雷射武器在地面作戰之運用

Implications of Laser Weapons for Ground Combat Operations

譯者　備役少將曾祥穎

2006年7月與8月，真主黨（Hezbollah）和以色列國防軍於黎巴嫩南部激烈的戰鬥，使世人大吃一驚。短短的衝突過程中，真主黨擊向以色列北部的火箭達4,228枚，造成以色列死亡53人，輕重傷2,000餘人，整個地區為之癱瘓，百餘萬居民躲到掩體中生活。以色列的經濟損害估計為55億美元。

The intensity of combat between Hezbollah and the Israeli Defense Forces (IDF) in southern Lebanon in July and August 2006 caught much of the world by surprise. In the short course of the conflict, some 4,228 Hezbollah rockets struck northern Israel, killing 53 Israelis, wounding some 2,000 more, paralyzing the region and causing a million civilians to live in shelters. The overall damage to the Israeli economy was estimated at $5.5 billion.

以色列對這種火箭彈幕的反擊，成效甚微。以軍砲兵的反砲兵火力及空襲，無法擊敗真主黨高度機動的自其本土發射並靈巧的運用掩蔽、隱蔽與欺敵的火箭發射小組。結果，以軍的因應僅能限於不時的對手無寸鐵的百姓，提供敵火來襲的警報而已。

The Israeli counter to this barrage was relatively ineffective. IDF artillery counterbattery fire and airstrikes were unable to defeat the highly mobile Hezbollah rocket-launching crews firing from their home terrain and deftly employing cover, concealment and deception. Consequently, the IDF response was limited at times to providing warning of incoming fire to the vulnerable civilian population.

其實不應該是那樣的。以色列是因缺乏一個有效的反火箭防衛所付出的代價，根源於以往不肯下定決心完成研發與部署一種有潛在價值，可以在飛行中摧毀真主黨火箭的雷射武器系統。1990年代初期，美軍即已認知到以雷射為基礎之防衛系統對付火箭、砲兵與迫擊砲的潛在優勢，並開始發掘其能力。1996年以戰術性高能雷射（Tactical High Energy Laser THEL），成功的對抗俄製卡秋莎（Katyusha）火箭之後，以色列便加入此一計畫。接下來的幾年，於野戰測試中擊落許多不同種類的火箭彈、砲彈與迫擊砲彈，但是卻未能於華府爭取到經費。至2004年底，陸軍撤銷了建造機動式戰術性高能雷射之經費支援。因此，2006年時，連一具不但可以用來拯救以色列北部人民生命財產，而且能夠在戰場上展示雷射武器革命性潛在能力的原型系統都沒有。以色列的生命與建築物的損失，再度的提供了一個明證，希望能有一個有效的、可負擔得起的防衛系統，得以對付曲射火力 — 一個運用先進高能雷射科技的防衛系統。

It might not have been so. The price Israel paid for lack of an effective anti-rocket defense was a consequence of past decisions not to complete development and fielding of a potentially valuable laser weapon system able to destroy Hezbollah's rockets in flight. Beginning in the early 1990s the U.S. military recognized the potential advantage of a laser-based defense against rockets, artillery and mortars and began developing such a capability. After a successful test of the Tactical High Energy Laser (THEL) was conducted against a Katyusha rocket in 1996, Israel joined the program. In subsequent years the system shot down many different types of rockets, artillery and mortar rounds in field tests but did not fare well in the competition for funding in Washington. By late 2004 the Army withdrew financial support for a mobile THEL. Thus, in 2006 when even a prototype system not only might have saved lives and property in northern Israel but also demonstrated the revolutionary potential of laser weapons on the battlefield, nothing was available. The shattered lives and buildings in Israel once again provided stark testimony to the desirability of an effective, affordable defense against indirect-fire weapons—a defense now made feasible by advances in high-energy laser technologies.

武器發射藉由化學反應以推進拋射物──槍彈、砲彈、飛彈──主宰戰術層級的作戰已有數世紀之久。如今，高能雷射科技的進步，已可使其他物理原理得以運用到一種新層級的武器之上。高能雷射軍用潛能之開發，是要產製出經由集束光將摧毀性之能量轉移至目標上之光束武器。假以時日，當這些下一代的武器逐漸能夠確定其於戰場存在之角色或新的任務，如主動防衛以對抗各類彈頭之時，以化學反應推進彈頭的優勢地位將不保，而與直接能的武器共存並相互競爭。

Weapons firing projectiles propelled by chemical reactions—bullets, artillery shells, missiles—have dominated the tactical level of warfare for centuries. Today, advances in technology of high-energy lasers allow the application of other physical principles in a new class of weapons. Development of high-energy lasers with military potential is leading to the production of light-beam weapons that transfer destructive energy to targets via coherent light. Over time, the primacy of chemically propelled projectiles may give way to dynamic coexistence and competition with directed-energy weapons as these next-generation weapons increasingly assume existing roles in the battlespace or new missions, such as active defense against projectiles.

美軍之難題是在於瞭解雷射武器科技，易；而將這些能力帶到部隊之中，難。可用於開發雷射武器之經費與儘快使此科技成熟所需者，相距甚遠。同樣不利於雷射武器成功部署的，則是對發展雷射武器作戰運用概念並不熱衷。不幸的是，此即意味著武器研製者雖然可以很快的設計出在戰場上極具潛能的系統，但卻口惠而實不至，徒然空談而已。對戰士們最重要的武器能力，沒有作戰需求之導引，便無法優先獲得適切的資源或關注。可悲的是，軍方卻只能部署一種昂貴並容忍新性能仍然無法充分發揮的武器，因為戰士們尚未全盤瞭解如何將其優勢發揮得淋漓盡致。

The challenge to the U.S. military is that its understanding of laser weapons technologies is outpacing efforts to bring these capabilities into the force. Available funding for laser weapons development lags behind what would be necessary to bring technologies to maturity as quickly as possible. Equally threatening to the success of laser weapons in the field is the lack of attention to concept development for laser weapons' operational employment. Unfortunately, this means that weapons developers may move along at great speed in designing advanced systems with tremendous battlefield potential, but they do so in splendid intellectual isolation. Lacking the guiding hand of operational requirements, they are unable to properly prioritize resources or focus on the weapons capabilities that are most important to warfighters. Just as sadly, military forces can field an expensive and promising new capability that remains underutilized because warfighters do not fully understand how to employ it to its greatest advantage.

