Joint Laser Interoperability, Tomorrow's Answer to Precision Engagement

by

Lt Col David Neuenswander

Introduction

We think of ourselves as a precision-capable air force, yet we have a serious gap in that capability. As of 2001, most US precision engagement capability comes from laser-guided "man in the loop" weapons carried on fighters/attack helicopters.[1] Very few US ground forces and some combat aircraft do not have any laser-guided precision weapons.[2] If the DOD is committed to JV 2020, it must find innovative ways to provide a precision engagement capability to all US forces. Since laser systems already provide most of the DOD's precision capability, the innovation must include lasers. JV 2020 talks full-spectrum dominance and precision engagement, but without lasers those visions are but a mirage.

According to JV 2020, innovation can occur, "from fielding new things, or by imaginatively recombining old things in new ways."[3] This is what must be done--combine current laser capabilities with new technologies to create a concept called Joint Laser Interoperability.

Background

Current US Laser Systems

Lasers and laser-guided weapons are not new to the inventory. In 1972 USAF fighters ushered the world into the age of precision engagement by destroying North Vietnam's Paul Doumer Bridge with laser-guided bombs.[4] Since the Vietnam War, every branch of the US Armed Forces created their own niche for laser systems. These laser systems fall into four basic categories: laser range finders, laser designators, laser spot trackers, and laser guided weapons.

Laser Range Finders

Laser range finders were the first military application of the laser as a tool of war. The US military developed these range finders less than five years after Theodore Maiman built the first working laser.[5] First used on tanks in the 1960s, laser range finders are now a necessary part of most direct fire targeting systems in the DOD.[6] The following is a basic description of how a laser range finder works, what platforms they are currently mounted on, and the difference between eye-safe and non eye-safe lasers.

A laser range finder has two basic parts, the laser and a laser receiver. When a laser is fired, the object it hits, or its target, reflects the laser energy and this energy disperses. Some of this energy is reflected back towards the laser and can be picked up by the receiver. A laser range finder fires a 10 to 30 nanosecond (billionth of a second) burst of laser energy at a target in a preset wavelength and the laser receiver is coded to pick up **only** the reflected laser energy in that same preset wavelength.[7] Laser energy travels at the speed of light, roughly 180,000 miles or 300 million meters per second.[8] The laser receiver has a small processor that knows the speed of light and using the **rate=time x distance** formula, the receiver solves for distance. Laser range finders are extremely accurate and incredibly fast.[9]

This quick and accurate range information greatly increases the chance of a first round hit for modern military weapons. Thus, tanks, anti aircraft guns, anti tank guns, direct fire weapons, and many ship and aircraft weapons rely on lasers for range information.[10] As previously stated, laser range finders are a part of most current US fire control systems. These range finders are built into tanks, armored personnel carriers, attack and reconnaissance helicopters, fighter and bomber aircraft, ship fire control systems, and even hand carried by soldiers. Table 2-1 below gives an overview of the many types of LRF systems currently used by the US military. The designator column denotes those range finders that are also laser designators, and will be discussed later.

Table 2-1[11]

Military Designation	**Platform**	**Comments**	**Designator**
AN/VVS-1	(M60A2)		N
AN/VVG-2	(M60A3)		N
AN/VVG-3	(M1Tank)		N
LAV-105	(Marine APC)		N
AN/TVQ-2 GVLLD	(M-113 APC, Bradley, ship fire control)	Also troop carried/tripod mounted	Y
Compact Laser Designator (CLD)	Navy Ships		Y
AIM-1	(Various machine guns)	Aiming laser	N
AN/PAQ-3MULE	(Handheld LTD)		Y
AN/PAQ-1	(Handheld LTD)		N
AN/PVS-X MLRF	(Handheld LRF)	Mini-LRF	N

AH-1W NTS	(AH-1 Helo)		Y
LAAT	(AH-1F)		N
TADS	(Apache Helo)		Y
MMS	(OH-58D Helo)		Y
F-117	(Stealth Fighter)	Targeting Pod	Y
LANTIRN	(F-16 CG/F-15E/F-14)	Targeting Pod	Y
AN/AAS-38A	(F/A-18)	Targeting Pod	Y
(AN/AVQ-19):	(AC-130)		Y

Although table 2-1 does not include every laser range finder in the inventory, it includes every class and most lasers still in active US service. A review of the table shows that laser range finders can be lumped into four categories. Those categories are; vehicle mounted (tanks/APC), hand carried (including tripod and ship mounted), helicopter mounted, and aircraft mounted. Many of the systems, such as the AF/Navy LANTIRN Pod, tie the laser range finder in with other capabilities such as Global Positioning System (GPS) navigation and target marking systems. By tying LRF to the GPS the pilot can fire laser at a target and instantly receive coordinates for that target with military GPS accuracy.[12] Of note, all of the laser range finders in table 2-1 are non eye-safe in their combat modes.

