Helicopters on the asymmetric battlefield: challenges for photonics

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ABSTRACT

The problem set of battlefield helicopters and related photonics in asymmetric scenarios is addressed with emphasis on survivability and electronic warfare. The problem set is identified starting from an operational perspective, asking how different the asymmetric battlefield is from the traditional Cold War scenario, and by identifying relevant characteristics of battlefield helicopters. Based on this information requirements for photonics are deduced. It is concluded that the shift to asymmetric conflicts brings evolutionary—but not revolutionary—challenges for photonics, mostly so for the laser community. Main causes for the evolutionary drive are shortened engagement ranges, increased threat from ballistic and CBRE weapons, stringent ROEs, and assassination operations.

Keywords: Helicopters, asymmetric conflicts, survivability, electronic warfare, photonics, lasers, CBRE threats.

1. INTRODUCTION

1.1 From cold traditional war to hot asymmetric conflicts

The demise of the Soviet Union pushed back the global threat scenario of nuclear and/or high technology conflicts between roughly equal enemies. Security thinking became preoccupied first by local ethnic and religious conflicts, with Somalia, Chechnya, and the former Yugoslavia being case examples. The next shift occurred with the terrorist attacks in the USA on September 11, 2001 (9/11), after which terrorism took over as the most popular politico-military theme. The US-led invasion of Iraq in 2003 was a brief return to conventional warfare (a.k.a. symmetric warfare, traditional warfare, regular warfare, etc.), although it was fought between unequal opponents. Military colleges are bound to study the security development in Iraq since summer 2003 as an example of the birth and escalation of asymmetric warfare (a.k.a. guerilla warfare, insurgency, unconventional warfare, irregular warfare, terrorism, etc.): An invading force, superior in men and materiel, being opposed by an ill-equipped but determined enemy, where—to paraphrase Henry Kissinger—the latter stands a good chance of “winning by not losing” and the former of “losing by not winning”.[1]

Although the outcome of the present “Global War on Terror” remains undetermined, it is obvious that the asymmetric battlefield that we now see in Iraq and elsewhere is different from the traditional Cold War scenario. One may even be tempted to claim that there is a revolutionary military change in progress. However, such a view was outlawed already half a century ago: “Observers constantly describe the warfare of their own age as marking a revolutionary breach in the normal progress of methods of warfare. (....) It is fallacy, due to ignorance of technical and tactical military history, to suppose that methods of warfare have not made continuous and, on the whole, fairly even progress.”[67]

1.2 Helicopters and warfare

From their humble start in World War II, helicopters have become an integral part of ground warfare. The virtues of transport helicopters are generally accepted, exemplified by the following statement: “As has been said a thousand times, there are two main elements of military strength in the land battle: mobility and firepower. We cannot be deficient in either, and nothing else—absolutely nothing else—affords the battlefield mobility of the helicopter.”[3] The merits of attack helicopters, in contrast, are debated. The failed operation at Karbala, Iraq, by a large contingent of Apache helicopters on the night of 23-24 March 2003,[25] led to the following critical view: “(…) when you compromise on survivability for the sake of mobility, you have a lot of formidable firepower that is of limited use, since it simply can’t survive.”[4]

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Helicopters are expensive platforms and a helicopter kill offers insurgents an aspired prize, publicity. Helicopters are therefore sought-after targets.[33] To the survivability scientist helicopters offer a unique set of problems that blends the scientific, military, and technical. Despite this, little all-encompassing research has been done in the field of helicopter survivability.[b] The discussions in Ball[5] and Heikell[6] cover most of the available information. Additional information can be found scattered in various books, research papers, and periodicals; particularly in the journal Aircraft Survivability (available at http://www.bahdayton.com/surviac/asnews.htm).

1.3 Photonics and battlefield helicopters

Military photonics, or better expressed *electro-optics*, also saw a humble conception during World War II (experiments with IR communication had commenced before World War I). Helicopters met the photonic challenge in 1971, when the first Strela 2 (SA-7) man-portable air defense (MANPAD[c]) missile was fired at a US helicopter during operation Lam Son 719 in Laos.[7] Today helicopters either exploit photonics or face photonic threats in the wavelength band from approx. 0.2 to14 µm.[d] Major uses of photonics are:[8-11,61]

- Fiber-optic avionics data buses, including fly-by-light systems for control of the aircraft
- Ring laser and fiber-optic laser gyros for navigation and stabilization
- Obstacle avoidance systems that reduce the risks of low-level flight
- Navigation lights that support manual collision avoidance
- Photonic gauges of the aircraft's health and usage monitoring system (HUMS)
- Multi-functional displays (MFDs) that show information on aircraft status, mission progress, and flight environment; together with head-up displays (HUDs) and/or helmet mounted displays (HMDs)
- EO night vision (NVIS) equipment that allows operations around the clock
- Visual and IR imagers, together with laser range finders, used to detect, identify, locate, and track targets
- Lasers, together with IR and visual band seekers/trackers/fire control systems (FCSs) for weapon aiming and guidance
- Threat systems—most notably guns, missiles, rocket propelled grenades (RPGs), and anti-helicopter mines—that exploit optical and/or EO devices
- Laser, IR and/or UV detectors that search for and track potential and approaching threats
- Threat evasion provided by broadband countermeasures (CMs), such as flares and omnidirectional infrared jammers, and/or narrow- or broad-beam/band directional infrared countermeasures (DIRCMs)
- Test and evaluation (T&E) equipment for maintenance, laboratories, and on open air ranges (OAR); together with hardware and software for modeling and simulation (M&S).

