tactical conditions.

Placing multiple sensors on the same platform would allow sensor operators to look at a target in different ways before it disappears from view. Advances in data-fusion software and in multispectral sampling suggest that it will be possible to produce a composite image of the target within seconds or minutes. By providing commanders with a reliable multidimensional portrait of the battlefield, it should be possible to identify and attack hostile targets when they are most vulnerable. Our research suggests that low-light television, IR, MTI, SAR, FolPen, hyperspectral imaging, and ground sensors (acoustic, EO/IR, seismic, magnetic, and chemical) all can make important contributions to detecting, classifying, recognizing, and identifying light infantry targets.

Chapter Four describes platforms for these sensors, as well as weapons and tactics; they are integrated in Chapter Five, which presents 12 OPCONs for anti-infantry operations.

SYSTEMS AND TACTICS FOR AIR OPERATIONS AGAINST LIGHT INFANTRY

Previous chapters described a generic light infantry opponent and the sensor technologies available to the USAF for operations against that opponent. This chapter briefly discusses light infantry air defenses, unmanned aerial vehicles as platforms for sensors, weapons, and command-and-control issues.

LIGHT INFANTRY AIR DEFENSES

Effective application of air power against light forces will require very precise information on the type, location, and activity of a target, as well as the nature of the target's surroundings: The tactics and weapons needed to attack an artillery position in an open field will be very different from those needed in a forest, and again from those needed in a hospital courtyard. In many cases, intelligence about a target area will have to approach eyes-on certainty to separate combatants from noncombatants and minimize collateral damage. The ability to acquire this level of information, in near-real-time, requires an aircraft (manned or unmanned) equipped with EO/IR sensors to loiter at low altitudes over a target area for relatively long periods of time.¹ At least one weapon system—the AC-130 gunship—must orbit to employ its weapons effectively. Thus, the USAF's ability to detect, identify, and attack light infantry targets is, in part, a function of its ability to operate in the presence of such air defenses as light adversaries are able to field. To conjure up a fairly simple yet potentially dangerous air defense environment for USAF operations—par-

¹In some situations, ground personnel or sensors may provide this information.

ticularly operations that put a premium on flying somewhat low and slow—it is not necessary to posit any quantum leaps in technology. The essential elements exist; many, in fact, have been employed quite successfully in past conflicts.

Manportable air defense systems (MANPADS), in particular, are growing in sophistication and are proliferating. MANPADS are also inexpensive, reliable, easy to use, and can be moved covertly, announcing their presence only after a missile is launched. They have been used successfully by light infantry forces in Vietnam, Afghanistan, Sri Lanka, and elsewhere. The most advanced systems (e.g., the SA-18 and Stinger RMP [reprogrammable microprocessor]) use a variety of acquisition and guidance methods for which existing countermeasures are inadequate. In addition to the direct loss of aircraft and personnel caused by MANPADS, the proliferation of MANPADS may impose virtual attrition on USAF operations—forcing platforms and weapons to be used from the altitude and standoff edges of their operational envelopes.² (Appendix B discusses the evolving MANPADS threat in greater detail.)

UNMANNED AERIAL VEHICLES

As noted in Chapter Three, TV and thermal-imaging sensors are particularly important for target identification. To achieve the quality of images necessary to identify adversary forces will, in most cases, require sensor platforms to loiter at altitudes and ranges within the MANPADS envelope.³ Future EO/IR sensors may have greater range, but atmospheric attenuation is likely to preclude the development of very-long-range, high-resolution imaging sensors. If so, a means must be found to carry these sensors well below 10,000 ft AGL

²We saw such virtual-attrition effects in the 1991 Gulf War. The lethality of MANPADS—13 of the 38 Coalition air losses were due to infrared-guided SAMs—forced the Coalition air component commander to order the cessation of low-altitude operations. Flying at higher altitudes had deleterious effects on the bombing accuracy of platforms such as the F-16, which can best deliver unguided ordnance from lower altitudes.

³The risks associated with loitering over a target were amply demonstrated in April 1994, when a Serbian SAM downed a British Sea Harrier near Gorazde as it made its third or fourth pass trying to identify and attack an armored vehicle suspected of firing on U.N. positions.

without suffering high attrition. Potential solutions include reducing the radar and IR signature of USAF aircraft, improving countermeasures, developing new tactics, and using low-cost unmanned aerial vehicles.

UAVs, in particular, appear to have great potential for low-altitude missions. Short-range UAVs (e.g., Hunter) and long-endurance UAVs (e.g., Predator⁴) could operate in many air defense environments without suffering unacceptable attrition. The Predator UAV, for example, has a small IR signature, is invisible to the naked eye above 7,000 ft AGL, and is inaudible above 4,000 ft AGL. The recent loss of a Predator over Bosnia⁵ demonstrates, however, that these aircraft are far from invulnerable. Predator is a relatively large, slow-moving aircraft.⁶ Whereas in many scenarios it can loiter safely at 15,000 ft—using its SAR or EO/IR sensors for standoff imaging—it cannot do the same at 4,000 ft. To avoid high attrition rates in medium- to high-threat environments such as Bosnia,⁷ more-cautious tactics will need to be developed for low-altitude operations. IR countermeasures might also be added to Predator. For low-altitude operations against advanced MANPADS, it may also be necessary to trade off some range/endurance/sensor payload in favor of a smaller, quieter platform.

One approach would recognize that no single UAV platform can be equally effective at all surveillance missions. A UAV painted black for night operations would stand out during the day, just as a white daytime UAV would stand out on a moonlit night. Thus, it makes sense

⁴Predator can fly 500 nmi to a target area, loiter for 24 hours, then return. It carries TV, thermal imager, and SAR sensors, and both line-of-sight and satellite communication (SATCOM) data links. Existing compact TV/IR sensors provide high-resolution images of personnel from 5,000 ft AGL and 3-km standoff. See U.S. Atlantic Command, *United States Atlantic Command Operational Concept Document for the Medium Altitude Endurance Unmanned Aerial Vehicle*, Norfolk, Va., May 1994.

⁵In August 1995, two Predators were lost in operations over Bosnia. One aircraft was shot down while flying at 4,000 ft AGL below a cloud ceiling, something a manned aircraft would not choose to do over enemy forces. The other was lost due to engine failure. See Bradley Graham, "Pentagon Loses Two Unmanned Spy Planes Over Bosnia," *The Washington Post*, August 15, 1995, p. 10.

⁶Predator has a 49-foot wingspan and cruises at 110 knots.

⁷It is interesting that no radar-guided SAMs have been fired at Predators flying above 15,000 ft in Bosnia.

to deploy multiple UAV designs, each optimized for a particular operating environment. This philosophy would equip larger, high-flying UAVs such as Predator with SAR, FolPen, and MTI radars. With these sensors, UAVs could operate effectively and with few losses at altitudes above 15,000 ft and at standoff distances outside the effective range of MANPADS. EO/IR sensors carried by UAVs for lower-altitude missions are much smaller and have less-demanding power requirements than radars. Thus, the UAVs carrying EO/IR sensors could be much smaller if optimized for operations at low altitudes. Some night-surveillance missions may require a platform that can fly undetected at very low altitudes (i.e., 1,000 ft AGL or lower). A small, inexpensive, air-launched, battery-powered UAV carrying IR sensors is one possibility.⁸

In short, while current UAVs may have some problems operating at the altitudes necessary to detect and identify light infantry, UAVs in general have tremendous potential for this mission. The continued miniaturization of electronic components and developments in lightweight optics suggest that high-resolution EO sensors can be deployed on very small airframes. Although it will need to be proven in tests and exercises, UAVs optimized for surveillance at low altitudes should be survivable against most adversary light air defenses.⁹ They can probably be made cheaply enough that attrition would not be a significant constraint on their employment.

WEAPONS

Current USAF weapons are well-suited for many anti-infantry operations. If a target can be identified as foe, current USAF combat ca-

⁸The Naval Research Laboratory has developed small, battery-powered UAVs that can carry small payloads for up to 2 hours.

⁹UAVs may also need to operate in compliance with international air-traffic-control regulations. Hostage rescue, border surveillance, counterdrug, and other special missions could put UAVs in situations where there is civil air traffic. In some covert operations, UAVs might want to mimic manned light aircraft; in others, collision avoidance could be a serious issue. The next Predator upgrade includes the Air Traffic Control Compliance System (ATCCS). This system has a transponder that would allow air-traffic-control radars to more easily track Predator. It also includes automatic collision-avoidance equipment such as that found on commercial airliners. This upgrade will also include Strike Finder, a bad-weather-avoidance device that detects thunderstorms out to 200 mi.

pabilities are more than adequate to destroy the target. In particular, guns on AC-130s and A-10s are very effective against personnel, as well as against the vehicles and equipment most often associated with light operations. Guns combine precision, penetration, and minimal collateral damage.

The AC-130 is often the weapon of choice, but it must fly quite low to detect and identify light forces. If USAF combat controllers are on the ground to do target acquisition and identification, AC-130s can fly above many MANPADS threats. When, for political or tactical reasons, U.S. personnel cannot operate on the ground, AC-130s must fly deep into the MANPADS envelope. In operations against foes who lack MANPADS and heavy AAA, current tactics can continue to be used indefinitely. Such tactics will, however, be increasingly risky against foes who do possess MANPADS. In medium-threat environments—against foes armed with SA-7s and SA-14s—UAVs could be used as offboard sensors for AC-130s, bringing the gunship down below 15,000 ft AGL and over the target only when it needs to fire. UAVs and A-10s might be combined in a similar fashion for daytime operations or situations in which the number or sophistication of MANPADS would put AC-130s at undue risk. In the highest-threat environments—against foes armed with Stinger RMPs, SA-18s, and the like—high-performance aircraft (e.g., F-16s) armed with standoff weapons may be the only survivable platforms.

Weapons for Urban Environments

One area that deserves additional attention is the application of air power in urban environments. When U.S. Army Special Forces were pinned down by General Aideed's militia in Mogadishu, Somalia, they needed sustained and precise heavy-fire support. Artillery was ruled out because of the urban setting; fixed-wing air support could have been decisive but was not available in-theater.¹⁰ If, for example, an AC-130 had been on-station, the suppressive fire from its 25mm,

¹⁰This statement is not meant to denigrate the contribution of Army helicopter gunships. U.S. Army aviators made a heroic effort to support their comrades, flying round-the-clock close-support sorties with AH-1 Cobras and MH-6 Little Birds. They flew aggressively, courageously, and to the point of exhaustion, saving many lives in the process.

40mm, and 105mm guns may have been enough to allow an airborne evacuation of the U.S. forces.¹¹

Alternatively, there may be a role for TACAIR in such situations. In some urban warfare settings, limited use of conventional munitions may be appropriate. Most situations, however, will require that collateral damage be minimized. Small, very precise, laser-guided weapons might make an important contribution in a future Mogadishu.

Less-Than-Lethal Weapons

Less-than-lethal weapons (LTLW) may also have a role against light forces, particularly when those forces are intermingled with or near noncombatants (e.g., in urban areas). For example, sticky foam barriers¹² could be used to delay noncombatants attempting to mix with, and thereby protect, combatant forces, as General Aideed's unarmed supporters often did in Somalia in 1993. Barriers could also help protect friendly facilities from hostile mobs.