雷射武器能力之增長（Growing Laser Weapons Capability）

雷射武器之功能已然開發出來並且經過測試。美國──以色列陸軍聯合之戰術性高能雷射已經擊落過短、中程戰術飛彈、砲彈與迫擊砲彈，並有能力把其他種類的飛彈於飛行途中摧毀。其他的雷射武器也有極大的進展。美國空軍的空載雷射（Airborne Laser ABL）反飛彈第一次射擊已預告於2008年實施，國防部的固態雷射計畫之進行亦極為順利，已經在實驗室中達到軍方所要求的能量水準。

Effective laser weapons have already been developed and tested. The joint U.S. Army-Israel Defense Forces THEL has shot down short- and medium-range tactical missiles, artillery rounds and mortars, and has the ability to destroy other types of missiles in flight. Other laser weapons are making significant progress. The U.S. Air Force's antimissile Airborne Laser (ABL) aircraft is on track to conduct its first trial shootdown in 2008, and the Defense Department's solid-state laser program is well on the way to achieving militarily significant power levels in the laboratory.

瞭解作戰運用進展挑戰之一，在於各式雷射武器不同之特性。技術上最成熟的系統為化學雷射，其極高之能量係以化學反應，產生強烈的紅外線輻射束而來。以電力為動力之固態雷射（SSL）之能量較少，其電力係經由一具水晶或玻璃媒介，以產生雷射光束。固態雷射之進展亦極其迅速，而且在戰術上極具實用性。第三類為自由電子雷射（FEL），係利用電子配合環境條件之變化，以不同之波長產生出雷射光。

One of the challenges in understanding the operational implications of this progress lies in the varied characteristics of different laser weapons. The most technologically mature systems are chemical lasers that derive their very high power levels from chemical reactions that produce beams of intense infrared radiation. Electrically powered solid-state lasers (SSLs) are less powerful and pass electricity through a crystal or glass medium to produce laser beams. SSLs are also progressing rapidly and promise great tactical utility. A third class, Free Electron Lasers (FELs), uses electricity to create laser light on different wavelengths to match changing environmental conditions.

然而，能量之強弱並非量測雷射武器技術成熟度之唯一方法。要成為一種威力強大的武器，雷射必須整合為一個完整的系統，可以獲取、追蹤與摧毀目標，並能與其攜行載臺之動力、指管與其他系統充分契合。以當前的經費水準而言，要將固態雷射武器系統整合好，從實驗室移至測試場，還得需要7至9年的工夫。

Power levels, however, are not the only measure of laser weapons' technological maturity. To create an effective weapon, the laser must be integrated into a complete system that can acquire, track and destroy targets and is fully mated with its carrying platform's power, control and other systems. At current funding levels, it could be seven to nine years before an integrated solid-state laser weapon system can be delivered from the laboratory to the testing range.

雷射武器系統整合之進展（Progress in Laser Weapon Systems Integration）

研製人員也正在從事將雷射武器整合至現有及新型的空中、地面以及海上武器系統之概念設計。例如，將戰術性高能雷射納入一種可以部署的，名為「高能雷射火箭、火砲與迫擊砲」(HELRAM)的戰鬥系統之設計業已完成，可用以摧毀包括火箭彈、砲彈與迫擊砲彈等各種形式之威脅。

Developers are also progressing with design concepts for integrating laser weapons into existing and new air, land and sea weapon systems. For example, much design work has already been done to modify the THEL into a deployable combat system known as High Energy Laser-Rockets, Artillery and Mortars (HELRAM) that can be used to destroy multiple types of threats, including rockets and artillery and mortar rounds.

固態雷射之概念設計亦已開發，不過其技術之成熟度較化學雷射之系統落後4至5年。因為其所需之電力太大，武器的研製人員正為能量之供應大傷腦筋。例如將雷射武器裝在一種油電混合的地面戰鬥車上，由外接之電力系統供電。

Systems concepts for SSLs have also been developed, although their technical maturity is four to five years behind that of chemical laser systems.7 Because SSLs draw very large amounts of electric power, weapons developers have focused on power supply. For example, a laser weapon could be carried on a hybrid electric ground fighting vehicle (figure 3) and powered by the electrical system.

雷射武器作戰概念之發展（Developing Operational Concepts for Laser Weapons）

儘管雷射武器之科技進步神速，但是軍方作戰圈子內的人，大多仍對其潛能一無所知。縱然舉辦了幾次瞭解這些系統在軍事上價值的座談會，軍方作戰圈子內認識到其潛能的還是不多。

Despite these technical advances in laser weapons, much of the military operational community remains unaware of their potential. Despite several nascent efforts to understand the military worth of these systems, appreciation of their potential throughout the military operational community remains low.

自從第二次世界大戰以來，美國國防計畫假定之基礎便是美軍將較其潛在敵人擁有技術上之優勢。對雷射武器則不盡然，因為他們給了一個可以克服美國先進的飛彈及其他高科技能力之機會，其他國家及非國家成員會基於其本身的安全、經濟與政治目標，尋求指向能的武器。雖然美國相信在雷射武器發展上保有極大之優勢，卻不能保證在不遠的將來，不會面對一個有某些雷射武器能力的敵人。

Since World War II, an underlying assumption of U.S. defense planning has been that U.S. forces will enjoy a technological edge over potential adversaries. That might not be true of laser weapons. Because they offer an opportunity to overcome the huge U.S. advantage in advanced missiles and other high-technology capabilities, other countries and non-state actors may pursue directed-energy weapons based on their own security, economic and political objectives.8 While the United States is believed to hold a significant lead in laser weapons development, there is no guarantee that we will not face an enemy with at least some laser weapons capability in the not-too- distant future.