Military photonics must be discussed with due respect for its dynamic operational environment: Atmospheric and terrain conditions that continuously change, threat and ownship signatures and their spatial distribution, battlefield friend-foe-neutral signatures, tactical actions that either augment or defy technical measures, threat scenarios with both conventional and unconventional weapons, and communication networks that support aircrew situational awareness (SA) and contribute to the helicopter's tactical behavior.

1.4 Research objective

It was claimed above (section 1.1) that methods of warfare make a continuous and fairly even progress. However, scrutiny of newspapers and articles in professional journals since 9/11 indicates a degree of puzzlement among politicians, military commanders, and within the military R&D establishment. There emerges, therefore, the question of how different the asymmetric battlefield is from the traditional (symmetric) one, and what should be learned and understood in order to fight effectively. These questions are addressed here in the framework of battlefield helicopters and related photonics, with emphasis on survivability and electronic warfare (EW). It should be noted that this is an unclassified work, which brings limitations since open information sources are mainly American and focus on the

[b] Survivability is generally divided into *susceptibility reduction* and *vulnerability reduction*. The present work deals exclusively with susceptibility reduction, unless otherwise is stated.
[c] The alternative abbreviation is MANPADS, for man-portable air defense *system*. In this case the missile launcher is included in the term *system*.
[d] This paper uses the term *electro-optics* for equipment that combine electronics and optics, and operate in the wavelength band 0.2 to14 µm. The terms *ultraviolet, visual,* and *infrared* are used to distinguish between respective wavelength bands.

present situation in Iraq and Afghanistan while asymmetric conflicts exist in numerous parts of the world. The present and future role of photonics in radiofrequency (RF) systems (communications and RF EW equipment, radars) will not be covered.

2. PROBLEM IDENTFICATION

Figure 1 presents the problem set of the research objective as a Venn diagram. The kernel of the objective is the shaded area. However, it must be expected that the discussion cannot be constrained only to this area since the border between symmetric and asymmetric conflicts is blurred. Further, the major force in an asymmetric conflict typically uses its superiority in military technology: So did the Romans two millennia ago, the European colonial powers in their wars of conquest, the USA in Vietnam and Iraq, and Russia in Afghanistan and Chechnya. The overlaid ellipse is therefore a better representation of the issues to address.

The previous statement raises a political question: Whose interest does the present research represent, the interest of the major force or the interest of the insurgents? In answer, the ambition is to take a neutral military-technological view although it must be admitted that helicopters are used only by major forces.

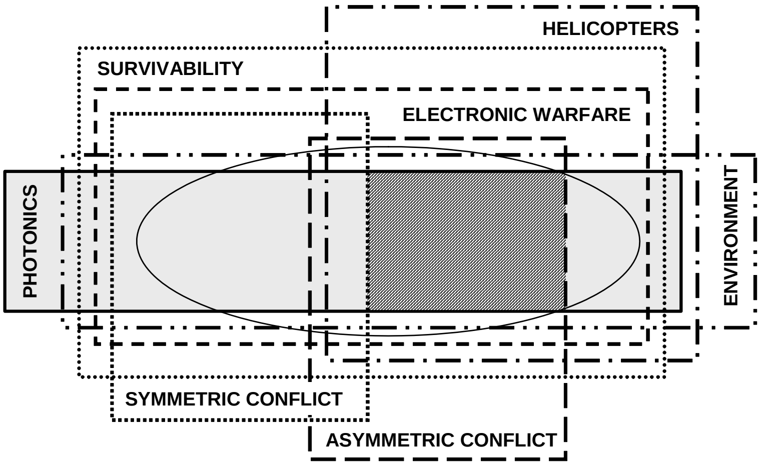


Figure 1. The problem set as a Venn diagram. Note the interpretation that electronic warfare is a subset of survivability, meaning that we are interested only in electronic warfare self-protection. Survivability and EW are not restricted to war; they have strong peacetime components in intelligence, R&D, etc. A further interpretation is that the operational environment must always be observed when discussing photonics on the battlefield.

2.1 The nature of asymmetric conflicts[e]

There is a vast body of publications on the politics and methods of asymmetric conflicts, some of which have been used for the present work.[1,2,12-19,66] On the other hand, there is no agreement as to what constitutes asymmetric conflicts, although the attempt in Primmerman to develop a general definition is noteworthy.[20] The following definition is adopted for the present work: *An armed conflict is asymmetric if there is considerable disparity between the antagonists with regard to men, materiel, and methods of combat, and if one party is superior in the traditional sense of warfare*.