Non Eye-Safe and Eye-Safe Lasers

Most of the laser range finders in table 2-1 use either a yttrium-aluminum garnet (YAG) or a glass laser. These lasers operate at a wavelength of 1.06 micrometers (microns) and are extremely hazardous to the human eye. Shining this laser in an unprotected eye for just a split second will result in permanent eye damage or blinding.[13] This eye hazard limits laser training to closed rifle or artillery ranges under strict safety guidelines similar to those used for direct fire weapons.[14] Currently, the DOD is researching ways to capture the benefits of a 1.06 micron laser range finder with a 1.54 micron laser range finder in the eye-safe range. Where the 1.06 laser's wavelength rapidly builds up heat and burns that back of the human eye, the 1.54 laser's longer wavelength and lower power does not build up the eye-damaging heat.[15] Systems, such as the AF/Navy LANTIRN pod, already have both combat (1.06 micron) and training (1.54 micron) modes.[16] This LANTIRN pod's dual capability allows aircrews to train almost anywhere with a less powerful eye-safe laser and then change to the 1.06 micron laser for combat.

Laser Designators

A laser designator is a laser range finder with enhanced capabilities. In addition to the normal functions of a laser range finder, laser designators can be used to guide a laser-guided weapon to a target. For laser designation operations, an operator shines his laser on a target during the terminal phase (last seconds) of the laser-guided weapon's flight and the weapon guides on the laser energy reflected off of the target.[17]

To insure the weapon hits the correct target, the laser is coded and the seeker on the weapon must have the same code set.[18] This code can be described as sort of a Morse code, with the split second laser burst sending dot-dash-dot, and the weapon set to the same code. The weapon will not see any laser that is not transmitting the dot-dash-dot code. Since each weapon has it's own separate code, multiple lasers and weapons can be fired into the same area without fear of interference or the weapon switching to the wrong target.[19]

Coding provides flexibility because the designator can be on the ground or in the air and does not have to be co-located with the system that launches the laser guided weapon. Thus, a soldier with a designator can laze for artillery, helicopter, or aircraft delivered laser guided weapons and fixed or rotary wing aircraft can laze for the same systems. When coupled with the many laser systems and weapons on a battlefield, this flexibility provides an almost endless number of ground to ground and air to ground lazing and weapons delivery options. Procedures for these tactics are located in Joint Pub 3-09.1.[20]

Laser Spot Trackers

Laser Spot Trackers are the least common of all US laser systems. A laser spot tracker is not a laser, it is a sensor that picks up coded laser energy from a laser designator and projects a symbol on a sight or heads up display. This symbol allows an operator to visually acquire the target designated by his or a friendly laser. Most laser spot trackers are mounted on helicopters or fixed wing aircraft.[21] Table 2-2 lists those US platforms currently equipped with a laser spot tracker. At this time, there are no ground-based systems with laser spot trackers and the only fixed wing aircraft with both a laser designator and a laser spot tracker are Navy F-18s and USAF fighters equipped with the new Lightning II targeting pod.[22]

Table 2-2: Platforms With Coded Laser Acquisition and/or Spot Trackers[23]

Rotary-Wing	**System**
AH-64 Apache	TADS
AH-6	LST
Fixed-Wing	**System**
A/OA-10	Pave Penny
AV-8B Harrier	ARBS/ATF

F/A-18 A/C/D	LST/LDT pod on selected aircraft
F-16 CG, F-15E	Lightening II Targeting Pod

While the OH-58D, SH-60B, and HH-60H do not have laser spot trackers, pilots can see a laser spot if they are carrying a Hellfire Missile due to the missile seeker head cuing in their weapons display.[24]

Laser spot tracker operations require direct communications between the laser operator and the platform with the tracker. Both the laser and tracker operators must have the same laser code set in their equipment, and the tracker operator directs the laser operator to turn on the laser when he is within range.[25]

Laser Guided Weapons

Laser guided weapons (LGW) are the business end of US laser systems. The primary LGW platforms are fixed and rotary wing aircraft, artillery, and naval gunfire.[26] For LGWs to be effective, an aircrew member or ground spotter must illuminate the target with a laser during the last seconds of the weapons flight. The seeker on the laser guided weapon sees the laser reflection from the illuminated target, and commands the weapon's guidance fins to steer to the target.[27] Table 2-3 lists the current laser guided weapons in the US inventory along with the platforms that deliver these weapons.