Incapacitating agents also have potential applicability against light forces. They could be used to help capture enemy forces for intelligence purposes, to stop suspicious-but-unidentified forces, or as riot-control agents. Finally, incapacitating agents could be used when combatants and noncombatants are in proximity. These and other LTLW concepts are currently being studied by DoD; some of them may prove to be operationally feasible.

However, two problems are associated with LTLW: potential for serious injury or death and impracticability of air delivery.

Many LTLW concepts could cause serious injuries or death under some circumstances. For example, sticky foam could cause asphyxiation if delivered on top of a crowd; blinding lasers could cause permanent loss of sight; anti-materiel agents could be lethal to nearby

¹¹Mogadishu offers a recent example of adversary air defenses that did not significantly impede AC-130 operations.

¹²Originally developed to protect nuclear weapons storage facilities, sticky foam is a rapidly expanding, powerful glue that immobilizes anyone or anything to which it is applied.

personnel; and incapacitating agents could be toxic to sensitive people. Incapacitating agents also are controlled by the Chemical Weapons Convention, which allows their use for humanitarian purposes (i.e., as an alternative to the use of deadly force against civilians) but prohibits their use "for military advantage." Use of these chemicals to control riots could be interpreted as humanitarian; the other applications discussed above would likely be prohibited.

The second issue is the practicability of aerial delivery of LTLW. Precision delivery of sticky foam would require an aircraft to fly slowly at low altitude, the use of a guided munition dispenser, or guided bombs that dispense foam on impact. It is not clear that a fixed-wing aircraft could fly slowly enough (or spew foam fast enough) to lay down a workable barrier. If the environment were so benign that low and slow air operations were possible, it seems likely that the foam could be delivered by armored tanker truck instead. In any event, a large cargo helicopter appears to make more sense if an airborne platform was required. A guided dispenser spraying foam would suffer from the same limitations as are placed on other fixed-wing platforms and would likely have insufficient capacity to produce more than a narrow barrier. Foam bombs may be feasible, assuming that they could be delivered with sufficient accuracy. A linear barrier could then be produced by dropping many of these foam bombs in a row.

Since some LTLW applications would require friendly forces to be on the ground either briefly or for extended periods, it might make more sense for LTLW to be delivered by ground forces. On the other hand, it would be useful to have an air-delivery option when ground delivery is impossible.

COMMAND-AND-CONTROL ISSUES

Anti-infantry operations may also require changes in the airborne surveillance and strike architecture. The current system is designed to detect and identify massed heavy ground forces producing large radar, IR, SIGINT, and visible signatures. In contrast, light forces typically appear as small, fleeting targets, often intermingled with noncombatants. Area-coverage requirements may be smaller, but target identification is challenging and often urgent. Finally, streamlined C2 is necessary to strike targets while they are exposed.

The operational concepts presented in Chapter Five assume that an airborne or ground-based fusion-and-control center will integrate the sensor data with other information, and that an officer in the center is authorized to approve air strikes based on this information. The details of these command, control, and communications (C3) arrangements were not addressed in this study, but they do not seem insurmountable. In most cases, anti-infantry operations involve a small number of aircraft operating under a single combat controller. Unlike high-intensity air operations, operations in adjacent sectors do not require extensive coordination or deconfliction.

Since most of the OPCONs involve UAVs, it may be useful to discuss briefly one UAV C3 model. This model would give the UAV-control cell—the team controlling the flight and monitoring the sensors—the authority and responsibilities of an airborne FAC. In this model, a FAC-qualified pilot would command the small team of flight controllers and sensor operators. The team would know the locations of friendly forces and noncombatants, and the FAC commander would have the authority to direct strikes in his area of operations just as does an airborne FAC. He might have to request the air strikes from a higher authority, but, once the aircraft were inbound, he would direct and control the flight.

Having described adversary light infantry forces and the sensors and weapons most effective against them, we now turn to potential operational concepts to accomplish six specific combat tasks.

ALTERNATIVE OPCODES FOR AIR OPERATIONS AGAINST LIGHT INFANTRY

In future conflicts, the USAF could be called upon to conduct air operations against light infantry forces in a variety of contexts. In this study, we identified six sample anti-infantry tasks for the USAF:

- Locate/destroy light infantry in the open.
- Locate/destroy light infantry in woods.
- Locate/destroy heavy weapons in woods.
- Protect convoy from ambush.
- Locate/destroy urban snipers.
- Interdict vehicles resupplying light forces.

To illustrate potential applications of the technologies discussed in Chapters Three and Four, we developed a near-term OPCODE and a far-term OPCODE for each combat task. Near-term OPCODEs are limited to systems already deployed, in the acquisition pipeline, or proven in Advanced Concept Technology Demonstration (ACTD) programs. They could be implemented within five years. The far-term OPCODEs are based on plausible applications of known technologies but require more time than near-term OPCODEs for the technologies to mature.¹ These OPCODEs were derived from the following approach:

¹The study team did a preliminary feasibility analysis of these technologies based on our technology survey, interviews, and some basic calculations. Much more detailed

- For a given task, invent alternative OPCODEs based on applicable technologies.
- Evaluate OPCODEs to identify fatal flaws.
- Modify OPCODEs to correct weaknesses.
- Discard OPCODEs that cannot be fixed.

To be included here, an OPCODE had to meet the following criteria:

- Manned airborne platforms must be survivable against light infantry air defenses under most conditions.
- Unmanned airborne platforms must be either low-cost or survivable against light infantry air defenses under most conditions.
- The OPCODE must provide high-resolution visual identification of targets prior to engagement.
- The OPCODE must not require the acquisition of large, expensive platforms.

The remainder of this chapter presents and discusses these OPCODEs.

LOCATE/DESTROY LIGHT INFANTRY IN THE OPEN: NEAR-TERM OPCODE

Locating light infantry in the open is one of the more straightforward tasks we identified. In this OPCODE, UAVs equipped with EO/IR sensors and laser designators are used to detect enemy infantry units moving across open areas (e.g., rice paddies, meadows, cultivated fields, trails, roads). Ideally, the UAVs would be cued to monitor an area because enemy units had operated there in the past, because intelligence analysis determined that enemy activity was likely, or because a broad-area sensor (e.g., an MTI radar) had detected movement. Uncued reconnaissance could be done by UAV, but UAVs equipped with EO sensors currently have relatively small coverage rates and are therefore not ideal broad-area surveillance platforms.

engineering studies and tests would be necessary to determine which, if any, of these technologies are both feasible and operationally effective.

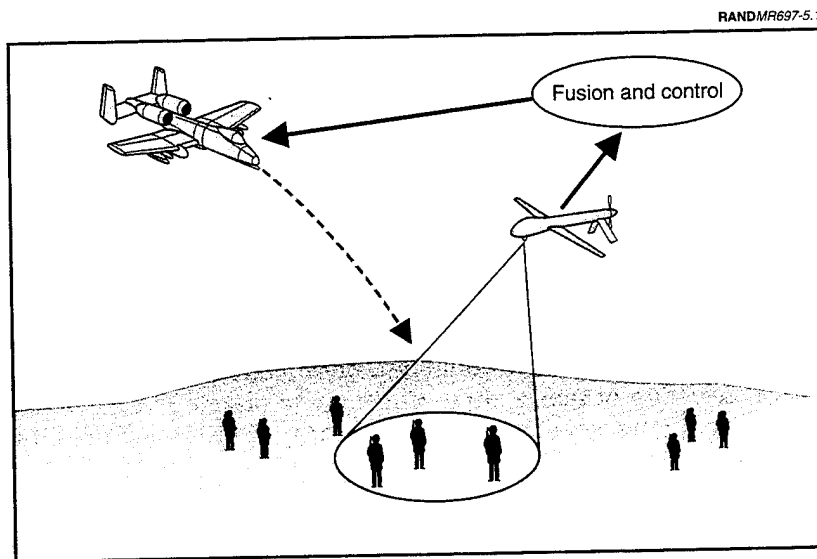


Figure 5.1—UAV/TACAIR Reconnaissance-Strike Team

UAVs would be more effective for monitoring approaches to friendly military installations, villages, and high-value facilities.

Once the enemy force was detected, TACAIR would be directed to the scene (Figure 5.1). UAV controllers would then use the onboard laser designator to identify the target for the TACAIR pilots, who would attack and destroy the target with the appropriate munitions. For this concept to work, the EO sensor images would have to be clear enough for the UAV FAC or other fire-control officer to make a high-confidence determination that the target was hostile. As stated in Chapter Four, UAVs flying at around 5,000 ft AGL with current-generation EO sensors can make such a determination under many conditions.

LOCATE/DESTROY LIGHT INFANTRY IN THE OPEN: FAR-TERM OPCON

In the far term, we envision using unattended ground sensors to detect and identify enemy ground forces. A UGS array would be im-

planted by air along a trail or road routinely traveled by adversary forces, around a friendly installation, or at some other promising location. Seismic and acoustic sensors would detect the movement of the enemy force. Magnetic, acoustic, and video sensors would be used to identify the forces as hostile. This information would be transmitted to a ground or airborne command-and-fusion center, where a determination would be made to attack the target or to gather additional information by UAV, manned aircraft, or ground patrol. Targets could be attacked by AC-130s, TACAIR, helicopter gunships, or artillery (see Figure 5.2).

The success of this OPCON would be determined in large part by the correct selection of sensor sites. Current and planned UGS are too expensive to be seeded, shotgun fashion, across an area of

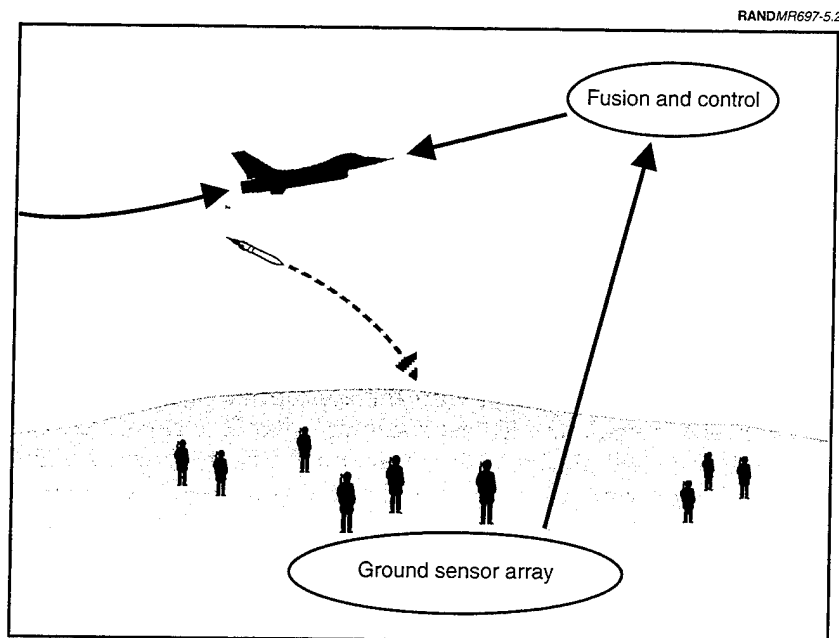


Figure 5.2—Unattended Ground Sensor Array

operations.² Thus, careful site selection relying on good intelligence and knowledge of enemy operations would be critical. Another issue is whether air operations could be based solely on inputs from the UGS array, particularly if the video images were of poor quality or restricted by foliage or line of sight. Remote areas controlled by enemy forces might be treated as free-fire zones, allowing immediate strikes on the basis of limited sensor inputs. Conversely, in areas close to noncombatants or friendly forces, it seems unlikely that the fire-control officer would authorize strikes unless he possessed unambiguous audio or video evidence that the target was hostile. Thus, in some cases, it might be necessary to supplement the UGS inputs with inputs from other sensors.