Table 1 lists features of asymmetric conflicts that are of main interest for the present discussion on helicopters and photonics. The list cannot consider all eventualities; for instance (cf. row 1.5), during the Lebanon War in 2006 the Hezbollah used not only portable weapons but also heavy weapons like rocket launchers and sea-skimming missiles.[35]

e The term *conflict* (or *armed conflict*) is chosen over *warfare* in order to stress that the asymmetric conflicts differ from traditional warfare. Similarly the major party—presently the USA in Iraq and NATO in Afghanistan—is termed the *major force* rather than *major power*, to account for coalition-type of fighting forces and the involvement of private military companies. The term *insurgent* is used here for what is also—depending on one's view—termed *guerilla*, *freedom fighter*, *terrorist*, *irregular*, *patriot*, *bandit*, etc.

Table 1. Features of asymmetric warfare, listed in an arbitrary order, and consequences of respective feature.

	Features of asymmetric warfare		Consequences
1.1	Asymmetric operations are conducted increasingly in urban environments	→	- Increased requirements on detection and identification of targets and threats in urban battlefield clutter - Environment provides excellent hideouts and opportunities for ambushes
1.2	Littoral operations are becoming increasingly common	→	Individual operations may cover both land and naval threats, and land and sea environments
1.3	Entire operational area is a combat zone; helicopters must expect attacks throughout the duration of missions	→	Missions are conducted under continuous stress. Automation is needed to reduce aircrew workload, to support situational awareness, and for automatic threat detection and execution of countermeasures
1.4	Combatants of major force are dressed in distinguishable uniforms, insurgents are dressed as and intermingled with civilians	→	- Helicopters can be attacked from friendly looking crowds - Indiscriminate violence towards insurgents will harm innocent bystanders, leading to loss of support for the major force
1.5	Major force is equipped with high-tech weapons, insurgents are equipped mainly with *ad hoc* and portable weapons. Insurgents do not honor agreements prohibiting weapons of mass destruction (WMD)	→	- Helicopters can meet unorthodox chemical, biological, radiological, and explosive threats; together with small and medium caliber ballistic weapons and man-portable missiles. - The radar threat is essentially absent, other types of radiofrequency (RF) threats—particularly RF trigged explosive devices—are omnipresent - Helicopters are detected and identified based on their aural and optical signatures
1.6	Major force has air superiority; insurgents use aircraft sporadically, if ever	→	- Insurgents can regard all aircraft as hostile— "anything that flies is the enemy"—which decreases the time lag when engaging helicopters - The air-to-air threat is virtually absent
1.7	Assassinations are conducted by all parties involved	→	Helicopters on assassination missions must locate and identify targets accurately in order to reduce collateral damages; the kill should be performed by precision weapons
1.8	Popular support is critical to all parties	→	Insurgents aim at discrediting the major force, the latter aims at isolating the insurgents from the population

2.2 Characteristics of battlefield helicopters and helicopter tactics

The shift from the Cold War scenario to the asymmetric scenario has had consequences for both helicopters and helicopter tactics. A notable event was the US Army's decision to terminate development of the stealthy RAH-66 Comanche in 2004, and shift funds to lower-cost traditional helicopters. A year earlier the pop-up flight tactics of attack helicopters, designed to meet onslaughts by armored units, had been found unsuitable in Iraq. Instead, the *running fire* tactics—later termed *running/diving* tactics—was adopted.[21-27]

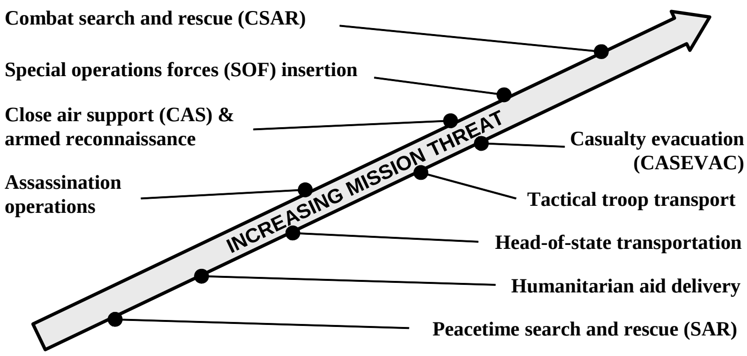


Figure 2: Threat levels of typical helicopter missions. Peacetime SAR is the lowest-threat mission, although the threat level is not zero. CSAR missions are high-risk due to lack of time for proper mission planning, and since the pick-up takes place in enemy-infested areas. CASEVAC missions in asymmetric conflicts typically have to be carried out within reach of enemy weapons, whereas they are lower risk missions in a traditional combat scenario.

There is a vast number of battlefield helicopters types, ranging from light reconnaissance/utility helicopters, to heavily armed and armored attack helicopters, and to transport helicopter in sizes up to the 56 tons of a fully loaded Mil Mi-26. Figure 2 shows some helicopter missions and their perceived threat levels. The decision on whether a mission can be executed in a perceived threat situation must be made based on the importance of the specific mission or operation.