Table 2-3: Laser Guided Weapons[28]

Category	Weapon	Platforms
Laser Guided Bombs (LGB)	GBU 10,12, 24,27,28	Virtually all fixed wing fighter aircraft
Laser Guided Missile	Hellfire	Apache, S/H-60, OH-6, 58, AH-1 Cobra
Laser Guided Missile	Maverick, AGM-65E	AV-8, F-18, [EA-6] F-14
Laser Guided Projectile	Copperhead	Arty and Naval Gunfire

In addition to these current LGWs, the US Army is working on upgrades to several weapons, including a laser guided mortar round and a guided MLRS projectile.[29]

This examination of current US laser capabilities may cause more confusion than clarity. Some systems have range finders but no designators, while others have laser spot trackers and no lasers. While the reader might expect interoperability at least within a specific service such as the USAF, a review of the table 2-1/2 shows that the primary Close Air Support (CAS) aircraft, the A-10 does not have a laser but is equipped with a laser spot tracker. Conversely, the F-16 has a laser designator, but no laser spot tracker.

With the exception of jointly acquired systems such as the LANTIRN pod, inter service interoperability is just as confusing. Table 2-1 shows that tanks and armored personnel carriers (APCs) are equipped with laser range finders that cannot be coded, and thus could not designate or mark for their own service helicopters or sister service fixed wing aircraft. Further, these platforms equipped with strictly range finding assets can not designate for the Copperhead munitions available from their own or sister service artillery. Simply put, current US laser system capabilities are not interoperable. To create the fully joint precision engagement capability called for in JV 2020, the US must make significant changes.

Proposal

As previously stated, almost all precision weapons in the US inventory are controlled by laser systems, and these laser-guided weapons have been the weapon of choice in recent conflicts. For example, during Operation Deliberate Force over Bosnia, the US employed a total of 622 precision munitions, of which 567, or 91% were laser-guided bombs.[30] If the US could make all laser systems and laser guided weapons jointly interoperable, then logically, the DOD would be well on the way towards achieving JV 2020's goal of a fully joint precision engagement capability. Significant changes must occur before Joint Laser Interoperability is a reality, however, most of the required systems are already available.

Joint Laser Interoperability

Joint Laser Interoperability is not a new concept. A close look at the previous tables shows that there are a few instances where systems in the DOD were intentionally created for use in joint operations. Laser interoperability will not happen by itself. There must be a joint effort where all services agree -- or are directed -- to make changes in existing and future weapons systems. To create this Joint Laser Interoperability, the DOD must direct and fund the following changes:

1. Modify all vehicle, aircraft, ship, and tripod laser range finders as laser designators.
    a. Designate that all of these laser designators have both combat (1.06 micron) and training (1.54 micron) settings
2. Modify all vehicles, aircraft, ships, and tripod laser designators with a laser spot tracker.
    a. DOD incorporate current research and development and field a laser spot tracker that works in the 1.06 (combat) and 1.54 (training) wavelengths.[31]
3. Equip all unmanned aerial vehicles (UAVs) with a laser designator and laser spot tracker.
4. Equip all ground, air, and sea units be equipped with some type of Laser Guided Weapon (LGW)
5. Establish Joint R&D to create a man-portable laser designator/spot tracker operating at 1.06/1.54 microns.

The DOD can significantly increase its precision engagement capability by combining current laser systems and by developing a laser spot tracker that works in both the combat and training wavelengths. Although this may seem like a huge order, certain parts of the DOD are already moving in this direction. For example, the current USAF Litening II LANTIRN pods have all of these capabilities.[32]

Understandably, the biggest drawback to this concept will be funding. Modifying fleets of tanks, APCs and aircraft will cost money, even if the majority of these capabilities are already on the shelf. Due to current contracting laws, vendors are prohibited from giving actual costs to DOD members who are not involved in the acquisition process. Sadly, this includes Senior Service Students who are doing research.

Air Interoperability

Laser systems are more common to aviation units than any other segment of the armed forces. Another review of the previous tables shows that all fixed wing fighters and most helicopters can employ laser guided weapons; yet, there is great disparity when it comes to laser designators and trackers. Some aircraft have designators, and some do not. Fewer still have a laser spot tracker so the operator can see where his laser spot or the spot of another designator is pointed. Though the idea of adding lasers to UAVs is so new it is not included in Joint Pub 3-09.1, UAV laser testing is moving at a fast pace. Recently a UAV shot a Hellfire missile at a tank and guided it to a direct hit with its own laser.[33] To achieve laser interoperability within the air component, this concept breaks the component into fixed wing, rotary wing, and UAV assets, and proposes changes for each asset class.

For purposes of analysis here, fixed wing assets are defined as fighter and attack aircraft and do not include the B-1, B-2, and B-52 bombers. It also excludes the F-117 stealth fighter due to the classification of that weapons system. Fighter and attack aircraft provide the easiest solution to laser interoperability, because the laser designator, laser spot tracker, and selectable 1.06/1.54 micron laser capabilities already exist in the form of the Litening II targeting pod.[34] Because the F-14, F-18, F-16 and F-15E all carry some type of targeting pod, equipping these aircraft with the Litening II as soon as possible would provide interoperability for these aircraft.[35] The A-10 attack aircraft does not carry a targeting pod, however, the Marines began mounting the Litening II on AV-8Bs in August 2000.[36] In the case of the A-10, the aircraft must be modified to carry a targeting pod and then equipped with the Litening II.