LOCATE/DESTROY LIGHT INFANTRY IN WOODS: NEAR-TERM OPCON

This near-term OPCON might be considered a base case, since it is closest to current tactics. The concept assumes that SIGINT has detected radio transmissions from an enemy base camp in a heavily forested area. Depending on the accuracy of the SIGINT fix, the availability of other intelligence about the site, and conflict ROE, it might be possible to launch an air strike without any further investigation.

It seems more likely, however, that further investigation would be required before an attack was feasible, let alone authorized. In this case, a small reconnaissance team (e.g., U.S. or allied special forces or infantry) would be inserted near the base camp. (The location of the insertion point or landing zone would depend on terrain, known enemy positions, and other tactical considerations.) The team would then infiltrate on foot and visually monitor activities near and at the camp (Figure 5.3). If enemy observation posts and defensive positions around the camp made it too hazardous to attempt a penetration to the camp perimeter, the team could use GPS offsets to note the enemy positions, then withdraw. At the least, these defensive positions could then be attacked. More probably, the existence of en-

²Advances in computing technology and hardware miniaturization could ease this constraint in the near future. Good-resolution charge-coupled device (CCD) cameras, for example, can be purchased for use with home computers for less than \$100.

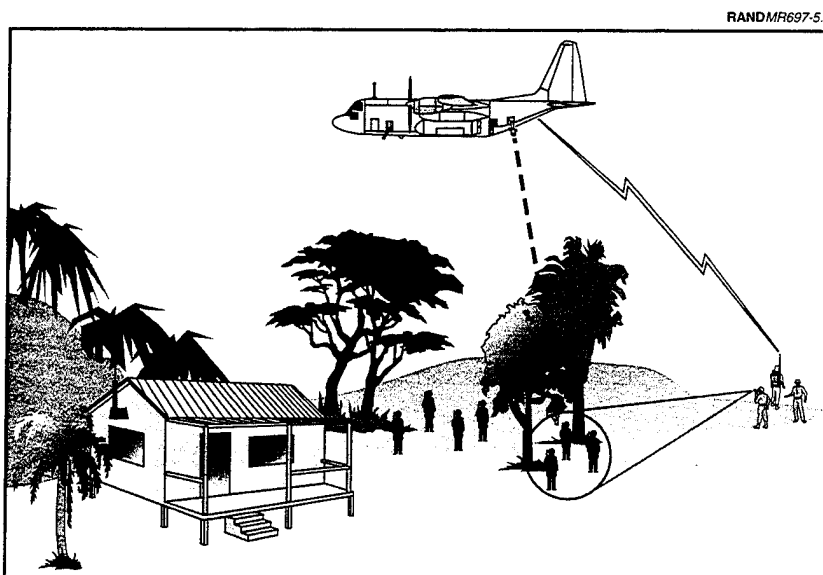


Figure 5.3—Ground Forces as Sensors

emy defensive positions near the suspected base camp would probably be sufficient to authorize an attack on the base camp proper (assuming its coordinates were known with precision).

If the reconnaissance (recce) team was able to penetrate to the camp, it could monitor activities, plant UGS, and use a laser range finder in combination with handheld GPS receivers to get target coordinates for air or artillery attack. If terrain and enemy force dispositions allowed, the recce team could also use a laser designator to guide TACAIR-delivered laser-guided bombs (LGBs).

The obvious weakness of this concept is that it puts a ground recce team at risk. On the other hand, ground observation is often the most effective technique when very close scrutiny of a relatively small area is required. Finally, having a ground team with eyes on the target minimizes the risk that air strikes will hit noncombatants or friendly forces. More broadly, ground reconnaissance teams could be used to search wooded areas for enemy infantry, calling in

air- or ground-based fire support when they discovered enemy formations.³

LOCATE/DESTROY LIGHT INFANTRY IN WOODS: FAR-TERM OPCON

Our far-term concept would exploit promising developments in foliage-penetrating radar, hyperspectral imaging, and unattended ground sensors to detect and identify enemy infantry.⁴ A manned aircraft or UAV would search wooded areas suspected of harboring enemy infantry, with FolPen radar (in both MTI and SAR imaging modes), and would use hyperspectral image processing. The search may have been cued by other sensors and intelligence or be a routine patrol. The FolPen would detect structures, vehicles, and large equipment in regular mode; in MTI mode, it would detect moving vehicles and possibly personnel. The hyperspectral imaging would look through gaps in foliage for the unique signatures of enemy uniforms, tents, tarps, and equipment. If either sensor detected suspicious activity, additional passes would be flown from different angles and altitudes. If the target was deemed worthy of further investigation, the UAV or another aircraft would drop several GPS-guided UGS onto the target area (Figure 5.4).

The advantage of UGS is their ability to provide seismic, acoustic, magnetic, position (from GPS), and video data from ground level. The video and acoustic data would be critical for target identification. Once the target had been identified as hostile, the GPS data from the sensor could be passed to a fighter and GPS-guided munitions could be dropped on the target.

³U.S. Army and Marine reconnaissance units routinely conduct long-range patrols in support of ground operations. Ken Watman at RAND has coined the term *aeroground operations* to describe a concept in which the primary role of forward ground forces would be to act as sensors rather than as weapon carriers. These forward forces would detect and identify targets for attack by air or artillery.

⁴Another possibility we considered would employ UAVs equipped with radio direction finders to detect and geolocate enemy radio transmitters. Even short-range FM radios could be detected by low-flying UAVs. A single UAV could take several fixes on a transmitter, possibly providing a location fix precise enough to bring in an air strike.

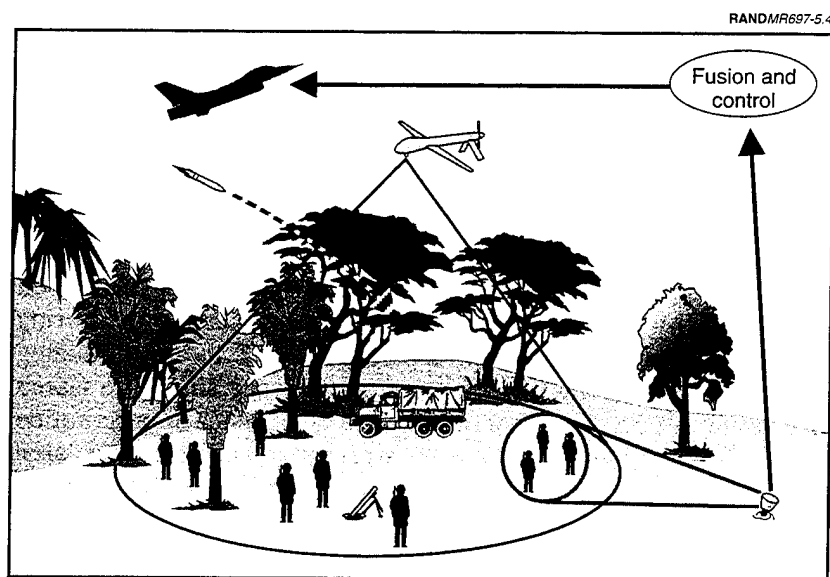


Figure 5.4—Foliage-Penetrating Radar, Hyperspectral Imaging, and Video/Acoustic Ground Sensors

The disadvantage of current-generation UGS is that the UGS spike is a high-speed, bomblike projectile that would make considerable noise as it crashed through the trees and implanted itself in the ground.⁵ Early in a conflict, enemy forces might investigate the noise, providing additional sensor inputs—possibly including close-range video images. Later in the conflict, enemy forces might flee upon hearing the UGS come through the trees. In either event, a prompt strike would be necessary, requiring strike assets to be orbiting nearby as the UGS are delivered. Clearly, it would be valuable to

⁵In general, UGS should be implanted prior to the arrival of enemy forces. Once in place, they are difficult to detect and could be considered one of the most covert sensors. One exotic UGS concept is the insectoid, a small, robotic sensor that could—in theory—be seeded in large numbers over a target. The insectoids would detect vibration, heat, or noise and crawl toward the source, providing a close look at the suspicious activities. See Keith Brendley and Randall Steeb, *Military Applications of Microelectromechanical Systems*, Santa Monica, Calif.: RAND, MR-175-OSD/AF/A, 1993, especially pp. 21–30.

have a small, lightweight UGS that could be delivered covertly, perhaps by GPS-guided parachute.

LOCATE/DESTROY HEAVY WEAPONS IN WOODS: NEAR-TERM OPCON⁶

This concept employs a ground-based counterbattery (CB) radar, UAVs with EO sensors, and TACAIR armed with LGBs to detect, identify, and destroy adversary artillery pieces encountered during peace, counterinsurgency, and other operations characterized by strict ROE.⁷ The concept assumes that a 20-km artillery-denial zone is being enforced around friendly forces or a city 10 km in diameter. A small UAV force would patrol this donut-shaped zone 24 hours a day; four counterbattery radars would be deployed to cover all azimuths (Figure 5.5).⁸

In conventional heavy combat, counterbattery radars can locate enemy artillery with sufficient accuracy and speed to enable counterbattery fire by a Multiple-Launch Rocket System (MLRS) or tube artillery. In Desert Storm, Iraqi artillery batteries were destroyed with these tactics. During counterinsurgency or peace operations, however, individual artillery or mortars are likely to fire on friendly forces

⁶Both our near- and far-term concepts address the problem of finding and destroying enemy artillery being fired from thick foliage—a problem that U.S. forces faced in Vietnam and, more recently, U.N. forces wrestled with in Bosnia. Heavy weapons that are not firing, whether tanks or artillery, would require other OPCONs to detect and destroy. FolPen radar, HSI processing, and ground sensors might be combined to counter this threat.

⁷For example, United Nations forces in Bosnia could have used such a capability in their efforts to protect Sarajevo from Bosnian Serb artillery and mortar fire between 1993 and August 1995. During this period, strict ROE prohibited U.N. forces from conducting traditional counterbattery fire against Serb forces. Our concept would have allowed precision air strikes to be conducted against the Serb artillery. It should be pointed out, however, that the reluctance of the U.N. and NATO leadership to take decisive action against the Serbs during this period suggests that this capability could well have gone unused.

⁸The U.S. Army AN-TPQ-36 and -37 "Firefinder" radars normally cover a 90-deg sector. For more on counterbattery radars, see C. R. Hooton and Kenneth Munson, eds., *Jane's Battlefield Surveillance Systems 1994–1995*, Surrey, United Kingdom: Jane's Publishers, 1994, pp. 75–76, and Mark Hewish and Rupert Pengeley, "Peacekeepers and Counter-Punchers: Counter-Battery Radars Hold Their Ground," *International Defense Review*, January 1995, pp. 46–50.