Table 2 gives a summary of the characteristics of battlefield helicopters that are of major interest for the present work.[5,8,9,28-33,61] As mentioned in connection with Table 1, all alternatives and combinations cannot be covered by a single list. For instance (cf. row 2.4), added equipment weight typically reduces payload and/or operational range. If, however, the added equipment weight reduces susceptibility, it may be possible to select shorter flight routes although their threat levels are higher and thereby maintain the operational range.

Table 2: Characteristics of battlefield helicopters and their consequences, listed in arbitrary order.

	Characteristics of battlefield helicopters		**Consequences**
2.1	Helicopters are inherently unstable and difficult to fly	→	Aircrew needs the support that technology can provide; however, automation must not have absolute priority over pilot inputs
2.2	Low flight heights—only some 50 feet under nap-of-the-earth (NOE) conditions—also under night conditions	→	- Need for obstacle warning systems and NVIS equipment - Engagement ranges are short, requiring fast automatic threat countermeasures - Flight within range of small arms fire and antitank weapons
2.3	Low flight speed—zero at hovering	→	- Threats cannot be outrun or outmaneuvered - Ejection of expendables requires careful consideration
2.4	The helicopter is weight constrained	→	Added equipment weight reduces payload and/or operational range
2.5	The helicopter is real estate constrained	→	The location of apertures of EO systems becomes a compromise between conflicting requirements of onboard systems
2.6	High platform vibration level, noticeable fuselage flexure	→	Structural movements in different spectral bands that affect sensor and tracker operation
2.7	High platform noise level	→	- Early detection and reduced enemy reaction time - Restricts use of on-board acoustic sensors
2.8	Large main rotor, small and fast tail rotor; both are vulnerable structures	→	- Possible influence of rotor modulation on sensors need be observed - Threat miss distance must be kept outside main rotor perimeter - Expendables can damage rotors
2.9	Operation from unprepared ground strips	→	Risk of snow, dirt etc. clogging and/or damaging sensor apertures
2.10	Strong IR signature, particularly from the engine and engine plume	→	Extended lock-on range for hostile IR seekers/trackers
2.11	Visual signatures and probability of being detected depend on platform size, sun reflexes, and tactical behavior	→	- Need to reduce size, particularly the frontal aspect of attack helicopters - Need to reduce reflexes from windows, rotors, and optical apertures - Need to match tactics to environment and prevailing conditions

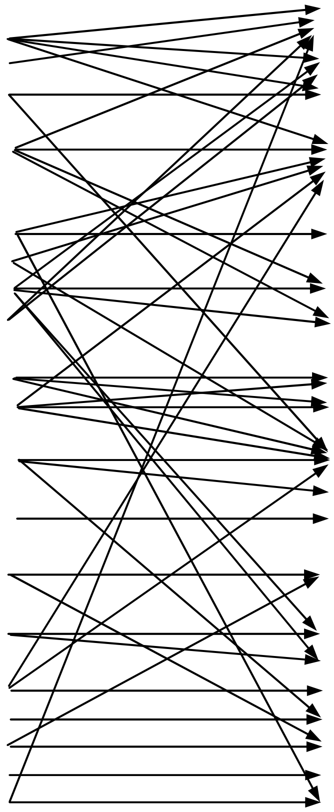
3. ANALYSIS

3.1 Implications of problem components

The foregoing examination of asymmetric conflicts and battlefield helicopters does not point to radical differences between symmetric and asymmetric conflicts. The factors identified in Tables 1 and 2 can now be fused to give the requirements presented in Table 3.

It is obvious that some of the requirements in Table 3 are subsets of others. For instance, the need to consider appropriate rules of engagement (3.2) is contained in the need to understand the operational environment (3.1), and the need for automatic countermeasures (3.10) can be seen as a consequence of short engagement timelines (3.4). In other cases the requirements are contradictory. A case in point is the ability to select equipment based on mission needs (3.12), which in fact may increase weight by demanding bulky fixtures and accesses—a typical problem with modular design. Further, some requirements are impossible to fulfill. Such is e.g. the requirement that priorities of shared resources shall be fully analyzed (3.8). Analyzing and validating all possible technical and tactical situations that may influence the behavior of a shared resource can lead to an almost infinite problem set—a situation that is known from software testing.

Table 3: Requirements deduced from consequences identified in Tables 1 and 2. The requirements are divided into *shall* and *should*, where the former is a firm requirement and the latter implies *to the possible extent*. Observe the multitude of factors contributing to short engagement timelines (3.4) and the related automatic CM execution (3.10).