In 2008 the first Joint Strike Fighters (JSF) will enter the US inventory. JSF aircraft will eventually replace many of the fighters mentioned above, including the A-10, AV-8B, F-16 and F-18 A and C models.[37] The JSF will have a laser spot tracker and laser designator, and combat and training laser modes, making it fully laser interoperable.[38]

Attack helicopters make up the rotary wing portion of the air component. A review of the tables in Section II shows that the Marine AH-1, and the Army Apache, OH-58, and MH-60 have laser designators. The Navy’s SH-60 is also laser designator equipped. Unfortunately, all of these helicopter mounted laser designators have a fixed wavelength of 1.06 microns and none of them have a true eye-safe training capability.[39] Hence, the DOD must modify attack helicopter laser designators with a selectable wavelength of 1.06 for combat and 1.54 for training. The "switchable eyesafe laser rangefinder/designator" (SELD) designed by Kollsman Inc. for the Comanche helicopter is an on the shelf solution for this problem.[40]

As for laser spot trackers, the Army OH-6 has a tracker and no designator, and the OH-58, MH-60, and SH-60 only have a tracker capability if they are carrying Hellfire missiles and reference the missile cue in their sights. The OH-58, MH-60 and SH-60 should be modified with a laser spot tracker. In the case of the OH-58 the tracker could be mounted in the mast sensor system. For the MH/SH-60s a fixed laser spot tracker similar to the USAF PAVE PENNY pod could be developed.[41] With new technology the size requirements for a laser spot tracker decreases. Mr. Ian Crawford (engineer for Analog Modules Inc. who worked extensively on the current F-18 laser spot tracker) believes future laser spot trackers will take up as little as .5 cubit feet of area.[42] In the case of the OH-6, its small size might make the addition of a laser designator unrealistic, however, the current laser spot tracker should be modified to see both 1.06 and 1.54 microns.

The only modification the Apache requires is a change to its laser spot tracker to pick up the 1.54 micron training wavelength. The US Army's next generation attack helicopter is the AH-66 Comanche, and it will be equipped with a 1.06/1.54 laser designator and a laser spot tracker.[43] When fielded, the Comanche will meet all of the requirements of Joint Laser Interoperability.

UAVs are the newest air asset in the US inventory. At the present time only the Pioneer and the Predator UAVs are operational, with the Outrider, Global Hawk, and Dark Star UAVs under development and the Hunter UAV in mothballs.[44] The DOD is making plans to add laser systems on UAVs, but the 1993 version of the Joint Pub that covers UAVs (Joint Pub 3-55) merely states that laser designators could be included on future UAVs.[45] In the case of UAVs current platforms should be modified to carry at least a 1.06 micron laser designator and a laser spot tracker.

Future UAVS should be equipped with a dual wavelength combat/training laser designator and a laser spot tracker that picks up both wavelengths. In addition, these laser systems should be tied into the UAV navigation system similar to the way the LANTIRN and Litening II pods slave to the GPS.[46] Tying the laser designator to the navigation system allows the UAV to mark targets with the laser and provide extremely accurate coordinates to the units it supports.

Ground Interoperability

Equipping US ground forces with the systems necessary for Joint Laser Interoperability is more difficult that outfitting the air component. Most airborne laser systems are pod mounted and hang on the exterior of the aircraft, while most ground systems are internal to the vehicle itself with some parts "hard wired" to the turret, fire control system, or chassis. The US Army and Marines currently mount laser range finders on the M-1 and M-60 tanks, Bradley Fighting Vehicles (BFV), and on certain variants of the Light Armored Vehicle (LAV) and HMMWV.[47] The only vehicle-mounted laser designators are on US Army Fire Support Team (FIST) vehicles (modified HMMWV or BFV's used to control artillery).[48] No US Army or Marine units have vehicle-mounted laser spot trackers.

The average legacy mechanized infantry brigade contains five infantry and four armor battalions. Within these battalions are an average of 180 M-1 tanks, 225 BFVs, 90 HMMWV scout vehicles, and four FIST BFVs assigned to the unit by Division Artillery.[49] Adding the tanks and BFVs yields a total of 305 non eye-safe laser range finders, with 4 laser designators and no laser spot trackers.

The idea of putting laser designators rather than just laser range finders on tanks and APCs is not a new one. A senior physicist at Raytheon who worked on the development of all current US Army systems said that his company suggested this concept 20 years ago, but the US Army chose not to make the modifications for budgetary reasons.[50] Due to current funding and the US Army's desire to create a new force for this century, it is unrealistic to assume that they would fully modify all 305 vehicles in the legacy brigade. On the other hand, modifying as few as 20% of these vehicles could give this brigade a significant precision engagement capability. At 20%, each tank or BFV company (usually composed of 14 vehicles) would have at least two laser interoperable vehicles to work with.[51] Since these companies typically operate in close proximity to each other, every company would have some precision-engagement capability.