雷射武器作戰特性與其運用之潛能（Operational Characteristics of Laser Weapons

and Their Potential Application）

為瞭解雷射武器之差異及其不同特性對未來戰爭之衝擊，實有瞭解這些武器獨特能力與限制之必要。

To appreciate how different laser weapons and their varied characteristics might impact future warfare, it is important to understand the unique capabilities and limitations of these weapons.

能力：雷射可用於作戰用途之能力有：

Capabilities. The following capabilities make lasers attractive for operational uses

●極其敏捷的光速投射能力：

雷射武器是以光速接戰目標——對投射之武器而言根本無所謂之飛行時間。這使得他們極其適於接戰臨近之機動目標，如地對空飛彈、空對空飛彈、無人飛行載具及巡弋飛彈，還有極高速之彈道目標，如火箭、砲彈與迫擊砲彈等。不過，雷射武器確實需要一些時間以獲得並追蹤目標，並且必須長時（幾秒鐘)「停駐」於目標上，以儲備足以摧毀或制壓目標之能量。

●Highly agile speed-of-light delivery: Laser weapons engage targets at the speed of light—there essentially is no time of flight as for projectile weapons. This makes them well suited for engaging close-in maneuvering targets—e.g., surface-to-air missiles (SAMs), air-to-air missiles (AAMs), unmanned aerial vehicles (UAVs) and cruise missiles)—and extremely fast ballistic targets, e.g., rockets, artillery and mortars rounds. However, laser weapons do require some time to acquire and track targets and have to “dwell” on the target long enough (several seconds) to deposit sufficient energy to destroy or neutralize it.

●多目標接戰及快速重標定之能力：

因為雷射武器活動之機件甚少，並且能常保其能量充足或藉由重新充填其化學或電能儲量而重新裝填，因此得以極其迅速的遂行多目標接戰；其最大限制乃是燃油或電力之供應，或者為了散熱。從一個目標轉移至另一個目標只需重新指向與鏡面重新對焦即可。因此，極適合對付砲兵或火箭之集火射擊之類的多目標接戰。

●Multiple target engagements and rapid retargeting: Because laser weapons have few moving mechanical parts and are constantly powered or reloaded by recharging their chemical or electrical energy stores, they can engage multiple targets very quickly, limited for the most part only by their ability to be supplied with fuel or electrical power or to dissipate waste heat. Shifting from one target to another involves only repointing and refocusing mirrors. Thus, they are well suited for the types of multiple-target engagements that might be required to deal with salvo firings of artillery or rockets.

●彈藥不虞匱乏：

因為雷射之消耗只有化學性燃料或電力，能射擊之總發數僅受限於其可用之化學性燃料，或以固態雷射而言，可用於驅動其電源之燃料。不過，固態雷射在其必須關機重新為其電池充電或散熱之前都可以射擊。

●Deep magazines: Because lasers consume only chemical fuel or electricity, the total num-ber of shots they can fire is limited only by the amount of chemical fuel available or, in the case of solid-state lasers, the fuel available to drive the electrical power source. However, SSLs can be fired for only so long before they have to shut down to recharge batteries or eliminate heat.

●每次射擊成本增加甚低：

武器系統之發射，每次射擊成本之增加基本上即其所耗彈藥之成本。每次射擊時，導引飛彈系統硬體之花費最貴(諸如：火箭馬達、導引系統、航電、尋標器與彈體等)。對雷射武器而言，所消耗的只有能量。

●Low incremental cost per shot: For a projectile weapon system, the incremental cost per each shot is essentially the cost of the ammunition expended. Guided missile systems in particular expend much expensive hardware (i.e., rocket motors, guidance systems, avionics, seekers, airframes, etc.) in the form of missiles every time they fire. Laser weapons, on the other hand, expend only energy.

●優異之精度及調適能力：

一旦接獲雷達或其他感測器信號傳輸，雷射武器便利用一具低功率之光束以獲取並追蹤其目標。在同軸瞄準的高功率雷射接戰之前，該光束可極精準的對焦於目標之任何一點，投射出對摧毀該點所需之能量，不會產生額外的損毀。

●Exceptional accuracy and adjustability: Once cued by radar or other sensors, laser weapons use a low-powered beam to acquire and track their targets. This beam can be focused anywhere on the target with great precision before the co-aligned high-power laser is engaged, delivering the desired level of damage at that exact point on the target with little collateral damage.

●後勤支援需求較低：

不像槍砲在消耗之後必須整補彈藥或飛彈，雷射武器只需額外的化學性燃料或油料，供其發電所需能量即可。

●Lower logistical support requirements: Unlike guns that must be resupplied with ammunition or missiles that must be replaced once expended, laser weapons require only additional chemical fuel or fuel to generate the electricity needed for power.

●運用彈性：

雷射武器為模組化且依其比例而定的。幾個相同的雷射模組可以「堆疊」成為一個高功率的雷射。

●Flexibility: Laser weapons are modular and scaleable. Several identical laser modules can be “stacked” to create a higher-powered laser.

限制：雷射武器確實有其獨特之限制會影響作戰之利用。

Limitations. Laser weapons do have unique limitations that could impact on operational utility:

●大氣之稀釋與擾動：

因為雷射必須經由大氣傳導，因此容易受到懸浮於空中的粒子(沙塵、煙霧）、水氣或空氣之擾動，而使雷射能量被吸收、折曲或散射。

●Atmospheric attenuation and turbulence: Because laser beams must be propagated through the atmosphere, they can be affected by airborne particles (dust, smoke), water vapor or atmospheric turbulence that absorb, bend or scatter laser energy.