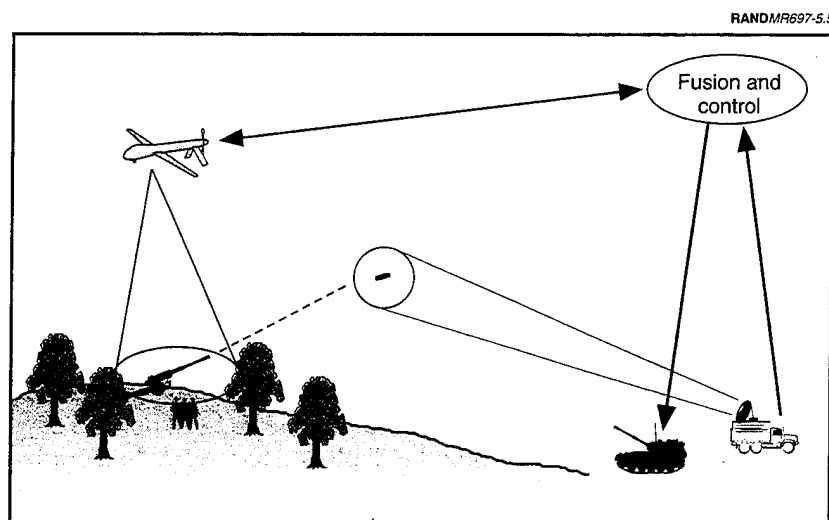


Figure 5.5—Ground-Based Counterbattery Radar to Cue UAVs

or noncombatants from locations near civilians. Traditional counterbattery barrage tactics would be inappropriate under such conditions. A more discrete and precise method for counterbattery fire is needed.

Our near-term concept employs a standard ground counterbattery radar to give the GPS coordinates of the artillery site to an airborne UAV. The accuracy of the counterbattery radar will vary as a function of how early it picks up the incoming round, the trajectory of the round relative to the radar, and other factors. Generally, the coordinates the UAV receives will be within 100 m of the artillery site. On a clear day, the UAV may spot the blast and smoke from the tube even before it receives cueing. Alternatively, it could slew its sensors to the coordinates and might detect the artillery from standoff. According to our calculations,⁹ four UAV orbits¹⁰ could cover 80

⁹See Appendix C for details.

¹⁰The current concept of operations for Predator dictates four aircraft per orbit for continuous coverage. Thus, a total force of 16 UAVs would be required to provide the highly robust coverage described here.

percent of this 20-km donut within 2 min, presumably spotting the artillery piece before it could be moved or camouflaged. Once at the firing location, the UAV would use EO, FolPen radar, and HSI to look for artillery in the open or hiding just inside the woods. The timeline (in minutes) for the OPCON under these conditions would be roughly as follows:

- T + 0 Enemy artillery opens fire.
- T + 1 Enemy artillery ceases fire.
- T + 2 Friendly CB radar detects incoming rounds, calculates position of enemy artillery, and relays coordinates to UAV.
- T + 3 Enemy towed artillery is packed up and moving.
- T + 3 51 percent coverage of target area by 4 UAVs.
- T + 4 80 percent coverage of target area by 4 UAVs.
- T + 6 100 percent coverage of target area by 4 UAVs.

In this scenario, it would be helpful to have MTI FolPen radars, on the UAV or on another platform, to track the artillery pieces on the move through woods to their hiding places. In either case, the UAV would use its laser designator to identify the target for TACAIR, AC-130s, or artillery.

Another possibility for peace operations would require the development of a database of known artillery sites. This database could be drawn from human intelligence (HUMINT), imagery, and other intelligence sources that can detect the artillery tubes, vehicles, ammunition boxes, aiming stakes, and other paraphernalia associated with artillery units. The GPS coordinates calculated by the counterbattery radar could be compared with the coordinates of known sites. When the two were within the known error range for the radar (say, 100 m) and no friendly forces or civilians were in the area, tube artillery,¹¹ MLRS, or TACAIR could be directed to the coordinates of the previously discovered site.

¹¹Whenever possible, tube artillery or multiple-rocket systems should be used for counterbattery fire; they offer a responsiveness unmatched by airborne platforms. For

LOCATE/DESTROY HEAVY WEAPONS IN WOODS: FAR-TERM OPCON

Our far-term concept envisions mounting a counterbattery radar in a pod that would be carried by a fighter aircraft (Figure 5.6).¹² In the past, it was not feasible to mount a counterbattery radar on an airborne platform, because the location of the radar at any moment was not known with sufficient precision to accurately fix the location of the firing artillery piece in coordinates that could be used for engagement by friendly forces. With the advent of GPS, aircraft and other mobile platforms now know their locations at all times in a standard coordinate system. Although it would need to be proven in tests, an airborne radar platform might offer greater precision than a ground-based radar,¹³ because the aircraft CB radar could detect the shell shortly after it leaves the tube, resulting in a much smaller error factor in the calculations based on the shell trajectory.¹⁴

This OPCON would use one or more aircraft with CB radars to patrol the artillery-denial zone. Once a shell was detected, the aircraft would calculate both the impact point and artillery site. Both would be compared with known friendly, neutral, and adversary locations by an onboard processor. Depending on the conflict ROE, the fighter pilot would either engage the artillery immediately or wait for a ground control cell to order a strike. In conflicts with strict ROE, the fighter might carry a small, air-launched UAV for a closer look at the target.

example, the M109A6 Paladin, the U.S. Army's most advanced self-propelled artillery, can fire within 30 sec of receiving a fire mission.

¹²Originally, we envisioned placing this radar on a light transport aircraft and passing the target location to orbiting fighter aircraft. USAF Col Rick Lewis convinced us that it would be preferable to put the radar in a pod carried by a fighter. We believe this is feasible. If it turns out not to be, another option—suggested by RAND's Carl Builder—would be to place the radar on an AC-130 gunship. Both the Lewis and Builder ideas have the advantage of combining sensor and strike platform, reducing the number of aircraft orbits.

¹³Airborne counterbattery radars could be increasingly valuable in future conflicts as rocket-assisted and terminally guided projectiles (both flying nonballistic trajectories) become more common.

¹⁴Winds, airborne particles, and imperfections in the artillery tube and shell prevent the shell from flying a perfect ballistic trajectory. The longer the shell is flying before detection, the more the trajectory will be affected by these factors. CB radar computers can be programmed to adjust for wind but not for these other factors.

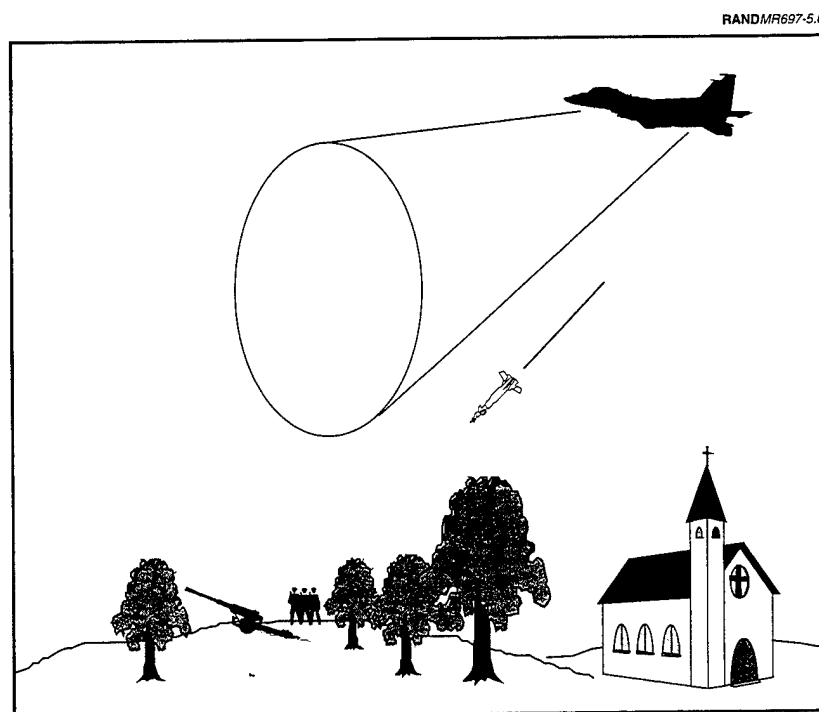


Figure 5.6—Airborne Counterbattery Radar

If the radar pod proves infeasible, a UAV or transport aircraft could carry the radar. In this case, a variety of strike options would be available. For example, the coordinates could be passed to an aircraft armed with a RAND-proposed weapon, the Precision Standoff Support Munition (PSSM).¹⁵ Designed to provide quick-response heavy-fire support to U.S. light infantry, the PSSM is an 8-in. artillery shell modified with fins and a GPS guidance system. It could be carried on special pallets on board C-130 transports, on bombers, or on fighters. When released from an aircraft at 25,000 ft, it can fly at 300 knots and glide 25 nmi in 3.5 min. In our example, a single aircraft orbiting over Sarajevo could cover the entire artillery-denial zone.

¹⁵See Watman and Raymer, 1994, pp. 15–18.

Finally—depending on the air defense threat—AC-130s, helicopter gunships, or friendly artillery could also be used for the counterfire mission.

PROTECT CONVOY FROM AMBUSH: NEAR-TERM OPCON

In counterinsurgency operations, lines of communication into the interior are often unsecure. Consequently, convoy protection receives considerable attention. During the Vietnam War, helicopters were routinely used to scout ahead of convoys, looking for roadblocks and other signs of trouble. Helicopters and fixed-wing aircraft also rode shotgun on convoys to provide immediate close support, particularly when the convoys were outside the range of supporting artillery.

If the air defense environment were relatively benign, helicopter gunships could continue to do so; AC-130s and OA-10s might also provide support. In situations in which advanced MANPADS were present, UAVs could provide the low-altitude eyes for convoys, using EO sensors. For improved detection of ambushers in dense brush or woods near the road, it would be helpful to have HSI processing and FolPen radars also. This concept would use these assets to patrol ahead of the convoy; a laser designator would mark targets for AC-130s or fighters (Figure 5.7).

PROTECT CONVOY FROM AMBUSH: FAR-TERM OPCON

Our far-term convoy-protection concept would seed acoustic, seismic, magnetic, and video unattended ground sensors at likely ambush sites such as creek fords, bridges, mountain passes, hairpin turns, and places of dense vegetation. These UGS might be implanted by ground forces or by air. The sensors would be monitored continuously. If the UGS detected suspicious activity but were unable to identify the target, UAVs could provide additional information. If targets were identified as hostile, then artillery, TACAIR, helicopter gunships, or AC-130s could be used to suppress them (Figure 5.8).