This paper proposes no less than 20% of tanks and BFVs be modified with a codeable 1.06/1.54 micron laser designator and outfitted with a laser spot tracker that operates in both wavelengths. The laser spot tracker would be similar to the one suggested for the MH/SH-60 and could be fixed on the turret and slaved to the main armament. At .5 cubit foot, a laser designator would be little larger than a coffee can, and the laser spot tracker cues could be projected on the gunner's thermal sight reticule.[52]

A real precision engagement advantage will occur if the US Army builds Joint Laser Interoperability into the IBCT and Army After Next Forces. These new forces must make JV 2020's precision engagement goal a reality. IBCT proposals set the brigade strength at 348 combat vehicles, all of which are variants of the LAV chassis.[53] These variants include two gun systems, an infantry carrier, a mortar carrier, a reconnaissance version, and a FIST vehicle to direct artillery fire. Unfortunately, the only variant with a laser designator is the FIST vehicle, and the brigade will have at most 15 of these.[54] The FIST vehicle will be outfitted with the AN/TVQ-2 G/VLLD.[55]

The G/VLLD is a fixed 1.06 laser designator with no training wavelength and no laser spot tracker capability.[56] Thus, the IBCT will have no more laser capability than a current legacy brigade. Since the IBCT has not yet been built, the US Army must start now and built a 100% Joint Laser Interoperable force to meet the precision engagement requirements of JV 2020. In this concept, the US Army would restructure their combat LAV requirements to include 1.06/1.54 micron laser designator and a laser spot tracker capable of picking up both wavelengths.

One possible solution is to proceed with the technology already underway on the Future Scout and Calvary System (FSCS). This low profile vehicle is jointly funded with the UK, and is fielded with a turret containing a 1.06/1.54 designator-range finder as well as a FLIR, Millimeter wave radar, and photo-optic capabilities.[57] Adding a laser spot tracker to this vehicle would make it a fully laser interoperable platform, and add significant capability to the IBCT.

In addition to manned vehicles with laser designators and spot trackers, US ground forces must develop unmanned vehicles with this capability for urban combat and areas where the risk might be too high (or the rules of engagement prevent that risk) to send troops. The US Marines have been working since 1985 on a "TeleOperated Vehicle" (TOV) that mounts a laser designator.

This remotely piloted APC has successfully lazed for live Copperhead and Hellfire missile tests, and the operator can drive the vehicle and laze targets from as far away as two kilometers.[58]

In addition to upgrading vehicle-mounted laser systems, US ground forces must also improve their current hand-held laser designators, such as the AN/PAQ-3MULE, G/VLLD and SOFLAM. These laser designators provide critical precision capability to light infantry units that do not have tanks or fighting vehicles. Sadly, current hand held laser designators are inadequate if tomorrow's infantry hope to use lasers for precision engagement.

As an example, the 25th Infantry Division has 8 G/VLLDs.[59] As previously stated, the G/VLLD is both a range finder and a designator in the 1.06 micron range. It has no training wavelength, no laser tracker, and weighs 61 lbs. with one set of batteries. Further, once a soldier takes the G/VLLD into combat, the batteries have a usable life of less than 10 minutes.[60] We need better--the DOD must leverage new technology and develop a single handheld laser designator that meets the requirements of joint laser interoperability, has at least 20 minutes of battery time, and weighs less than 25 lbs. If technology allows, this unit should also have a training mode at 1.54 microns, and a laser spot tracker.

Laser Guided Weapons

Once ground, air, and sea elements of the DOD achieve laser interoperability, it is of little use without the Laser Guided Weapons (LGW) these laser systems support. Although LGWs have been successful in recent conflicts, these weapons are not uniformly available to all combat units. A review of table 2-3 in Section II reveals that all LGWs are employed from fixed or rotary wing aircraft with the notable exception of the US Army's Copperhead artillery round. To achieve true Joint Laser Interoperability, all combat units must have LGWs in their arsenal.