●視線之依賴：

雷射武器需要直接看得到目標才能接戰。其效能會因燒不穿的屏障或掩蔽物質而降低。

●Line-of-sight dependence: Laser weapons require direct line-of-sight to engage a target. Their effectiveness is reduced by screening or shielding materials that cannot be readily burned through.

●目標之適切性：

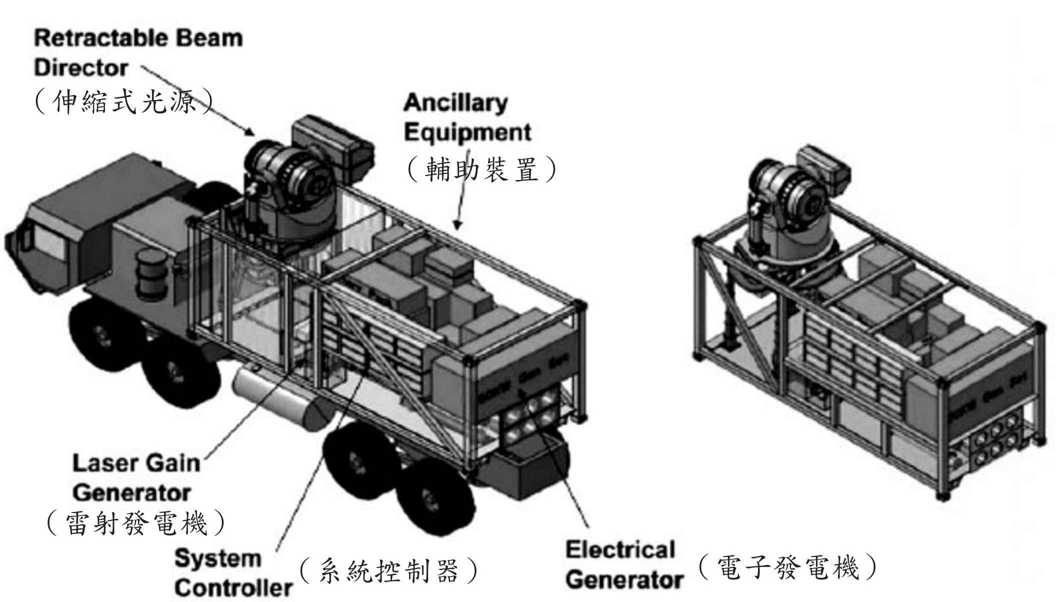
因為功率相對較低，有時雷射武器可能缺乏較大型非雷射化學或動能武器「穿透」之能力。他們最適用於必須儘快而精確接戰者，像飛行中的火箭、飛彈或砲彈之類的目標；或者可以藉聚焦使其小面積毀損而殺傷，或使其失去行動能力，如蒙皮很薄的車輛等。對堅固的建物，如掩體或建築物之效率非常小。對付裝甲車其效力只限於使其易損性高之組件如天線、感測器與外掛油箱等失效而已。

●Target suitability: Because of their relatively low power levels, laser weapons will probably lack the “punch” of larger non-laser chemical or kinetic weapons for some time. They are best suited for targets that must be engaged very quickly and precisely, such as rockets, missiles or artillery rounds in flight, or that can be killed or disabled by focusing damage on small areas, such as thin-skinned vehicles. Their effects are minimal on hardened structures like bunkers or even buildings. Against armored vehicles they are effective only in disabling vulnerable components such as antennas, sensors and external fuel stores.

●眼睛保護之問題：

使用雷射武器的一大關鍵便是眼睛的保護。雖然有些化學性雷射是在對眼睛無害的波長之下操作的，但是目前高功率的固態雷射並非如此。因為任何未被目標吸收的雷射能量，不是被散射就是被折射；這種未被吸收的能量，對在目標附近沒有配備雷射保護鏡之友軍或百姓之眼睛安全有其風險。

●Eye-safety issues. Eye safety is a major concern in the use of laser weapons. While some chemical lasers operate at eye-safe wavelengths, high-power SSLs currently do not.9 Because any laser energy that is not absorbed by the target is either scattered or reflected,



高能雷射火箭、火砲與迫擊砲

this non-absorbed energy poses an eye-safety risk to friendly personnel without laser eye protection and to civilians in the target's vicinity.

●化學性燃料及廢氣：

化學性之雷射需使用化學性燃料，射擊時便會產生廢氣。有些燃料，如空載雷射的化學性氧化碘雷射之高腐蝕性燃料，需要多重的安全系統與降低風險之計畫。其他像戰術性高能雷射使用重氫氟化物，則相當安全。

●Chemical fuels and exhaust. Chemical lasers require chemical fuels and generate exhaust when they fire. Some fuels, like the highly corrosive fuel of the ABL's Chemical Oxygen Iodine Laser (COIL), require multiple safety systems and risk mitigation plans. Others, like the deuterium fluoride reactants used by the THEL, are relatively safe.

作戰之影響：

如果美國或其他強權成功的部署雷射武器於不同的戰鬥載臺上時，對軍隊之作戰指導會產生什麼樣的影響？這是個作戰需求以指導雷射武器技術發展最根本的問題。在作戰運用上分析雷射武器之能力與限制，在下列兩個重要的任務範圍內，其角色最為合適：

Operational Implications

If the United States—or another power—successfully fields laser weapons on different warfighting platforms, how might they affect the conduct of military operations? This question is fundamental in prioritizing operational requirements to guide the technical development of laser weapons. Analyzing the capabilities and limitations of laser weapons in an operational context implies they are well suited to roles in two key mission areas:

●部隊防護：

雷射可以提供空中、地面、海上與太空之載臺防護自身、其他載臺與地域之能力。他們可以在敵人火力到達所望之目標前將其摧毀或制壓，以防範飛彈、飛機、炸彈、砲彈或火箭之為害。對飛彈防禦而言，雷射可提供某一特定目標之點防禦，或作為區域防禦之輔助，以對抗戰區彈道及巡弋飛彈。

● Force protection: Lasers can provide air, land, sea and space platforms the ability to defend themselves, other platforms and geographic areas. They can defend against missiles, aircraft, bombs, artillery shells or rockets by destroying or neutralizing these threats before they reach their intended targets. For missile defense, lasers can provide point defense of a specific target or area defense against theater ballistic and cruise missiles as a complement to defensive missiles.