	Inference	#	Deduced requirements
1.1		3.1	Shall understand the operational environment (enemy & population behavior, climate, topography, environmental signatures, atmosphere, etc.)
1.2		3.2	Shall observe strict rules of engagement (ROEs)
1.3		3.3	Capability (weapons, warning sensors, countermeasures) should be uniform over 360° azimuth (Az)
1.4		3.4	Should be able to cope with short engagement ranges & timelines of ballistic and guided threats (small arms fire, rocket propelled grenades, MANPADS, improvised explosive devices (IEDs))
1.5 1.6		3.5	Standoff detection of chemical, biological, radiological, and explosive (CBRE) threats should be possible
1.7		3.6	Sensors shall have high spatial resolution
1.8		3.7	Sensors for target detection, identification, and location should be compatible with those of other intelligence, surveillance and reconnaissance (ISR) assets
2.1		3.8	Priorities of shared resources (e.g. MFDs and buses) shall be fully analyzed
2.2		3.9	Obstacle avoidance sensors shall have high probability of detection at a range that allows evasive maneuvers
2.3		3.10	Threat evasion countermeasures shall be executed automatically
		3.11	Real-time aircraft navigation data shall be available during fast maneuvers
2.4		3.12	Weight savings should be sought through multipurpose sensors, MFDs, shared apertures, miniaturization, equipment setup based on mission needs, etc.
2.5		3.13	Unorthodox solutions shall be searched for protected aperture locations with optimal field-of-view (FOV)
2.6		3.14	Sensors and trackers shall be stabilized
		3.15	Possible parallax errors shall be neutralized
2.7		3.16	Alternatives to on-board acoustic sensors should be found
2.8		3.17	The influence of rotor and platform geometry and dynamics shall be observed
2.9		3.18	The location of apertures should be selected to minimize hazards to them
2.10		3.19	The helicopter should have IR suppressors and low-emissive paint finish
2.11		3.20	Visual signatures should be minimized by built-in features and by optimizing flight tactics to prevailing conditions

Projecting the requirements of Table 3 to the question of how much they differ from requirements that could be found in traditional war, the following observations can be made:

- For the major force, asymmetric conflicts are “hearts and minds” campaigns; actions must be judged against how they affect the population (3.1, 3.2)
- The requirement for 360° Az coverage (3.3) is stricter in asymmetric conflicts. On the other hand, the risk of top attack is nearly absent—save for missions in mountain or urban canyons
- Engagement ranges and timelines (3.4) are traditionally shorter for helicopters than for fixed-wing aircraft, but the problem is accentuated in asymmetric conflicts
- Detection of CBRE threats (3.5) has not traditionally belonged to the requirements for battlefield helicopters, standoff detection is a new challenge. An implicit consequence of the insurgents’ limited reliance on high-tech weapons is that hazards by a helicopter’s active on-board sensors (lasers, radars, etc.) are negligible
- Helicopters have been used as tools of assassination only in asymmetric conflicts (3.6)
- Requirement 3.7 is also imposed by the development of network centric warfare (NCW) capability for symmetric warfare
- Requirement 3.8 is somewhat more critical in asymmetric operations due to the *running/diving fire* flight tactics
- Need for acoustic sensors on helicopters (3.16) is not generally foreseen in symmetric operations
- Requirements 3.9-3.15 and 3.17-3.20 are similar for symmetric and asymmetric conflicts.

3.2 Challenges for photonics

The analysis in section 3.1 will now be extrapolated to helicopter photonics, but the discussion will be limited to the nine points in which asymmetric operations differ from symmetric operations (rows 3.1-3.8 and 3.16). The numerical references are with respect to rows in Table 3.

The operational environment (3.1) of asymmetric conflicts typically differs from traditional warfare in the following aspects: 1) Difficulty in separating enemies from non-combatants, including the tendency of insurgents to provoke the major force to open fire on unarmed civilians; 2) anti-helicopter ambushes with multiple fire positions, using different types of weapons; 3) unfamiliar terrain; 4) climate and atmospheric conditions; and 5) unfamiliar signature environment.[f]

The first challenge for photonics, combined with signal and data processing and aircrew observations, is to detect and identify atypical behavior that indicates the presence of enemy combatants. A warning sign can be a crowd of civilians that suddenly disperses.[16] The capability of present-day EO sensors is sufficient to detect this scenario, the challenge is to develop image processing and artificial intelligence that can come up with the right deduction. The next challenge, detecting and identifying firing positions, is foremost a task for laser technology since most weapons have optical sights that can—in principle—be detected through retroreflection of a scanning laser beam. The problems involved are, first, to distinguish between reflexes from hostile weapon sights and other optical instruments and, second, to scan the entire footprint of helicopter threats. The third challenge, unfamiliar terrain, puts strict requirements on the helicopter's obstacle warning system. Laser-based obstacle warning systems are in the forefront of development, but they may have to be supported by passive means in order to provide reliable hazard detection under dynamic flight conditions.[34] The fourth challenge, climate, with effect on propagation and equipment performance, can cause surprises in unfamiliar geographic regions. Atmospheric models like MODTRAN can give clues but have been found inaccurate in specific regions.[36] The challenge is therefore to compile available atmospheric data for the operational region and to supplement this data with measurements. Finally, the signature environment is complicated by the fact that asymmetric combats are fought in and above functioning societies. The challenge is of course to maintain adequately low sensor false alarm rates with high detection probability. This requires collection of sufficient data on non-combat signatures and incorporation of the data in signal processing algorithms of sensors.