The air component has a myriad of effective LGWs at its disposal, including laser guided bombs and missiles. Most of these weapons are very effective, provided the target area is not defended beyond the aircraft's ability to penetrate the Integrated Air Defense (IAD) and the weather is adequate to allow the aircraft to laze the weapon to impact. To solve some of this problem, the USAF is modifying many of its laser-guided bombs with Global Positioning System kits that allow terminal guidance to impact if the laser cannot laze until impact.[61] In addition, both the USAF and USN are funding research to modify a number of Tomahawk and Standoff Land Attack Missiles (SLAM) with a laser seeker for terminal guidance.[62] These systems could be deployed below bad weather with the aid of a ground or UAV system lasing the weapon to impact.[63]

While the air component is well equipped with LGWs, US ground units do not have a direct- fire LGW, and their only indirect-fire LGW is the US Army/USMC Copperhead round, a 1980s era weapon that uses terminal laser guidance for artillery fire. Although aging, the Copperhead has a greater than 50 percent hit rate.[64] The Copperhead's hit rate is significantly better than that of normal unguided artillery, which averages between 15 and 17 percent.[65] Unfortunately, the Copperhead is almost at its maximum shelf life and will be obsolete if the Army and Marines do not take action.[66] The DOD faces a significant challenge if it hopes to achieve JV 2020's precision engagement capability for the ground component. If the DOD is serious about JV 2020, it must take immediate action to equip ground units with both direct- and indirect-fire LGWs.

To avoid the risk of close combat in ground warfare, many prominent members of civilian and defense establishments are calling for a move away from direct-fire capabilities to more indirect and precision fires.[67] Wrong move.[68] There will be times when our ground forces, for whatever reason, cannot keep the enemy at arms length and must commit to close combat. JV 2020 calls for US forces to dominate the full spectrum of warfare, and those service members involved in close combat deserve robust direct-fire systems that have a precision engagement capability.

One promising direct-fire LGW for ground units is the Hellfire missile. This missile has a proven track record in Operations Just Cause and Desert Storm.[69] The US Army's Redstone Arsenal recently launched Hellfire missiles from both a HMMWV and an Improved Tow Vehicle (ITV).[70] Coupling vehicle mounted Hellfires with the laser systems mentioned above could give ground units a lethal direct fire precision capability.

If the US Army does transition to an ICBT composed of LAV variants, there will be a measurable loss of firepower compared to legacy units equipped with the M-1A1 tank. Assuming all or some ICBT LAVs have the laser systems outlined above, vehicle-mounted Hellfires could makeup for some of this lost firepower without adding significant extra weight.

The same laser systems that provide guidance for direct-fire LGWs could also provide guidance for indirect-fire LGWs launched from other platforms at greater distances from the target. The US Marines have validated the Hellfire in both direct- and indirect-fire testing from a vehicle-mounted system.[71] The US Army is currently testing a laser guided 120mm mortar round, and is developing a precision variant of the MLRS rocket .[72] In addition to these two systems, the US Army and Navy both use the Copperhead laser guided artillery round. Unfortunately, the Copperhead is not a weapon of choice for US Ground forces, and US Army FM 17-95 calls the weapon unresponsive and ineffective against targets of opportunity.[73]

The US Army and Marines must develop new indirect-fire weapons to replace the aging Copperhead and take the next step towards precision engagement. For tube-launched weapons, precision capabilities should meet or exceed those of the Russian Krasnopol semi-active laser guided artillery round which has both anti armor and cluster variants, and is reported to be much better than the Copperhead in range, payload, and response time.[74] Army and Marine artillery units could use this weapon, and the US Navy could develop a variant of this round for use in the main guns of surface combatants. Testing should continue on a laser-guided variant of the MLRS system for deep strike precision missions.

Analysis

In his article "The New Joint Warfare", Fredrick Strain stated, "the need to identify, target, and attack in near real time is now a fact of life."[75] Strain goes on to say, "no single weapon or force reaches its full potential unless employed with complementary capabilities."[76] Joint Laser Interoperability provides joint forces the ability to communicate with each other in real time.

Regardless of the operations area, forces equipped with interoperable laser systems create a synergistic effect on the modern battlefield. If all players have a laser designator, a laser tracker, and a common radio link, lasers can be used as a communications system to accurately identify and destroy enemy targets. An operator with only a tracker or designator can be compared to a person with only the top or the bottom of a telephone; he can transmit or receive, but not both.

When a force is Joint Laser Interoperable, the first friendly to detect and identify a hostile target has options: kill the target, provide laser guidance for an off board LGW equipped system to kill it, or positively pass the target to another laser equipped system that has the capability to kill it. The real beauty of laser interoperability comes from this real time, speed of light, ability to pass targets accurately from one platform to another. With joint interoperability the options between systems are almost limitless; however, it is important to provide an example here so the reader can understand the concept.

Using an A-10 Forward Air Controller (FAC-A) and an M-1A1 tank as examples, with laser interoperability here is how the A-10 might pass an enemy target to the M-1A1 using a "laze - spot - laze - confirm" technique. After verification that he was communicating to the friendly tank, either through secure communications or an authenticator card, the A-10 would tell the tank commander to slew his turret to a specific heading, or provide the target grid coordinates. The A-10 would pass the M-1 the four digit laser code, and the M-1 would load this code into his laser spot tracker and laser designator. The A-10 would then transmit "laser-on," and the M-1 would immediately see a symbol over the enemy tank in his gun sight. To confirm it is the correct target, the M-1 would transmit "confirm laser," and the A-10 would see a symbol over the tank in his targeting pod. If the A-10's laser spot tracker symbol was not on the enemy tank, the A-10 could abort the M-1 before he fired.