In both the near-term and far-term convoy-protection concepts, target identification is less of a problem than in previous tasks. The

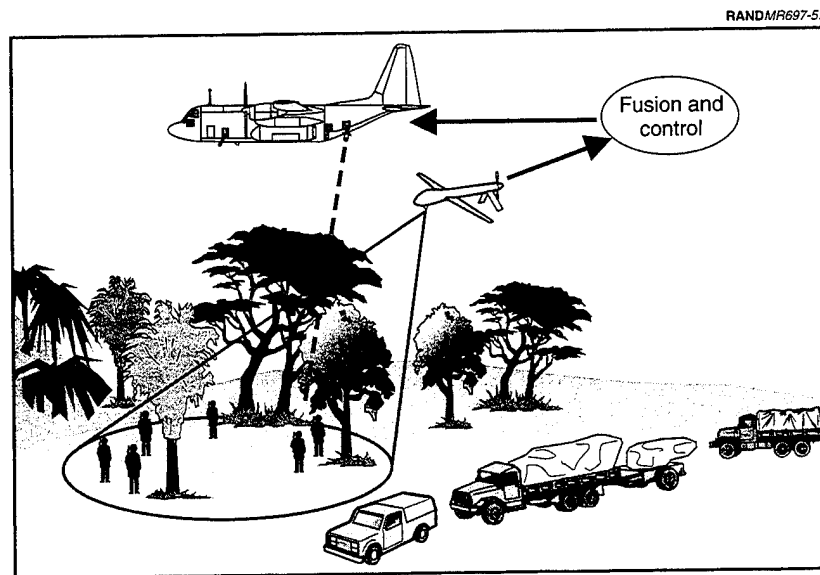


Figure 5.7—UAV Scouts for Convoy Protection

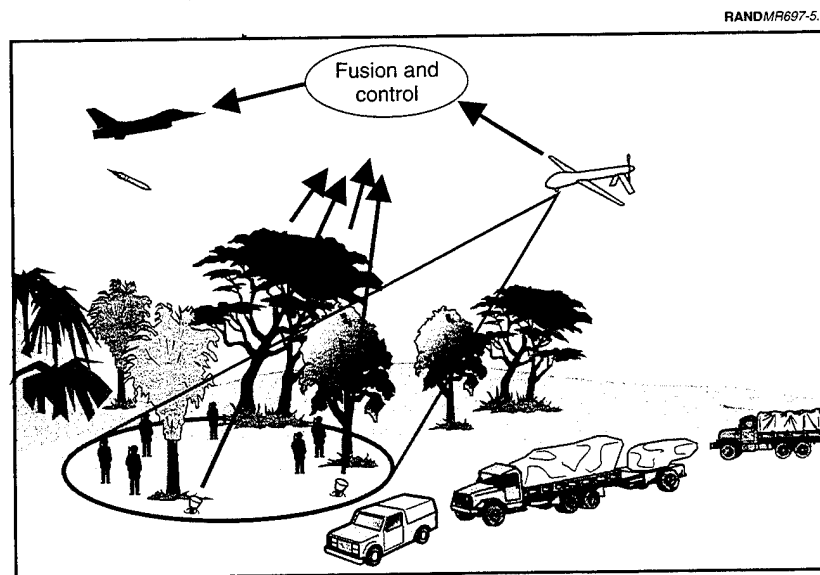


Figure 5.8—Unattended Ground Sensors Along Convoy Routes

objective is to provide early warning to the convoy. If the UGS/UAV/attack team can detect, identify, and destroy a threat, so much the better, *but warning is most important*. The convoy can always be halted and ground forces sent ahead if target identification is problematic. As long as the sensors do not have a major false-alarm problem, the convoy's progress should not be significantly hindered by these alerts. An experienced convoy commander who lacked air support would stop his convoy and send ground patrols ahead at dangerous sites, anyway. Thus, air support is not likely to induce additional delays. If anything, support by highly capable airborne platforms and UGS could give the convoy commander sufficient confidence to drive through areas where he would otherwise have insisted on stopping.

LOCATE/DESTROY URBAN SNIPER: NEAR-TERM OPCON

A skilled sniper operating from a concealed position in a building is extremely difficult to detect and defeat from the air.¹⁶ In many cases, he will have to be defeated by friendly ground force snipers. Fortunately, many snipers are poorly trained and fire from rooftops, balconies, and windowsills.¹⁷ These latter snipers are more vulnerable to detection and attack from the air. Our near-term concept uses a UAV equipped with Lifeguard¹⁸ and EO/IR sensors to detect and identify enemy snipers (Figure 5.9).

Lifeguard is a sniper-location system developed by Lawrence Livermore National Laboratories. It uses an undisclosed sensor phenomenology to detect the sniper's bullet. A ballistic model running on a commercial processor uses the sensor inputs to identify the bullet's position, speed, ballistic drag coefficient, and angle of flight.

¹⁶For more on sniper tactics, see John Plaster, *The Ultimate Sniper: An Advanced Training Manual for Military and Police Snipers*, Boulder, Colo.: Paladin Press, 1993.

¹⁷For example, in Mogadishu, U.S. snipers had no trouble dispatching Aideed's second-rate snipers firing from open locations. See Tony Capaccio, "U.S. Snipers Enforce Peace Through Gun Barrels," *Defense Week*, January 31, 1994, pp. 1, 8.

¹⁸Lifeguard could also be deployed on ground vehicles, at fixed sites, or as a man-portable system. See Scott R. Gourley, "The Sniper's Latest Nightmare," *International Defense Review*, April 1995, p. 66.

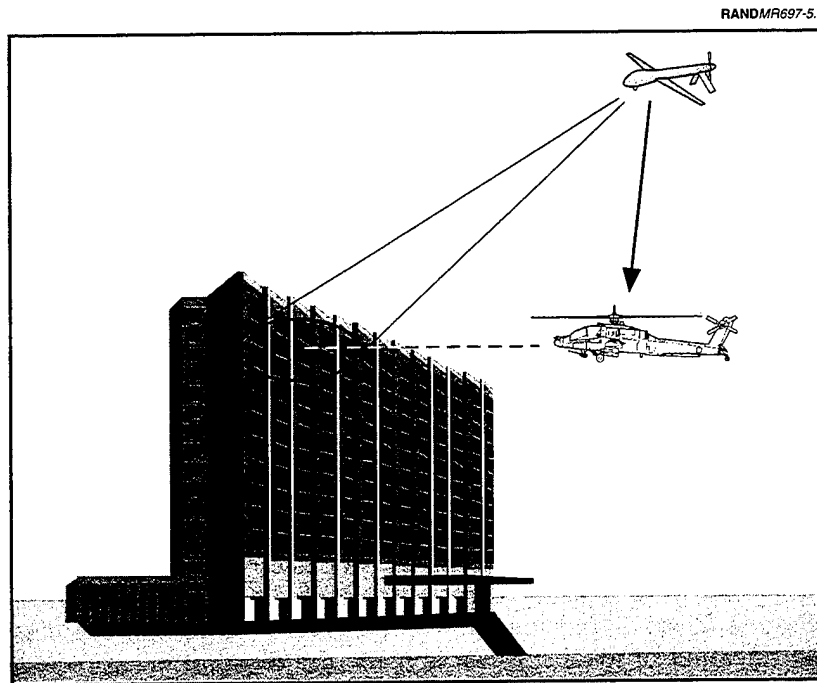


Figure 5.9—UAVs for Sniper Detection

This information is used to trace the bullet path back to the sniper. This entire process happens in an instant, showing each bullet track and the sniper's location on a video display. At 300-m range, a single Lifeguard can backtrack to within 2 ft of the sniper; with multiple sensors, it could backtrack to under an inch.¹⁹ In some tactical situations, the sniper could then be engaged with AC-130s, helicopter gunships, or, perhaps, TACAIR. In situations with tighter ROE, friendly counter-sniper teams would be cued by Lifeguard and engage with sniper rifles, grenade launchers, and heavy machine guns.

¹⁹Phone conversation with Dr. Thomas Karr, Lifeguard Program Director, Lawrence Livermore Laboratory, September 8, 1995.

LOCATE/DESTROY URBAN SNIPER: FAR-TERM OPCON

The initial tests of Lifeguard suggest that it may be the system of choice for both the near and far term. If, however, Lifeguard fails to live up to expectations, other approaches will need to be explored.

One concept would use an array of acoustic and LLTV/IR sensors to detect and locate the rifle fire, and a laser designator to mark the position for aircraft. The acoustic sensors would essentially triangulate the position and cue collocated video cameras with angle and azimuth. LLTV and IR, rather than basic video, would be necessary, because competent snipers fire from camouflaged positions—within the shadows of rooms and attics.

Given limited lines of sight and the complexities of sound propagation in urban environments, the array would probably have to be within a block of the sniper. Consequently, either the sensors would have to be so cheap that they could be seeded across the city or, more probably, placed with great care at places where sniper fire is considered most likely or is already a problem. This assessment would be based on previous sniper operations, intelligence reports, identification of ideal sites for snipers, the location of protected civilians, key friendly facilities, and other factors.

It might not be possible to insert these sensors from the air. They would have to be sited with great precision on roof tops, on balconies, in yards, and near building windows. The traditional spiked sensor that buries itself in soil clearly would not work in an urban setting, and current parachute delivery techniques lack the required accuracy. As briefly alluded to in the discussion of the far-term OPCON for detecting infantry in woods, it may be possible to design a GPS-guided parachute delivery system that could land sensors on rooftop-sized targets. If parachute delivery proved infeasible, these sensors would have to be inserted by friendly ground forces or civilian authorities—most likely in areas under the control of “friendlies.”

Once the sniper was located and lased,²⁰ we envision using a fighter to deliver a guided sticky foam bomb (see Figure 5.10). The bomb

²⁰A laser designator on the ground sensor would be directed at the outside of the building (i.e., at the window or hole in the wall) where the sniper fire came from. The

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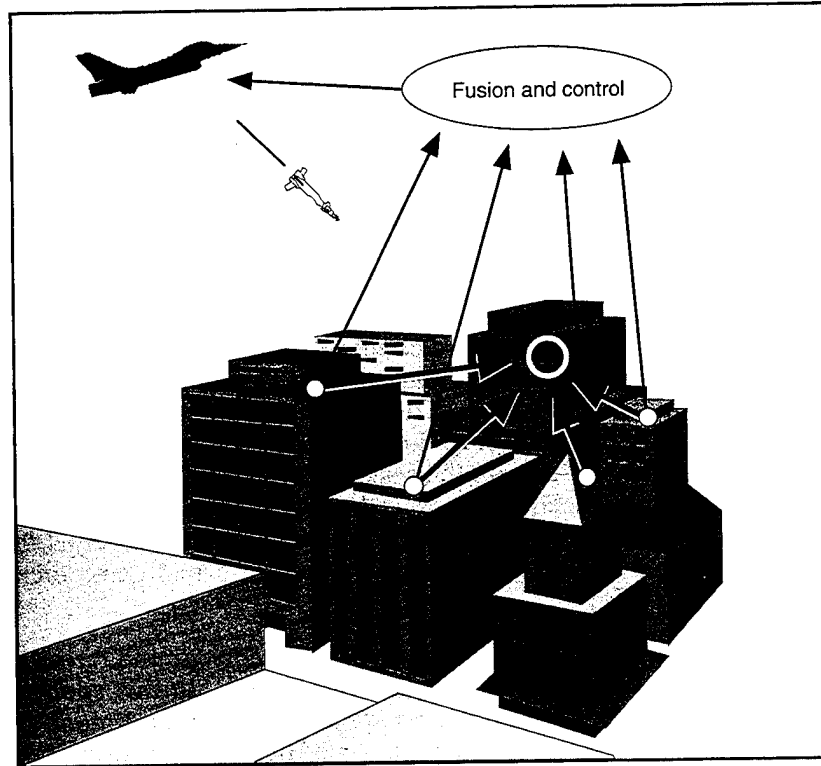


Figure 5.10—Acoustic Sensors for Sniper Detection

would be guided into the room the sniper was firing from and would detonate on impact, filling the room with sticky foam and incapacitating or killing the sniper. The bomb would consist of a foam generator wrapped in a lightweight plastic skin. Its brittle shell and light weight would prevent the bomb from going through walls and harming anyone other than the sniper. An alternative would make the acoustic/video sensor a weapon system by adding a high-pow-

laser illumination can be seen by a variety of sensors on board the attacking aircraft, allowing weapons to be directed at this part of the building.

ered rifle, machine gun, or grenade launcher to the sensor. A system operator at a remote site (airborne or ground-based) would make the final determination that the target was hostile and would remotely fire the weapon. Indeed, the weapon might even be triggered automatically by the sensor, although it is hard to imagine urban-warfare rules of engagement that would allow autonomous weapon discharge.²¹

INTERDICTION VEHICLES RESUPPLYING LIGHT FORCES: NEAR-TERM OPCON

The USAF is quite proficient at interdicting enemy lines of communication and supply. If a future counterinsurgency campaign faced enemy resupply operations similar to North Vietnamese movements along the Ho Chi Minh Trail, there can be no doubt that the USAF would wreak havoc on enemy trucking. In contrast, if the conflict were much smaller—say, on the scale of Farabundo Marti National Liberation Front (FMLN) operations during the El Salvadoran insurgency—interdiction would be more challenging, particularly if the insurgents use civilian trucks mixed in with normal commercial traffic.