Rules of engagement (3.2) are important in symmetric conflicts to avoid fratricide. In asymmetric conflicts aspects of collateral damages rise to the forefront. The typical case for aircraft is restrictions on dropping flares above urban and industrial areas. The challenge, therefore, is to develop less hazardous expendables, e.g. pyrophoric flares based on metal foils or nanomaterials.

To date, helicopters have not been equipped extensively with lasers (save for laser range finders and target designation lasers on attack helicopters) and the issue of laser safety has not been addressed in ROEs. This will change as obstacle avoidance systems and DIRCMs become more commonplace. The challenge will in particular be with DIRCMs that have to jam missile seekers operating in the visual band. A related challenge will appear if lasers are used to detect optical sights. ROEs—and before them, system designers—must assure that the use of lasers is not in conflict with the UN Protocol on Blinding Laser Weapons.[37] The next, and more futuristic challenge is a DIRCM laser suited also for non-lethal tasks: destruction of tires on cars, damaging optical sights, etc.

Uniform horizontal capability (3.3) has not always been requested in symmetric scenarios. For instance, the IR signature of most battlefield helicopters—even those fitted with IR suppressors—is typically much higher in the rear sector. Experience from Iraq now shows that insurgents conduct complex ambushes, including dispersed firing positions that allow helicopters to be engaged by MANPAD missiles from the tail.[33] In this particular case helicopters with upward-facing exhaust have an advantage, while the solution is less favorable in traditional scenarios that include threats from top-attack weapons. Thus, the challenge is to reduce the IR signature within given weight limits and to guide the residual IR emission in optimal—"sacrificed"—directions.

Installation of warning sensors and other EO systems on the helicopter's fuselage leads to FOV sectors that are obscured by the tail boom, winglets, pods, etc. Obscured angles are critical in asymmetric conflicts with high possibility of being attacked from any direction. The challenge is to locate EO systems even more carefully than in the traditional case and for aircrews to be aware of the weak spots. A related issue is EO targeting sensors, which have typically covered only the

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[f] Unfamiliar terrain, climate, and atmospheric conditions refer in particular to military operations outside the homeland.

front sector (e.g. TADS on the AH-64 Apache). The urban challenge asks for broader FOV, including IFOV, to give more uniform capability. The progress of staring arrays provides the basic technology for the task; consequent challenges are necessary apertures, increased signal processing load, and presentation of information to the aircrew.

Flare dispensers have traditionally been directed horizontally to each side of the fuselage. Today one can see dispensers pointing forward-down and rear-upward. These installations are better suited to counter threats approaching from arbitrary directions and under different flight conditions. The challenge is to select ejection directions that match the properties of expendables without endangering helicopter structures (rotors, engines) during fast maneuvers, and to find optimal ejection parameters for each dispenser and flare type (including flares used as DIRCM backup). Ideally, the efficiency of expendables should allow liberal preemptive use without exhausting stores; nor should expendables highlight the platform.

Short engagement ranges and timelines (3.4). Figure 3 shows event sequences of a typical MANPAD missile attack on an aircraft.[38,39] The challenge of the EW self-protection (EWSP) suite is to quickly and unambiguously detect, identify, and locate the approaching threat; and to execute countermeasures that cause sufficient threat miss distance. UV missile launch detectors (MLDs) operating in the solar blind region (typically in the 250-285 nm band) have been the preferred solution for helicopters, since the UV background clutter at low altitudes is less severe than in the IR band. However, narrow-beam DIRCMs require IR detectors for precision tracking. It is an advantage if the cueing MLD also operates in the IR band. Detection of antitank missiles with low radiant exitance is a further proponent for IR MLDs.

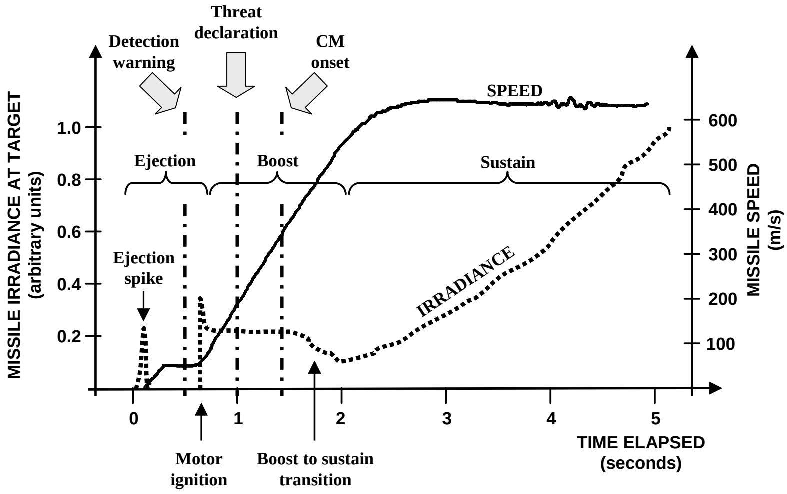

Figure 3: Event sequence during MANPAD engagement; divided into the ejection, boost, and sustain phases. The missile is assumed to reach its maximum speed in about 2 seconds. The irradiance of the motor at the target, which is assumed to be initially at a range of 2.4 km, grows exponentially as the missile closes in. In helicopter engagements the range can be well below 2000 meters and flyout times 3-4 seconds or less. This is a challenge for closed-loop jamming DIRCMs.