The *laze, spot, laze, confirm*, communication technique is quick, and the laser's pinpoint accuracy leaves little room for error. The entire process could have been done just as easily if the M-1, or another friendly vehicle was passing the target to the A-10. Because the first friendly who sees the enemy keeps track of it until he kills it or passes it off, the enemy stays engaged from first sighting until it is destroyed.

Deep Operations

Since Operation Desert Storm the US has been committed to the concept of precision engagement. Nightly news clips of laser guided bombs hitting targets in Iraq or Kosovo provided visual evidence of the lethality of precision munitions. This highly publicized precision warfare often creates a misconception with both the public and the military that all enemy targets can be destroyed at will with a laser-guided bomb.

In a recent Rand study on deep operations, precision weapons received high marks against fixed targets such as electrical power, bridges, and POL (petroleum, oil, lubricants) sites. Conversely, precision weapons did not fare well against moving armor, and small and mobile targets.[77] If the US wants to meet JV 2020's goal of precision engagement across the full spectrum of warfare, the DOD must achieve the same level of precision success with small and mobile targets that it has with large fixed targets.

During Operation Desert Storm, deep operations focused primarily on enemy "centers of gravity".[78] In Iraq most centers of gravity were fixed targets that fell into the Rand target sets where LGWs excel.[79] In the more recent Kosovo conflict US forces directed much of their effort against the enemy's fielded forces. These forces were made up of the type of targets the Rand study identified as "difficult to destroy with precision weapons" (i.e. moving armor and small and mobile targets).[80]

Post Kosovo discussions about the success of the bombing campaign and the proper use of precision weapons differ greatly depending on the service of the advocate. Lt Gen Michael Short, JFACC for the Kosovo operation, advises against future uses of airpower to whittle down enemy fielded forces, unless those forces are identified as the enemy center of gravity.[81] Whether the US Army and Air Force can agree on centers of gravity matters little. Neither does the fact that according to the USAF, deep operations against non-moving, entrenched fielded forces are not the most doctrinally sound use of military force. If a future operation identifies the enemy's fielded forces as the center of gravity, US forces will be tasked to operate and succeed in that scenario. Because JV 2020 directs dominance in the "full spectrum," US forces need the ability to precisely engage all targets whether big or small, fixed or mobile.

After Kosovo the US did not publish a DOD-wide lessons learned, but the United Kingdom quickly published an after action report with specific references to precision weapons. This report stated, "There is a need for the UK and its allies to improve capabilities in the following areas: precision joint all-weather attack capability against both static and mobile ground targets."[82] Both the Rand study and the UK lessons learned call for an increased deep strike capability against small and mobile targets. It is not illogical to assume that actions that increase US precision capabilities against these small targets will increase precision capability against the large fixed targets the US has successfully hit since Desert Storm. Joint Laser Interoperability can provide a significant increase in capability against small and mobile targets in deep operations, while at the same time, maintaining the ability to target and destroy large fixed targets. Laser interoperability would save time, minimize exposure to enemy threat systems, allow a positive handoff of previously identified enemy targets, limit collateral damage, and increase the probability of a kill.

Consider this in the context of Kosovo. Deep air operations require large amounts of intelligence support both to find the targets and to provide planning materials for use during the mission. In the case of "man in the loop" systems like laser guided weapons, pilots must have accurate target coordinates prior to the mission or have an outside agency direct them an area where they can acquire the target themselves.[83] During Kosovo air operations against Serbian ground forces, NATO used the Airborne Battlefield Command and Control Center (ABCCC), Joint Surveillance Target Attack System (JSTARS), UAVs, and other national assets to find small and mobile targets.[84] Once located, these small targets were passed to Airborne Forward Air Controllers (FAC-A) or Killer Scouts whose responsibility it was to visually confirm the target as an enemy and then talk friendly aircraft onto that target.[85]

Often it takes the FAC-A or Killer Scout a while to get his eyes on the target in a hostile threat environment.[86] During some missions over Kosovo, UAV operators had already identified small or mobile targets as hostile before the FAC-A came on scene, and were able describe where the targets were located or "talk the FAC-A's eyes onto the target" after he arrived.[87] Once the FAC-A saw what the UAV operator was describing, he took over himself. At this point the FAC-A often used non-precision guided rockets or a precision guided bomb to mark the target for follow on fighters. Both the FAC-A and the fighters orbited in the target area exposed to the threats while the FAC-A talked the fighter's eyes onto the target.[88] All of this talking occurred because there was no way to quickly and precisely pass these small targets from one platform to another. A review of the tables in Section II reminds the reader the targeting pods on the F-16 and F-14 aircraft operating as FAC-As have lasers but do not have laser spot trackers. The UAVs who had contact with the targets and identified them as hostile did not have any laser capability at all.[89] With the exception of the A-10, Harrier, and F-18, none of the NATO fighters had laser spot trackers. Laser communications were not possible in Kosovo because none of players had both halves of the laser telephone.