In the near term, the USAF could support friendly ground forces by providing information about vehicle movement. In this concept, JSTARS would be used to detect suspicious vehicle movement, for example, after a curfew. If some parts of the country were under complete enemy control—free-fire zones, in essence—then JSTARS could be teamed with TACAIR to interdict enemy movement. It seems more likely that the rules of engagement would not allow air attack of vehicles without conclusive identification. We know of no near-term sensor that could identify the cargo of a closed truck. UAVs with various sensors could identify the type of truck, read its license plate, etc. Ultimately, however, ground forces would have to stop and search the vehicle to authoritatively determine its cargo. Thus, our concept envisions JSTARS cueing a UAV to take a closer look at the vehicle with EO sensors. If the vehicle looks suspicious to

²¹Lawrence Livermore Laboratory has proposed doing just this with their Deadeye system. It would couple an autonomous weapon to their Lifeguard sensor.

the UAV sensor operators, they could notify ground forces to set up a roadblock and search the vehicle (Figure 5.11).

INTERDICT VEHICLES RESUPPLYING LIGHT FORCES: FAR-TERM OPCON

Our far-term concept envisions using a large array of acoustic, seismic, video, and magnetic ground sensors and UAVs to monitor all vehicle traffic in suspect areas. X-ray, ultrasound, and other techniques might also be used to identify vehicle cargoes. A database combining visual, IR, magnetic, and acoustic signatures of vehicles with vehicle registration and other information would be used to identify suspect vehicles. This system would probably allow some vehicles to be identified as hostile and destroyed by TACAIR (Figure 5.12). Suspicious vehicles not clearly identified could be stopped by airborne delivery of less-than-lethal weapons (e.g., incapacitating agents, sticky foam barriers, electromagnetic pulses [EMPs], or high-

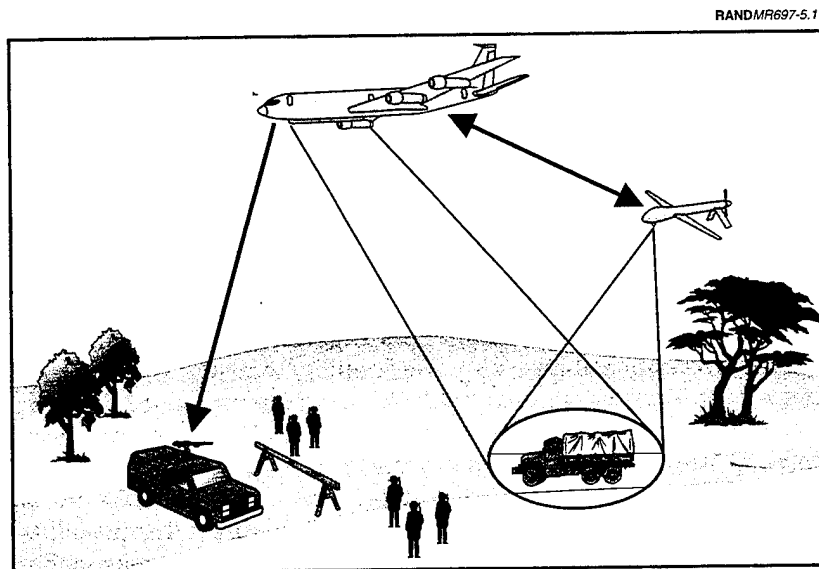
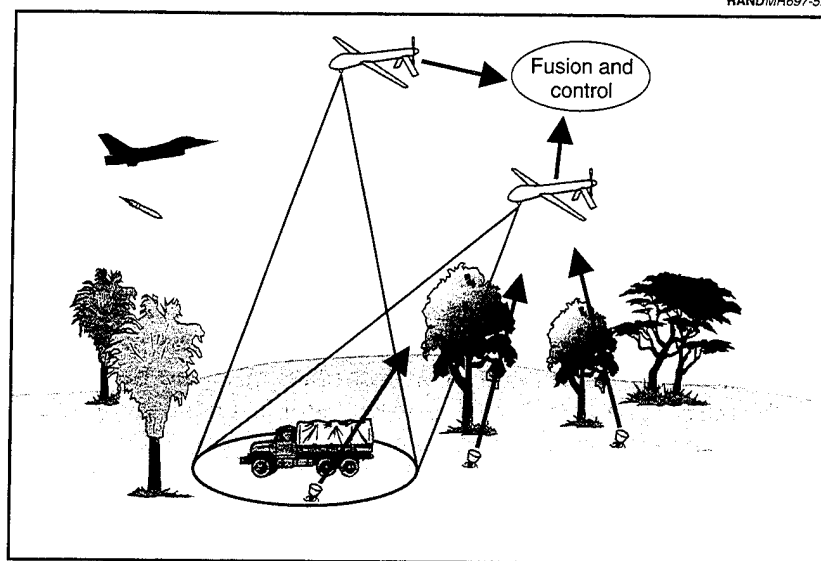


Figure 5.11—JSTARS/Ground Force Interdiction Team



power microwave to damage electrical components of vehicle engines). Airmobile ground forces would then land and investigate.

EVALUATING THE OPERATIONAL CONCEPTS

Several caveats are in order. First, we assume that these tasks are to be accomplished in the presence of a MANPADS threat that prohibits loitering at or below 10,000 ft AGL. We believe this is a reasonable assumption but recognize that in some benign air defense environments (e.g., in Panama during *Operation Just Cause*), AC-130s and other assets will operate at low altitudes. In those situations, the

Table 5.1
USAF Current Capabilities Compared with Near-Term and
Far-Term OPCONs

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Task	Current	Near-Term	Far-Term
Locate/destroy light infantry in the open	Some capability	Good capability	Good capability
Locate/destroy light infantry in woods	Very limited capability	Some capability	Good capability
Locate/destroy heavy weapons in woods	Some capability	Good capability	Good capability
Protect convoy from ambush	Some capability	Good capability	Good capability
Locate/destroy urban snipers	Very limited capability	Good capability	Good capability
Interdict vehicles resupplying light forces	Very limited capability	Some capability	Good capability

Very limited capability
 Some capability
 Good capability

USAF capabilities against light infantry in the open would have to be rated as excellent. Similarly, we rate the USAF capability to interdict vehicles resupplying light forces as very limited, only because we envision the efforts in most lesser conflicts to be more like smuggling (e.g., a relatively small number of commercial vehicles at times mixed in with civilian traffic) than classic military resupply. If, in contrast, the conflict is akin to Vietnam, with hundreds of enemy trucks traveling down well-defined lines of communication, we would rate the USAF capability to interdict those supply efforts as excellent.

That said, we would argue that Table 5.1 accurately reflects limitations in current USAF capabilities to accomplish the six combat tasks under the most likely lesser contingencies. Our preliminary analysis suggests that the near-term sensor programs described in Chapter Three and the UAV programs described in Chapter Four would improve USAF capabilities to accomplish all six tasks. The long-term OPCONs described here have the potential to give the USAF a good capability to accomplish all six tasks.

All these OPCONs have four features in common. First, they require a tightly integrated reconnaissance/surveillance/battle management system that can pass cueing from a broad-coverage, low-resolution

sensor to increasingly higher-resolution sensors. Second, they all use a mix of sensor platforms ranging from high-altitude manned aircraft to unattended ground sites. Third, they all require that high resolution EO sensors (for target identification) operate well within the MANPADS envelope. Fourth, most rely heavily on unmanned aerial vehicles because of their superior endurance, survivability, and expendability.

All the OPCONs would require that new sensor systems, aircraft, and other systems be developed and acquired. The USAF already plans to deploy a small force of Predator UAVs and is involved in the development of unattended ground sensors. Other systems, such as small air-launched UAVs or covert UGS, would necessitate new development programs.

It is premature to project costs for a robust anti-infantry capability. We can, however, make a few observations. The first is that the procurement cost of individual anti-infantry systems, such as Predator and ground sensors, is quite low compared with that of virtually all other USAF systems. Predator costs roughly \$3 million per aircraft, the ARPA UGS program projects individual costs to be below \$200,000, and the Naval Research Laboratory has produced small UAVs for under \$200,000. In most cases, data fusion and information dissemination for anti-infantry operations can be handled by existing or programmed systems. There will be some cost in developing new doctrine and procedures, but such costs typically are small compared with the cost of new communication or information management systems.

Additional engineering and operational testing of these and other OPCONs will have to be completed before the USAF even begins to consider what anti-infantry force enhancements would entail or cost. What we can say with some confidence at this point is that the USAF should not turn away from these issues because of a fear of the potential high cost of anti-infantry systems. If anything, these systems are likely to be a bargain, greatly enhancing USAF capabilities to accomplish important missions at a small price.

MAJOR FINDINGS

For the past 30 years, the USAF and DoD have rightly directed most aerospace ground attack R&D and procurement at technologies and systems that could improve air power's ability to detect, identify, and destroy armor. This massive effort resulted in dramatic improvements in air power's anti-armor capabilities, as demonstrated by the rout of Iraqi armor by allied air during the 1991 Gulf War.

With the end of the Cold War, the armor threat facing the U.S. military has significantly diminished. Now, U.S. forces are increasingly facing light opponents—often in difficult urban or mountainous terrain. With the proper focus, the USAF could achieve as great a leap forward in its abilities against these opponents as it did against armor.

To sum up, the major findings of our research are as follows:

- Light infantry forces produce signatures that can be detected by airborne and air-implanted ground sensors.
- A multiphenomenology approach—combining many different sensor types—offers the highest probability of detecting and identifying enemy light forces.
- Electro-optical sensors on platforms flying at 5,000 ft AGL and within 2 to 3 km of the target are key to distinguishing between enemy forces and noncombatants or friendly forces.

- The proliferation of advanced manportable surface-to-air missiles will increasingly constrain USAF operations at these low altitudes.
- Unmanned aerial vehicles will increasingly have to replace manned aircraft as sensor platforms for operations against light infantry.
- Integration of advanced airborne and air-implanted ground sensors, UAVs, and combat aircraft (from all services) can vastly improve air power's contribution against adversary light forces.
- These improvements do not require the development and acquisition of large, extremely expensive, or complex surveillance/strike platforms.