Engagement timelines shrink with ballistic weapons. Gun muzzle velocity is typically 700 m/s. The maximum speed of the omnipresent rocket propelled grenade, the Russian-designed RPG-7, is close to 300 m/s. If a helicopter is engaged, the time to impact after the telltale muzzle flame is a second at the most. Preemptive countermeasures are required under such circumstances; blinding the gunner is the most realistic alternative. The challenges that this presents were discussed above in connection with the operational environment.

The next step in shrinking timelines and engagement ranges is represented by anti-helicopter mines, whether these are purpose-built devices or IEDs. In this case the timelines are measured in milliseconds. Against such threats helicopter susceptibility reduction requires accurate intelligence and meticulous mission planning, supplemented by standoff detection of explosives (discussed below as part of CBRE threats).

Standoff detection of CBRE threats (3.5) has attracted increasing interest after 9/11.[40-44] It is generally agreed that terrorists will use CBR weapons as soon as they can acquire or produce them, which is only a matter of time. (The Aum Shinrikyo cult used Sarin nerve gas in Tokyo in 1995.) When such weapons are used, battlefield helicopters are likely to be called upon to support rescue services. Standoff detection of CBR agents is then needed to get warning of, and if possible avoid, contaminated areas. Related to the CBR problem are IEDs, the present scourge in Iraq and Afghanistan and one that is bound to be encountered in future asymmetric conflicts.[g]

Standoff detection of chemical agents and explosives aims primarily at identifying associated molecule traces in the air. A problem with many explosives is that the vapor pressure is insufficient to cause a measurable amount of evaporation. Biological warfare agents of interest have sizes from 0.25 to 5 µm.[45] However, there is currently no method to distinguish between pathogens and other types of bioaerosols (common bacteria, fungal spores, pollen). It seems likely that even if techniques for determining biological pathogens become available, the bioaerosols in new operational habitats must be determined by measurements—which relates to the earlier discussion on measuring atmospheric data. Radiological substances differ from the other three CBRE agents since the decay of radionuclides gives—at least in principle—opportunity for passive remote detection. In other respects radionuclides are like chemical substances.

The most promising technique for detecting bioaerosols is UV laser-induced fluorescence (UV LIF). In one case the system is based on a frequency-tripled Nd:YAG laser at 355 nm, while detecting the fluorescence with a telescope and an intensified CCD detector.[46,47] Active and passive Fourier transform infrared (FTIR) is the main technology used in present standoff chemical detection systems and has also shown promises for standoff detection of bioaerosols.[48,49] Coherent differential absorption lidars (DIALs) are being investigated as chemical detectors; the work also contributes to the development of frequency agile lasers.[50-53] This development has reduced earlier interest in switched CO_2 lasers in the 9-11 µm band. Standoff explosives detection is presently under intensive investigation, to the degree that a 2004 review article on the subject had to be updated in less than three years.[64,65] The detection range should be 100 m or more to provide safe warning of IEDs.[43,62] The range requirement makes most standoff detection methods unsuitable (e.g. systems developed for airport security), but DIAL[h] and reverse photo-acoustic spectrometry may be able to satisfy the requirement.[44,54] Differential reflectometry (a.k.a. differential reflection spectroscopy) may not become useful for tactical field use since it requires scanning of explosives traces on surfaces.[58] Non-linear laser wave mixing is a novel technique for detecting and identifying isotopes and molecules suspended in air. Its claimed sensitivity is in the ppq (10^{-15}) range, in addition to offering small and low-cost equipment. However, the need to illuminate the suspected space from different angles could put limits on practical applications.[55-57] To conclude, despite intense research on CBRE standoff detection numerous challenges remain before a comprehensive solution, fit for deployment on helicopters, will materialize. Only standoff chemical sensors are known to have been installed on rotary-wing aircraft.[63]

Insurgents presently trigger IEDs with diverse methods, including cellular phones, car alarm receivers, remote keyless entry systems, etc.[60] IR triggered explosively formed penetrators (EFPs) have also been reported. If, however, present efforts to jam RF trigging devices are successful it seems natural that insurgents will turn to lasers as an alternative standoff technology. Cheap laser triggers could be built using commercial off-the-shelf components. This potential problem area has to date found little interest, but it should be addressed before the threat emerges.