●攻勢打擊：

雷射可以在其射程內，對適切的目標實施極其精準的致命性或非致命性打擊，大多作為化學能或動能武器之輔助。

●Offensive strike: Lasers can provide the capability to achieve highly precise lethal or nonlethal effects against a range of suitable targets, mostly as a complementary capability for chemical and kinetic weapons.

以下探討雷射武器對幾種地面戰鬥任務之作戰影響。

The following sections address the operational implications of laser weapon capabilities for several ground combat mission areas.

增強存活力Enhanced Survivability

提供主動性之部隊防護雷射，可增強地面部隊之存活力。因為在可見的未來，高能雷射防衛性系統可能重達數千磅，不是人力可以攜行的。這些系統將會裝至專用的車輛，以為在其射程內之其他戰鬥系統、官兵及部隊，提供主動區域防護。但是為改進雷射系統之存活力，便可設計較輕的戰鬥車輛，以建立更具戰略部署、戰術機動彈性之地面部隊。

Ground forces can profit from the enhanced survivability provided by active force-protection lasers. Because high-power laser defensive systems will probably weigh several thousand pounds for the foreseeable future, they are not man-portable. These systems will be mounted on dedicated vehicles that provide active-area force protection for other combat systems and Soldiers and units within their coverage range. But the improvements in survivability offered by laser systems may enable the design of lighter combat vehicles, supporting efforts to build more strategically deployable, tactically mobile ground forces.

今日，傳統地面戰場上之戰損大多來自於曲射武器──包括循彈道軌跡的火砲、火箭及迫擊砲──以及空投的炸彈。導引的直射武器，如反裝甲導引飛彈（ATGM）及人攜式防空系統，也十分有威力。高速大口徑的戰車砲彈為另一個極具威脅之直射火力。陸軍艾布蘭M-1戰車發射的──每秒可飛行數千英呎約1碼長的耗乏鈾棒──脫殼穿甲彈（APDS）便是一例。

Today, most losses on the conventional ground battlefield are caused by indirect fire weapons—including artillery, rockets and mortars that follow ballistic trajectories—and air-delivered bombs. Guided direct-fire weapons, such as antitank guided missiles (ATGMs) and man-portable air defense systems, are also very lethal. Hyper-velocity large-caliber tank rounds are another significant direct-fire threat. An example is the armor-piercing discarding sabot (APDS) round—essentially a yard-long depleted uranium rod traveling at thousands of feet per second—fired by the Army's M-1 Abrams tank.

目前要防範這些武器便需要有厚厚的裝甲，使得車輛像70噸的M-1戰車般成為龐然大物，需要可觀的資源來部署，在戰場上油料的消耗甚大。主動性雷射之部隊防護防衛，可在威脅未抵達其目標前，將其擊滅，而增進較輕型車輛的存活力。結合其他曲射武器所提供之反砲兵火力，雷射可降低敵人曲射火力在戰場上之作用。戰術性高能雷射已能將飛行中之火箭、砲彈與迫擊砲彈摧毀，顯示出雷射可以對付這些曲射火力之威脅。以戰術性高能雷射所展示之能力來研判，顯然類似的雷射系統也有對抗有人駕駛飛機之能力。

Protecting against these weapons at present requires heavy armor, leading to massive vehicles such as the 70-ton M-1 tank that require considerable resources to deploy and consume large amounts of fuel on the battlefield. Active laser force-protection defenses could improve the survivability of lighter vehicles by defeating some of these threats before they reach their targets. Together with indirect fire systems providing counterbattery fire, lasers can make enemy indirect fire much less effective on the battlefield. The THEL has already destroyed rockets, artillery and mortar rounds in flight, demonstrating that lasers can deal with these indirect-fire threats. Given THEL's demonstrated capabilities, it appears that similar laser systems would also be capable against manned aircraft.

除了保護戰鬥部隊，主動性之雷射防護也可以保護重要的固定設施與建物，像後勤基地、機場與港口，免於曲射火力之危害。在伊拉克與阿富汗之類的反暴亂作戰環境下，則可能

是其主要之任務。

In addition to protecting combat forces, active laser defenses can also protect key fixed facilities and infrastructure, such as logistic bases, airfields and ports, from indirect fire. In counterinsur-gency environments, such as Iraq and Afghanistan, this would probably be their key role.

官兵及部隊防護之輔助Complement Soldier and Unit Force Protection

雷射並不適於擊滅諸如反裝甲導引飛彈、戰車砲彈以及火箭推進之槍榴彈之類的直射火力之威脅。這些武器彈道平直，飛行時間甚短，發射數量甚多，使得對一種需要長時期停駐一個目標上，始能造成其爆炸或改變方向之雷射系統而言，實在無能為力。因此，雷射之部隊防護系統頂多只能輔助其他主動防護系統之不足。目前之發展是致力於以毫米波雷達或紅外線感側器，偵測與追蹤進襲之曲射火力之威脅，然後於近距離以近發信管之榴彈，或較遠時以火箭來接戰。這些火箭與榴彈之主動防護系統，在可見之未來，仍將是對付直射火力威脅之辦法。

However, lasers are not well suited for defeating direct-fire threats, such as ATGMs, tank rounds and rocket-propelled grenades (RPGs). The flat trajectories, very short times of flight, and mass of these munitions make them difficult targets for a laser system, which must dwell on a target long enough to cause it to explode or veer off course. Consequently, laser unit protection systems will work best when complemented by other active defense systems. Current development efforts have focused on detecting and tracking incoming direct-fire threats with millimeter-wave radars or infrared sensors, then engaging them at close range with proximity-fused grenades or at longer ranges with rockets. These rocket and grenade active defense systems will most likely remain the preferred solution to direct-fire threats for the foreseeable future.