NEXT STEPS

In this study, we have identified deficiencies in the USAF capabilities against light infantry opponents and have presented new OPCODEs that may help address these deficiencies. The sensors and OPCODEs described here are all promising, but much more work will need to be done before their operational feasibility and effectiveness can be established. Some of this work can be done at RAND and other research institutions, but much of it will have to be done by the Air Force. As a first step, we recommend that the Air Force convene what Glenn Kent and William Simon call a Conceivers' Action Group (CAG)¹:

The CAG is an interactive partnership between those who know what is technically possible and those who know what is operationally viable and useful. . . . The Conceivers should be led by operational planners and include operators from the user commands, development planners from acquisition commands, scientists and engineers appropriate for each functional area in the operational concept, and a "Red team" to identify possible countermeasures to the concepts being defined.²

¹See Glenn A. Kent and William E. Simon, *A Framework for Enhancing Operational Capabilities*, Santa Monica, Calif.: RAND, R-4043-AF, 1991.

²Kent and Simon, 1991, p. 20.

The Director of Requirements (AF/XOR) on the Air Staff or Director of Requirements for Air Combat Command (ACC/DR) are two possible sponsors for this Light Adversaries CAG. The CAG could use the OPCONs in this report as a starting point. After identifying a set of promising OPCONs, the CAG would then propose additional engineering studies, and would field tests and exercises to evaluate their technical feasibility, operational practicality, and robustness. The CAG would also identify doctrinal and command-control-communication issues raised by these new OPCONs. It is our hope that the CAG report, tests, and exercises would convince a major user—such as Air Combat Command—to take the next steps necessary to turn these concepts into fielded capability.

FINAL THOUGHTS

It is unlikely that, in future lesser conflicts, the USAF will ever deploy an array of sensors so extensive and integrated that local commanders would have a complete view of enemy activities. Nothing equivalent to AWACS for air threats or JSTARS for armored threats is likely to exist in the world of light infantry. Even if the USAF deployed *all* the sensors described here—including patrols by friendly ground forces—along with a large UAV force, some enemy infantry activities would go undetected. Thus, the question is not, Will a multiphenomenology sensor array on UAVs, manned platforms, and ground sensors give a 90 percent probability of detecting adversary light forces? This is unlikely. Rather, the question is, Can these new technologies be integrated in a way that significantly improves USAF capabilities against light forces at an acceptable cost?

Some conflicts, because of terrain, ROE, weather, and other factors, will be more amenable to “air only” options than others. In some situations, enemy ground forces cannot be effectively detected, identified, and attacked from the air, so friendly infantry will be required to accomplish one or all of these tasks. Although overlaps with Army tactical surveillance assets would have to be worked out, most of the sensors and concepts discussed in this report would be applicable to close support and other air operations supporting friendly ground forces.

One thing is certain. The role of air power against light forces is likely to remain small if current USAF sensor deficiencies are not cor-

rected. It is our judgment that the USAF can make a significant contribution in virtually all scenarios if it embraces this mission area and pursues the possibilities described in this report.

CHARACTERISTICS OF U.S. ENDURANCE UAVs¹

Characteristic	Name/Contractor		
	TIER II ^a Predator/ General Atomics	TIER II+ Global Hawk/ Teledyne Ryan	TIER III- Darkstar/ Lockheed- Martin/Boeing
Length (ft)	27	44	15
Wing span (ft)	49	116	69
Endurance and range (with payload below)	24 hours at 500 nmi	24 hours at 3,000 nmi	8 hours at 500 nmi
Coverage per mission ^b (sq. nautical miles)	10,000	40,000	17,000
Maximum takeoff weight (lbs)	1,873	25,000	8,600
Cruise speed (knots)	110	345	250
Range (nmi)	500	3,000	500
Maximum altitude (ft)	25,000	65,000	45,000
Payload (lbs)	450	2,140	1,287
Sensor type	EO/IR/SAR	EO/IR/SAR	EO or SAR
Cost (\$M)	3.2	10	10

^aTier designations are original names for the three UAV programs. Each tier reflected specific capabilities.

^bUsing SAR from their normal operating altitudes.

¹For more information on UAVs, see U.S. Department of Defense, *Unmanned Aerial Vehicle Master Plan*, Washington, D.C., 1994, and *Jane's Battlefield Surveillance Systems*, London: Jane's Publishing, 1994.

LIGHT INFANTRY AIR DEFENSES

This appendix discusses the evolving manportable air defense system (MANPADS) threat and how potential adversaries might integrate MANPADS into a Distributed Integrated Air Defense System (DIADS).

MANPORTABLE AIR DEFENSES

One need only look to today's newspaper to find proof of the deadly accuracy of MANPADS. In April 1995, Tamil separatists downed Sri Lankan transports; in August 1995, Bosnian Serb gunners used a MANPADS to down a low-flying French Mirage.¹ As noted in Chapter Four, more than one-third of the aircraft lost in the Gulf War were shot down by MANPADS, and U.S.-supplied Stinger surface-to-air missiles (SAMs) helped the Afghan resistance drive the Soviet Union from Afghanistan. MANPADS have also played roles in conflicts as diverse as Vietnam, the 1973 Arab-Israeli War, and the Falklands War in 1982.² Use of MANPADS is likely to expand as increasingly sophisticated systems join those already deployed globally.

¹See "Sri Lanka Says Rebels Down Two Planes," *The Washington Post*, May 1, 1995, p. A20, and "Serbs Cheer as French Mirage Shot Down," Reuters newswire report, August 30, 1995.

²The Blowpipe system was, in fact, used by *both* sides in the Falklands. See, for example, Rodney Burden et al., *Falklands: The Air War*, London: Arms and Armour, 1986, p. 385, and Jeffrey Ethell and Alfred Price, *Air War South Atlantic*, New York: Macmillan, 1983, p. 131.

MANPADS were originally designed to supplement radar-guided mobile air defenses for deployed forces.³ They can be carried by one or two men—the launcher, with a missile round in place, typically weighs from 35 to 46 lbs. Most systems can be deployed in under 15 sec and can be reloaded and fired again in as little as 8 sec. More-modern variants, such as the French Mistral, feature all-aspect engagement and can engage targets at altitudes up to 15,000 ft. Most use a passive detection system, usually acquiring their target and guiding the missile by infrared or ultraviolet (IR/UV) radiation.⁴ Those systems that do require some target illumination employ a very narrow and hard-to-detect laser beam to guide the missiles. Table B.1 summarizes the salient characteristics of most currently deployed MANPADS.

Older MANPADS acquire and track in the 1.7–2.8- μ m range (the signature wavelength for aircraft exhaust); newer systems with IR/UV sensors acquire and track in two spectral bands (under 0.4 μ m and between 3 and 5 μ m). Other systems signal the gunner when they see the IR or UV return of the aircraft itself (as opposed to the engine exhaust). Advanced MANPADS have propulsion and control technology that enables the missile to execute 8-g turns; fighter aircraft can no longer count on outmaneuvering attacking missiles.

Because they rely on passive detection and tracking, MANPADS launches are often not detected until the missile is in flight.⁵ Thus, a

³They also are used by special forces to attack enemy aircraft as they take off and land at their own bases. MANPADS that can be fired remotely or triggered using a time-delay and remote sensor are ideal for this role. The latter MANPADS become, in essence, anti-aircraft mines.

⁴By *passive* we mean the targeted aircraft is not illuminated by the acquisition sensor of the system, as it is by an active radar homing system or a semiactive radar homing system. The gunner aims the missile sight in the direction of the airframe, and the aircraft's IR signature is acquired by the sensor suite. The missile is fired, and the missile seeker homes in on the aircraft by following the IR signature.

⁵When operating in areas where MANPADS are thought to be deployed, AC-130 gunship crews man observation bubbles on the underside of the aircraft's rear cabin and starboard side expressly to look for missile launches.

Table B.1
Key Attributes of Selected MANPADS

System	Country	Type	Aspect	Maximum Target Speed (kph)	Range (km)	Altitude (km)
Mistral	France	IR	All	2,000	6.0	4.5
Hongying 5	PRC	IR	Rear+	—	4.4	2.3
Type 91	Japan	IR/UV	All	—	—	—
SA-7	Russia	IR	Rear	540	3.6	2.0
SA-7b	Russia	IR	±30 deg	936	4.2	2.3
SA-14	Russia	IR	All	1,116	4.5	3.0
SA-16	Russia	IR	All	1,296	3.0	3.5
SA-18	Russia	IR	All	1,440	5.2	3.5
RBS-70/90	Sweden	Laser	All	>1,000	7.0	4.0
Javelin	UK	SACLOS	All	<1,000	5.5	3.0
Blowpipe	UK	IR/SACLOS	All	<1,000	3.4	2.5
Starstreak	UK	Laser	All	>1,000	7.0	—
Starburst	UK	Laser	All	>2,000	4.0+	—
Redeye	U.S.	IR	Rear	<1,000	5.5	2.7
Stinger	U.S.	IR	Rear+	>1,000	8.0	3.5
Stinger RMP	U.S.	IR/UV	All	>1,000	8.0	3.8

NOTES: IR—infrared; SACLOS—semiautomatic command to line of sight; UV—ultraviolet (pseudo-imaging); RMP—reprogrammable microprocessor.

pilot engaged by a modern MANPADS finds himself attempting to evade a missile that

- he could not detect until after it was launched
- is faster and more maneuverable than his aircraft
- has a seeker head that defeats many of the countermeasures—flares, sudden jinks, and so forth—that would have fooled an earlier-generation SAM.

Conventional IR MANPADS

Early systems (e.g., SA-7, SA-7b, Redeye, and Blowpipe) featured IR seekers in the 3.5–5.0- μm range for detecting engine signatures. For this reason, these systems were fired at a target moving away from the gunner. Fast-moving aircraft routinely outrun such missiles, if they are warned of their launch. Other countermeasures include

flares (which imitate an engine signature) and evasive maneuvers (which the missile cannot follow).

Pseudo-Imaging MANPADS

Pseudo-imaging MANPADS (e.g., SA-14, SA-16, Stinger, and Shorts Starstreak) detect the skin signature of the aircraft rather than the engine signature. This signature allows them to engage the aircraft from all aspects and to defeat flare and similar countermeasures. Other systems, such as the British Shorts Starstreak and the Swedish Bofors RBS-70, use a laser-designating beam to guide the missile to its target.

The latest advances in pseudo-imaging MANPADS technology are reflected in the U.S. Stinger RMP (reprogrammable microprocessor) and the Japanese Toshiba Type 91 Kin-SAM (in production as of 1991). Both feature (UV/IR) imaging guidance systems.

The next generation of SAMs will likely achieve a full imaging capability via advanced multiphenomenological sensors and automatic target recognition (ATR) software.

Countering MANPADS

Defeating early-generation MANPADS was often a simple matter of outrunning or outmaneuvering the missile once the launch was detected. Countermeasures (e.g., flares) were also often effective against these systems. These weapons were typically limited to day-only operations, not because of any limitation in their seeker but because the gunner could not detect an incoming target and train his missile on it in darkness. Finally, weapons such as Redeye and the original SA-7 had firing envelopes that covered only low altitudes and thus could be overflowed without overly degrading the aircraft's operational effectiveness.

The technical evolution of MANPADS is rendering many of these defenses obsolete. Newer weapons can fly faster, go higher, track through higher-g turns, and have homing sensors that are ever more difficult to spoof. Even darkness is no longer a guarantee of safety, because "some countries are now giving their air defense weapons, including man portable surface-to-air missiles, a 24-hour capability

by installing thermal night sights.”⁶ Table B.2 arrays the effectiveness of aircraft defensive tactics against currently deployed MANPADS.