High spatial resolution (3.6) and **compatibility with ISR assets** (3.7) are not unique to asymmetric conflicts, but the reason for the requirement—assassination—mostly is. Assassination operations should be executed with high accuracy, as they were against Hezbollah leader Abbas al-Musawi in 1992, Chechen leader Dzhokhar Dudayev in 1996, and Al-Qaeda operative Abu Musad Al-Zarqawi in 2006. The alternative is collateral damages and a hostile population that turns its support to insurgents, which is the road to strategic defeat.[i] Aircrews must therefore be able to locate and identify their targets beyond reasonable doubt. In urban environments only optical and EO instruments can provide the necessary spatial resolution to distinguish between the target and bystanders, and to aim or guide weapons with sufficient accuracy. Present EO targeting and tracking systems of attack helicopters can mainly manage the task, although a clear agreement between visual and IR images would improve the situation. Laser illumination can mitigate the latter problem. Another challenge at present is to cue ownship sensors with images and data from other ISR assets, which asks for improved data fusion.

g IEDs are not a new invention, only the extreme interest in them is. A famous case is the roadside bomb that was intended to kill Napoleon in Paris on Christmas Eve, 1800. In a larger context the IED problem is closely related to mine detection.

h *Existing and Potential Standoff Explosives Detection Techniques* (Ref 43) expects that the sensitivity of DIAL ultimately limits detection range to 10-30 meters.

i In the mentioned cases Israel, Russia, and the USA were not in a position to gain popular support by avoiding collateral damages. Limited damages did, however, help to avoid international condemnation. Apparently, Al-Musawi was killed by an antitank missile fired from a helicopter, Dudayev by an artillery missile, and Al-Zarqawi by laser-guided bombs dropped from a fighter aircraft. Although the attacks on these individuals killed others, those were closely associated with the target.

Priorities for shared resources (3.8) are e.g. questions of prioritizing MFD popup frames and allocating access to multiplex buses. It may seem important to immediately flash information on a detected MANPAD missile launch, but overriding an MFD frame with EW information could erase data that is critically needed by the aircrew to save the helicopter from an immediate crash. Likewise, an avionics bus can be needed concurrently to eject flares and to fire the turret gun—which task is more time-critical? The challenge is to define and resolve temporal conflicts of this kind.

Alternatives to on-board acoustic sensors (3.16) are a minor issue since acoustic sensors have not been installed on noisy platforms. This is recognized by the developers of the earlier mentioned reverse photo-acoustic spectrometry technology, who are investigating laser-based alternatives to the acoustic part of the system.[54]

3.3 Is there a case for integrated photonics architecture?

The foregoing discussion raises the question if development of photonics equipment is too compartmentalized, with specialized groups developing little-used equipment for specific purposes. The DIRCM is the extreme case. In Iraq a helicopter has been downed for approximately every 20,000 sortie, while the ratio of unsuccessful to successful attacks is between 1:7 and 1:49 (depending on the time period observed).[33] MANPAD missiles have not been used in many of these attacks, and if used, the DIRCM would be needed only for a few seconds. For 99.9999% of helicopter combat flight time the DIRCM is a costly weight, space, power, and logistics burden. Can the situation be improved?

It is tempting to say that the photonics community should look at the development in the RF world, where the goal is to use a single electronically scanned antenna array for radar, communication, signal intelligence, RF jamming, etc. If this example could be followed, a single multi-wavelength/power-agile laser system and stabilized pointer system could act as a combined DIRCM unit, non-lethal weapon, obstacle warning system, CBRE detector, etc. Another option is a multipurpose sensor with common apertures and detectors and different software for target detection/tracking, laser warning, missile launch detection, etc. That said, one must recognize practical limitations of multipurpose solutions. Laser warning receivers and MLDs have to date not been successfully fused, mainly due to the extreme dynamic range that such a solution would require. Even the seemingly trivial case of a composite laser for a damaging-jamming DIRCM is beyond present technology.[59] The idea of integrated photonics architecture is therefore futuristic, but that does not exclude the challenge of better cooperation between scientists and engineers in the various branches of photonics, nor that the idea of higher integration levels is kept alive.

4. CONCLUSIONS

The shift of helicopters from symmetric to asymmetric battlefields has not brought revolutionary challenges for photonics. The change is rather an evolutionary one, imposed by shorter engagement ranges and timelines, increased threat from low-tech ballistic weapons, need for highly accurate target identification and engagement, and requirements on CBRE standoff detection. Additional requirements rise from uniform horizontal distribution of threats and from ROEs tailored to long-term operations in and above functioning urban societies. The heaviest burden of the derived challenges goes to the laser community, to which the requirements quickly exceed present limits of science and technology. Weight limitations on helicopter equipment further aggravate the challenges. The learning lessons are, first, that the operational and scientific-technical communities must cooperate to produce reasonable operational requirements for photonic equipment and systems. Second, survivability of battlefield helicopters cannot be optimized by photonic or any other single technology. Survivability requires a multi-tier approach that merges operational, tactical, scientific and technological solutions in a systematic and symbiotic way. Third, the need to understand the varied aspects of the operational environment with threats, topography and atmosphere at one end of the spectrum and socio-cultural issues at the other, and to recognize how photonics can help win wars, not just engagements and battles.

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