發展有效的部隊防護雷射將有助於地面部隊規劃人員，在戰略部署與戰術機動及存活力之需求間取得平衡。要存活就需要裝甲，但那會增加重量，降低部署與機動能力。結合了火箭與榴彈之主動防護以對抗直射火力之威脅，而主動防護之雷射可增強存活力並減少重裝甲之需求，減輕戰鬥車輛之重量，並增加其戰略部署力與戰術機動力。

Development of effective force-protection lasers would assist ground force designers in balancing the conflicting requirements for strategic deployability and tactical mobility and survivability. Survivability requires armor that adds weight and reduces deployability and mobility. In combination with rocket or grenade active defenses against direct-fire threats, active defense lasers can enhance survivability and reduce the requirement for heavy armor, reducing the weight of combat vehicles and thus increasing their strategic deployability and tactical mobility.

對可負擔的重層防禦之彈道飛彈防禦而言Ballistic Missile Defense (BMD) for Affordable Layered Defense

彈道飛彈所裝備的不是大規模毀滅武器，就是尖端能力的傳統彈頭，為已完成前進部署或正部署中的美軍最大威脅之一。雖然愛國者三型飛彈已證明其對抗戰區彈道飛彈相當有效，可是太貴了。飛雲飛彈與其他以1940年代科技為基礎的飛彈則相對的便宜(約百萬美元)；1枚愛國者三型之成本約為其兩倍有餘。

Ballistic missiles armed with either weapons of mass destruction or advanced capability conventional warheads pose one of the greatest threats to forward-deployed or -deploying U.S. forces. Although missiles such as the Patriot Advanced Capability-Phase 3 (PAC-3) have proved relatively effective against theater ballistic missiles (TBMs), they are expensive. Scuds and other TBMs based on 1940s technology are relatively inexpensive (around $1 million) while a single PAC-3 costs approximately twice as much.

就預算角度而言，防衛性的飛彈，縱然是最富裕與最先進國家的軍力，都不免有低密度/高需求項目之傾向。防衛一個機場那樣的點目標，以極高水準的信心來對付戰區彈道飛彈時，每一枚來襲的飛彈，都得需要兩枚防衛性飛彈才行。只不過防衛少數幾個重要目標，為了對抗大批的飛彈來襲，很快就會負擔不起。因為攻擊的飛彈只要在其弧形射程之內可以重新標定，就足以對付任何一個目標；如果敵人願意耗費攻勢作戰所需數量之飛彈，即便是相當強固之飛彈防禦體系，亦將無法有效防護。

For budgetary reasons, then, defensive missiles tend to be low-density/high-demand items for even the most wealthy and advanced military powers. Defending a point target such as an air base against theater ballistic missiles with a high level of confidence can require two defensive missiles for each attacking missile. Defending more than a few critical targets against large numbers of missiles quickly becomes cost-prohibitive. Because offensive missiles can be retargeted against any target within their range arcs, even relatively robust missile defenses can be overwhelmed if the enemy is willing to expend the required number of offensive missiles.

一枚彈道飛彈之攻擊，到達目標要經過三個階段的飛行：助推段，當火箭馬達燃燒時；中途段，當飛彈沿著彈道軌道滑降時；終端段，向目標下降時。一個飛彈防禦的基本原則有那麼多的階段，就須建立那樣多不同的防禦「層次」，因為每一個防禦層都增加了將敵人飛彈在擊中目標之前予以摧毀的機率。較長程的防禦系統負責防衛大面積的地區防禦；較短程的系統則為特定的目標提供要點防禦。

An attacking ballistic missile goes through three phases of flight en route to the target: boost phase, when the rocket motors are firing; mid-course, when the missile is coasting along its ballistic trajectory; and terminal, when it is descending toward its target. One of the basic principles of missile defense is to create as many different “layers” of defense in as many of these phases of flight as possible because each defensive layer increases the probability that the enemy missile will be destroyed before it hits its target. Longer-range defensive systems can provide area defense of large areas; shorter-range systems provide point defense of specific targets.

大家都知道空載雷射之計畫角色為助推段的飛彈防禦，但是陸基的雷射也十分適用於重要目標終端段之點防禦。這些雷射可極其迅速的發射數十次以對付來襲的飛彈，使其難收壓制之效。化學性的雷射每射擊一次之成本消耗不到10,000美元，遠較動輒百萬美元的防禦性飛彈要少。因此，縱使將雷射武器之初期成本計算在內，以雷射為基礎的彈道飛彈防禦顯然是一個高度有效的——而且是更能夠支應的—亦即可以額外增加一個層次的防禦，以對抗戰區彈道飛彈之攻擊。

The projected role of the Airborne Laser in boost-phase missile defense is well known, but ground-based lasers are also well suited to terminal point defense of critical targets. These lasers can fire tens of shots against offensive missiles very quickly, making them difficult to overwhelm. The chemicals consumed per shot cost less than $10,000, much less than the millions of dollars for defensive missiles. Thus, even taking into account the initial cost of the laser weapons, laser-based point BMD may prove to be a highly effective—and more affordable—means of adding an additional layer of defense against TBM attack.