The consequences of these advances are especially troubling when the types of platforms, weapons, and tactics the USAF currently would employ against light forces are considered. For example, the AC-130 Spectre gunship is a very effective sensor and weapon platform against infantry, light vehicles, and guerrilla encampments. The Spectre, however, is most effective when it can orbit its target at or below 10,000 feet. This profile puts the big, slow, valuable aircraft directly in the heart of the performance envelope of many modern MANPADS.⁷ Although the aircraft is equipped with some warning and countermeasures systems, those systems are directed more against radar-guided SAMs and early-generation MANPADS; survivability against modern IR SAMs must be considered questionable unless the aircraft moves much higher, where its sensors and weapons are less effective.⁸

The key weaknesses of modern MANPADS are essentially twofold: MANPADS have limited range and so can cover only a limited area and, historically, they have not been netted together in a way that provided timely warning of aircraft approach to missile operators. Because of advances in rocket motors, missile ranges have gradually increased over time; however, the need to retain portability puts an upper limit on booster size and, hence, range.⁹ The second failing

⁶“The Air Defence Evolution Takes Off,” *Jane's World of Defence* 1995, London: Jane's Publishing, 1995, p. 137.

⁷Chapter Five presents several OPCONs that use UAVs as offboard sensors for AC-130s. UAVs would minimize the time the gunship spends over the target and would enable it to operate from higher altitudes.

⁸The second-largest single loss of life inflicted on U.S. forces in the Gulf War resulted from the shooting down of a USAF AC-130H gunship with 14 on board; the aircraft was lost to a shoulder-launched SAM.

⁹Increasingly, MANPADS are being fitted with vehicular mounts suitable for a range of carriers from jeeps and high-mobility multipurpose wheeled vehicles (HMMWVs) to light armored vehicles. For the most part, though, these seemingly oxymoronic vehicle-mounted MANPADS are being developed to increase both the mobility of the systems and the number of ready rounds available to a fire unit. It does not seem impossible, however, that a missile with performance similar to the 1960s-era Chapparral/Sea Sparrow/SA-8 class of SAM—15-km ranges and effective altitudes ap-

Table B.2
Effectiveness of Aircraft Defensive Tactics Against Selected MANPADS

Selected MANPADS	Aircraft Countermeasures			
	Fly Above 20,000 ft	IRCM/Flares	Evasive Maneuver	Laser CM
SA-7b	X	X	X	
SA-14	X	X	X	
SA-18	X	X		
Stinger	X			
RBS-70	X		X	X
SA-16	X	X		
Mistral	X			
Keiko	?			

NOTE: IRCM—infrared countermeasure.

may be addressed by taking advantage of the ongoing revolution in microelectronics and information processing to create an air defense system that combines the strengths of the Integrated Air Defense System (IADS) and of MANPADS-type weapons. We call this a Distributed Integrated Air Defense System and view it as the most challenging threat to future USAF operations against light forces.

DIADS

The idea behind a DIADS is to exploit and integrate available technology into a system that maximizes the effectiveness of MANPADS-type weapons while avoiding the vulnerabilities—such as critical fixed sites—associated with a traditional IADS.¹⁰

The key to a successful DIADS appears to be mobile surveillance and command-and-control (C2) technologies. The French firm Thomson, among others, offers a variety of small radars with ranges

proaching or exceeding 20,000 feet—could be developed for deployment from utility-class vehicles (e.g., HMMWVs) in the next decade.

¹⁰It is probably worth noting that these same technological advances could be used by a more advanced opponent to enhance the survivability and capability of a true IADS. We discuss the DIADS concept in the context of SA-18s and radars with a 20-km range; however, we encourage analysis of the applicability of the same technologies and techniques on larger scales.

typically of about 20 km. Ericsson of Sweden also produces a truck-portable radar for use with the Bofors RBS-90 SAM. Several companies produce remote surveillance sensors, such as the Thomson-Thorn Air Defense Alerting Device (ADAD), a passive IR system that can "detect targets through battlefield smoke, mist and haze."¹¹ These systems can be vehicle-mounted or set up on the ground.

These detection and tracking systems can be netted together, using the Global Positioning System (GPS) and cellular and/or satellite communications technologies. The French Aspic system is an example of a C2 architecture well-suited to this type of application.

Advanced MANPADS and vehicle-mounted MANPADS missiles would then engage and destroy the enemy aircraft. Using a variety of guidance technologies—advanced IR, target-imaging, laser-beam riding, and even active radar homing—these missiles would be more lethal than their current counterparts. By operating in a variety of spectra, they would also be more resilient to countermeasures. Engagement control would be provided by improved variations on already-existing systems, such as the U.S. Army's Avenger or the German Atlas, each of which combines multiple MANPADS launchers with IR and optical sensors, a laser range finder (LRF), and a highly automated command station—all of which can be mounted on a heavy-duty 4 × 4 vehicle.

Survivability is enhanced by performing all key functions—surveillance, tracking, C2, and engagement—with a system that is entirely or largely passive, mobile, or both. Such a system could greatly complicate mission planning, compel the use of tactics that reduce the efficacy of air power, divert effort into piecemeal suppression of enemy air defense (SEAD) against the individual components of the system, and inflict sufficient attrition to either impede operations, create a "strategic event," or both.¹²

¹¹T. Nash, "Dossier: Manportable Air Defenses," *International Defense Review*, September 1995, p. 88.

¹²We define a *strategic event* as an occurrence that has ramifications on conflict outcome far beyond its actual military effect. "Bloody Sunday" in Somalia is a classic example. Although the loss of U.S. life was tragic, the Rangers accomplished their mission. They captured several of Aideed's key advisors, successfully defended their positions from attack by a force that outnumbered them at least 10 to 1, inflicted horrific casualties on Aideed's militia, and conducted a successful withdrawal. Furthermore,

However, such a system also has vulnerabilities that the USAF could exploit. Since the DIADS is composed mostly of very-short-range passive components, it is heavily dependent for coordination on the early-warning and area-wide picture provided by the longer-range radars and by the satellite communications (SATCOM). The SATCOM can be jammed in a variety of ways, and the radars can be localized by signals intelligence (SIGINT) assets and attacked. To the extent that such attacks are successful, the USAF would then be faced with isolated MANPADS, anti-aircraft artillery (AAA), and mobile radar-guided SAM threats. Experience in Bosnia and Iraq suggests that high-performance aircraft flying at medium altitudes would be relatively safe in such an environment but that operations of other critical aircraft could be significantly constrained.

HYBRID SYSTEMS

Perhaps the most likely threat the USAF will face in future lesser conflicts is neither the basic MANPADs threat nor the elegant DIADS threat pictured here. Most adversaries will lack the resources, organization, and technical sophistication to fully exploit the DIADS concept, but many may copy some of its features. Such a hybrid system might contain the following:

- A mix of old and new MANPADS (SA-7s, Stingers, SA-14s)
- A mix of AAA (23mm, 37mm, and a few large pieces)
- A warning network of spies and observers connected by standard, cellular, or direct satellite telephones and military radios, and, possibly, by e-mail.

This system would not attempt to defend all rebel territory; rather, it would focus on defending key locations, taking advantage of targets of opportunity and conducting the occasional ambush of USAF air-

the ability of U.S. forces to carry out their tasks in Somalia was not significantly degraded by the U.S. casualties. Nonetheless, the shock effect of the day's horrors on the U.S. public forced a major adjustment in U.S. policy. Since many, if not most, of the conflicts in which the United States confronts a light adversary will likely be undertaken with tenuous domestic political support, the risk of a strategic event (e.g., the loss of an AC-130) will need to be kept in mind. Operationally insignificant attrition could have enormous political effects.

craft. This approach could make even old MANPADS (e.g., SA-7s) a threat at night. Spies and early-warning observers would relay information about aircraft activity to the base camp. This information might be based purely on acoustic intelligence (e.g., "I heard a plane fly over at 10:30 p.m. on a heading of 180 degrees").¹³ Other observers would be equipped with night-vision goggles (NVG) and assigned to MANPADS and AAA teams.¹⁴ The observers would use their relatively wide-field-of-view NVG to scan the night sky. When they detected USAF aircraft, they would talk the MANPADS crews (with their narrow-field-of-view sights) onto the targets. This process might be something as simple as grabbing the MANPADS crew member and pointing him in the right direction and to the right elevation.

SUMMING UP

In this appendix we have discussed a range of air defense options available to a future light adversary. While the USAF is unlikely to face an IADS in such a contingency, even the simplest MANPADS-based air defenses could present a threat to air operations. As the missiles become faster, smarter, and longer-ranged, that threat will increase.

Beyond that, the USAF should be prepared to counter DIADS and hybrid threats. In the near future, DIADS and hybrid defenses will probably be cobbled together with air defense equipment left over from the Cold War, as happened in Bosnia when Bosnian Serb forces netted some elements of the old Yugoslavian IADS with mobile launchers. Looking farther out, it is likely that at least a few adversaries will seek to exploit advances in civil and military technologies to deploy an air defense system less vulnerable to air attack than the classic IADS.

¹³The Viet Cong used simple techniques such as this to great effect. See Ronald H. Cole, "Development of a Viet Cong Antiaircraft Capability: 1962-1965," in Robert Futrell, *The United States Air Force in Southeast Asia: The Advisory Years to 1965*, Washington, D.C.: Office of Air Force History, 1981, Appendix 2, pp. 283-285.

¹⁴Both Russian and U.S. NVG are widely available today and are likely to become more so. Less-expensive night-vision devices are also being sold in outdoor-recreation stores for night animal watching and other activities.

UAV COVERAGE POTENTIAL

This appendix presents additional details on the use of unmanned aerial vehicles (UAVs) in the counterbattery mission discussed in Chapter Five.

The scenario assumes that the rules of engagement require visual identification of the enemy artillery battery. Using the 900mm electro-optical spotter, the Predator can detect and recognize towed artillery at 9,500 ft above ground level and 3.6 km ground range.¹ The city is assumed to be 10 km in diameter, and the area around the city from which the shelling is emanating is assumed to be 20 km in diameter. Terrain and foliage effects are not considered. After being cued by a ground-based counterbattery radar, the UAV moves toward the coordinates of the enemy artillery at 100 knots. Table C.1 shows the percentage of the surveillance area that can be covered as a function of time, based on the number of UAVs dedicated to this mission. The UAVs were initially placed at locations that were considered operationally desirable.

This analysis assumed that artillery could operate anywhere in the surveillance area, which would not be the case in a real-world situation. For example, terrain will often dictate the enemy's launch points. The enemy also may have presurveyed launch points; U.S. forces may have identified some of these. Both of these factors will

¹U.S. Department of Defense, *Medium Altitude UAV Program Status Report 2*, Washington, D.C.: UAV Joint Program Office, February 1995 (videotape).

Table C.1
Percentage of Surveillance Area Covered as a Function of Time
and Available Number of UAVs

Number of UAVs	Time (min)						
	0	1	2	3	4	5	6
1	4	12	21	29	38	49	58
2	9	25	40	55	70	86	97
3	13	38	60	82	97	100	100
4	17	51	80	98	100	100	100

allow the U.S. forces to use more-optimal starting locations for the UAVs than this analysis shows. In addition, since U.S. forces will have some idea of the time required for the enemy to prepare its weapon for travel and move away from the firing location, they can place their search UAVs in optimal locations.

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