因為比較能負擔得起，雷射防禦可以散布得更廣。他們可以彌補長程飛彈防禦之不足。百萬瓦級的化學性雷射可以擊滅戰區彈道飛彈；要擊毀速度較快而且較堅硬的洲際彈道飛彈重返大氣之載具，將需要數百萬瓦級的雷射(遠大於任何目前發展中的系統)。以上這兩種雷射飛彈防禦之效能，將有賴於其研發之系統概念，能否克服雲、霧或塵爆之潛在作用而定。舉例而言，機載雷射便使其得以於這些天候影響之上方作業。

Because they are more affordable, laser defenses can be more widely spread. They can complement missile defense missiles of longer ranges. Megawatt-class chemical lasers could defeat theater ballistic missiles. Multi-megawatt class lasers (much larger than any system under development today) would be required to defeat the faster and much harder targets presented by intercontinental ballistic missile (ICBM) reentry vehicles (RVs). In both cases, effectiveness of a laser defense would depend on developing systems concepts that overcome the potential effects of clouds, fog or dust storms. For example, aircraft basing would allow the laser weapon to operate above these weather effects.

攻勢作戰 Offensive Operations

由於雷射進入目標之內的破壞能量，遠低於大型的化學能或動能之彈藥，雷射運用於攻勢作戰時，應以其他之特性如精準、接戰之速度與數量等為重，而非以純粹之破壞能力為考量。

Because lasers put considerably less destructive energy into a target than the larger chemical or kinetic munitions, offensive applications of lasers will most likely be dedicated to those missions where their other characteristics (e.g., precision, speed and numbers of engagements) are more important than pure destructive power.

地面作戰：理想的極精準打擊系統 Ground Operations: Ideal Ultra-Precision Strike Systems

因為其體積、重量與缺乏強力的穿甲／強大的侵徹能力，地面作戰運用雷射於攻勢作戰時，最適宜執行精準、光速接戰、可隨時調整與將百姓損失降至最低之類的任務。例如，以反狙擊手任務而言，在雷射武器與聲光感測器配合下，可以追蹤狙擊手之子彈回溯至其發射地點，而立即自動瞄準，在狙擊手採取掩蔽前將之擊斃。雷射武器比傳統機槍好的是雷射並無「飛行時間」，附帶的損傷甚小。

Because of their size, weight and lack of heavy armor-piercing/deep -penetration capability, offensive applications of laser weapons in ground combat will most likely be dedicated to those missions where the precision, speed-of-light engagement time, adjustability and minimal collateral damage of laser weapons are desired. For counter-sniper missions, for example, a laser weapon paired with acoustic and optical sensors that track a sniper's bullet back to the firing point almost instantly could automatically be aimed to engage the sniper before he is able to take cover. The advantages of laser weapons over conventional machine guns are that lasers have no "time of flight" and produce little collateral damage.

雷射「隱形」之特性也是一個讓他們成為理想的極精準打擊系統之原因。他們並不像好萊塢所描寫的那樣，真正的雷射武器沒有可見的光束與音響的「報告」，也沒有防火帽的閃光與後座力。在絕大多數的大氣條件下，敵人唯一能夠知道他被擊中了的方式是目標上的雷射作用。雷射系統利用低功率的雷射瞄準，以供同軸的高功率雷射行致命一擊。一旦瞄準點無誤，操作手只需輸入高功率雷射以擊斃目標——這正是狙擊手格言「一槍斃命」的寫照。這種使用雷射方式所造成無辜百姓的傷亡，會比目前所使用的精準導引飛彈要少得多。

The “stealth” characteristics of lasers also make them ideal ultra-precision strike systems. Unlike their portrayal by Hollywood, real laser weapons have no visible beam and have no sonic “report,” muzzle flash or recoil. Under most atmospheric conditions, the only way an enemy would know he was being engaged by a laser would be to see the effect on the target. The systems use low-power lasers to establish the aim point for co-aligned high-power lethal lasers. Once the aim point has been established, the operator has only to energize the high-power laser to kill the target—the epitome of the sniper’s “one shot, one kill” motto. Such use of lasers permits less collateral damage than today’s precision guided missiles.

雷射武器之精準與可隨時調整之特性，使其在某些部隊使用必須非常小心，因為以反暴亂與維持社會穩定支援社會建設(SASO)的任務而言，這類武器極其有效。例如，可以將雷射武器用來擊斃或制壓躲藏在人群中的武裝暴民，那些地方使用其他武器容易傷及無辜百姓。功率較低時，雷射只能達到非致命的作用。要達到這些目的，將雷射武器裝到無人飛行載具或直升機上，並於遠距離使用時最為有效。作戰計畫時必須將現行禁止蓄意以雷射使戰鬥與非戰鬥人員致盲的條約與限制考量進去。

The precision and adjustability of laser weapons could make them highly effective in counterinsurgency or stability and support operations (SASO) where force must be applied carefully to achieve a desired effect. For example, laser weapons could be used to kill or neutralize armed insurgents hiding within a crowd where other weapons would injure innocent civilians. At lower power levels, lasers might achieve only nonlethal effects. For these purposes, laser weapons would probably be most effective when mounted on UAVs or helicopters and used at extended ranges. Operational planning must take into account existing treaty constraints that prohibit the intentional blinding of combatants and noncombatants by lasers.

建議 Recommendations

經驗顯示技術的創新可能會引發無可想像的重大結果，由上已可知其重要性為何。美國國防圈內的人，實在有必要加強雷射武器在作戰運用上之瞭解，並發展其使用之作戰概念。

As important as these consequences may be, experience shows that technological innovation may generate even more important consequences that are impossible to predict. This makes it imperative that the U.S. defense community pursue a robust process toward enhancing understanding of the operational implications of laser weapons and development of operational concepts for their use.

第一個需求是實際接手，實際體驗，以建立對雷射武器能力真正之評價。意即儘速而實際的推動現有的雷射武器計畫。應慎重的考量儘快部署一種戰術性高能雷射之原型系統。該系統已證明能有效的對付火箭、砲彈與迫擊砲彈，只須將現有的測試系統稍加改良，便可用以防

衛伊拉克與阿富汗境內之重要設施與基地。這是其重要目標之一，但是也說明了雷射在主動防衛上之戰鬥效益，可激勵雷射武器之研發。專家們曾經說過雷射武器若不能在最近的戰鬥中證明其功效的話，那就得十年以後才能在戰場上再見到他們了。

The first requirement is to develop a true appreciation of laser weapons capabilities by hands-on, practical experience with them. This means pressing on with existing laser weapons programs as rapidly as practical. Serious consideration should be given to fielding a productized prototype of the THEL as quickly as possible. With its proven effectiveness against rockets, artillery and mortars, relatively modest improvements in the existing test system would allow prototypes to defend key facilities and bases in Iraq and Afghanistan. This is an important objective in itself, but it would also demonstrate the combat effectiveness of active defense lasers, serving to spur interest and progress in laser weapons development. Experts have said that either laser weapons will prove themselves in current combat operations or it will be another ten years before they are fielded.

其他讓美國國防圈內的人迅速瞭解雷射武器的作為，應包括積極的演習與實驗計畫。該計畫應遵照作戰概念發展之標準步驟為之：

—桌上兵棋推演，以確定應關注之重要地域；

—詳盡的模式模擬，以作為發展原型武器與概念運用之指導；

—將整組之雷射武器模組裝至作戰飛機、車輛與船艦上，以供野戰實驗之用；

—由作戰部隊實施野戰實驗，以發展雷射武器運用之戰術、技術與作業程序。

Other efforts to speed the U.S. defense community’s appreciation for laser weapons should include an aggressive wargaming and experimentation program. This program should take the following standard steps for operational concept development:

—tabletop wargames to identify critical areas of focus;

—detailed modeling and simulation that will in turn guide the development of prototype weapons and employment concepts;

—prototype modular laser weapons packages that can be mounted on operational aircraft, vehicles and vessels for hands-on field experimentation; and

—field experimentation in operational units to develop tactics, techniques and procedures for laser weapon employment.

結論Conclusion

從技術發展的立場而言，作戰用的雷射武器已呼之欲出。挹注充足的資源，一種可以在戰場上空射擊火箭與迫擊砲彈的化學性雷射武器「成品」，可望在18個月內問世。可增加雷射武器射程的固態與自由電子雷射武器，所需研發時程則不到10年。同時，位居研發、獲得與運用這些系統決策要津的人士，其軍旅生涯業已過半，但是對雷射武器之潛能所知仍甚有限。

From the technology development standpoint, operational laser weapons are right around the proverbial corner. Given adequate resourcing, a “productized” chemical laser weapon could be shooting rocket and mortar rounds from battlefield skies within 18 months.15 Solid-state and free-electron laser weapons, adding to the range of laser weapons capabilities, may be less than a decade away.16 Meanwhile, the personnel who will make key decisions on the development, acquisition and employment of these systems are already half-way or more through their military careers, but most have developed little awareness of the potential implications of laser weapons.

即便只是極其簡略的驗證了雷射武器之潛能，亦可顯示出將他們用之於作戰，能夠大幅改變戰鬥的動力，其中尤以其攻防能力之競爭力為然。雷射可以提供有效的主動防護，以對付各種能力不斷增強，而目前不易或無法擊滅者，諸如地對空、空對空、火箭、砲彈與迫擊砲彈，以及潛在的戰區彈道飛彈之威脅。這些攻擊性武器之精度、射程與威力已大幅增進，使其危險性日增，但是雷射武器能使部隊輕易的保護自己，而得以扭轉此一劣勢。將裝置在各種不同戰鬥載臺上之雷射武器用之於攻勢，可使精準用兵變得更加可能。

Even a relatively cursory examination of the potential capabilities of laser weapons indicates that their introduction to operations can cause significant shifts in warfighting dynamics, especially in the competition between offensive and defensive capabilities. Lasers can provide effective active defenses against a range of increasingly capable threats that are now difficult or impossible to defeat, such as SAMs, AAMs, rockets, artillery and mortars—and, potentially, theater ballistic missiles. Major improvements in accuracy, range and lethality have made these attacking weapons increasingly dangerous, but laser weapons may reverse this trend by making it much easier for forces to defend themselves. Offensive use of laser weapons may make possible the much more precise application of force from a variety of combat platforms.

如果雷射武器的潛能達到目前為止所展示的，而且能依計畫儘速的發展，戰爭進入雷射武器的時代將會比大多數人預期的要快上許多。美國有必要以作戰概念指導科技轉型投資於雷射武器之上，以利用這種新興的能力。發展其作戰概念以開發美軍的知識能量，實為國家安全當務之急也。

If laser weapons live up to the potential they have shown thus far and if their development proceeds as fast as projected, warfare may enter the age of laser weapons much sooner than most expect. To leverage this emerging capability, the United States needs operational concepts to guide investment in the transformational technology of laser weapons. The implications for national security are so significant that developing these operational concepts merits top priority for U.S. military intellectual energy.

作者：史卓普（Theodore G. Stroup, Jr.），美國陸軍退役中將，目前為AUSA負責教育之副總裁。在35年的軍旅生涯中，曾歷練各種指揮與幕僚職，包括參謀長室之計畫分析與評估主任，及人事署副署長等。

杜恩（Richard J. Dunn Ⅲ），陸軍退役上校，曾在越南、夏威夷與韓國帶兵，並曾在陸軍部之各部門歷練過。

Lieutenant General Theodore G. Stroup, Jr., U.S. Army Retired, is currently serving as AUSA's Vice President for Education. He served in various command and staff positions over his 35-year career in the Army, including Director for Program Analysis and Evaluation in the Office of the Chief of Staff and Deputy Chief of Staff for Personnel.

Colonel Richard J. Dunn, III, U.S. Army Retired, led Soldiers in Vietnam, Hawaii and Korea. He also served extensively at Headquarters, Department of the Army.

資料來源：美國陸軍地面戰學會

資料時間：2006年12月