In the above scenario, a laser interoperable UAV could pass the target coordinates and UAV laser code to ABCCC or JSTARS who would pass the information on to the FAC-A. When the FAC-A arrived in the target area, the UAV would begin the *laze, spot, laze, confirm* technique. With his targeting pod looking at the coordinates he already had from the UAV, the FAC-A could immediately pick up the UAV's laser spot, mark the target with his inertial navigation system, and then laze the target for the UAV to confirm it was the correct one. Here the UAV would be the first friendly to find the target, and the operator would hold onto it until he positively passed it off.

Rather than a lengthy dialogue where the UAV operator describes the terrain that he sees and tries to talk the FAC-A's eyes onto the target, the FAC-A picks up the target when the UAV's laser puts a symbol in his targeting pod. This time-saving process now takes seconds rather than minutes, minimizing the time in unfriendly airspace as well as preventing a mobile target from moving before the FAC-A can locate it. When all fighters have Joint Laser Interoperability, the FAC-A or Killer Scout aircraft uses the same *laze, spot, laze, confirm* technique to positively pass the target to the fighters working his area. These laser interoperable fighters could then use their LGWs to destroy the target, increasing the chance of a kill and decreasing the chance of collateral damage due to the weapon's accuracy and the decreased probability of target mis-identification.

If the FAC-A is working the area without the assistance of a UAV, he uses Night Vision Goggles (NVGs), binoculars, Ground Moving Target Radar (GMT), coordinates from JSTARS, his targeting pod, or his eyes to find and confirm targets.[90] Once he has these targets identified he can use his laser to quickly pass them to friendly fighters, and confirm those fighters are looking at the correct target with his laser spot tracker.

In the future, pilots could talk directly to a UAV operator in the same way as he worked with a FAC-A. During periods when weather or enemy air defenses prevent FAC-As from operating over enemy targets, UAVs could work under the weather or in the threat ring if the priority of the target warranted risking a UAV. These UAVs find targets, could pass coordinates, and laze for standoff LGWs such as the laser modified SLAM or Tomahawk missiles.

Laser communications are not limited to FAC-As and UAVs passing hostile targets to friendly aircraft. Fighters or helicopters working deep missions against hostile targets can also pass targets to each other. When aircraft are working a target rich environment like a moving enemy troop formation they can positively pass the targets to follow-on aircraft before they leave. This action saves time and immediately increases the situational awareness of the new aircraft on the scene.

The advantages laser interoperability offers in deep operations cannot be understated. Providing this capability to all delivery platforms would significantly increase a platform's probability of kill, while at the same time, lessen the threat of collateral damage. During Desert Storm laser guided bombs were only 4.3% of the weapons dropped, but accounted for 75% of the damage to Iraqi infrastructure.[91] When all platforms are LGW capable, the probability of kill will go up, and the chance of collateral damage will go down. During operations in Kosovo only 20 of the estimated 23,000 bombs caused any collateral damage.[92] While no collateral damage is ever good, the fact that only 20 bombs missed their mark is a testament to the precision munitions used in the conflict.

With Joint Laser Interoperability sea and ground components could reap many of these same advantages in deep operations. Naval surface combatants could use the hellfire missile or copperhead fired from ships' guns to conduct deep operations (behind the enemies lines) close to the shore with helicopters, fixed wing aircraft, UAVs, or ground teams with laser designators providing the terminal guidance. SEAL teams or UAVs could strike deeper targets by designating for a laser-guided Tomahawk missile fired from surface combatants.

For the most part, the ground component does not conduct deep operations. There are cases when highly trained troops such as reconnaissance or special operations forces venture far behind enemy lines as they did during Desert Storm on the "Scud Hunting Patrols."[93] A Special Forces team, armed with an improved man-portable laser designator, could call on air- or ground-launched LGWs to accomplish its mission. This capability will be enhanced when the US Army develops a laser-modified MLRS and an advanced artillery launched LGW. Armed with the improved laser designator, Special Forces units could receive real time fire support limited only by the time of flight of a LGW position. This capability would significantly increase the combat power of US ground forces conducting deep operations and enable them to move from a reconnaissance to a direct action role against the enemy.

Although this paper calls for changes in military equipment, none of these concepts are new. Tactics, techniques, and procedures for laser designation already exist in Joint Pub 3.09.1. Regardless of the type of platform launching LGWs for deep operations, the platform providing terminal guidance would designate the target in accordance with the procedures already established in Joint Publication 3.09.1.[94]

Close Operations

Joint Laser Interoperability has the potential for even greater precision advantages in close operations than it does in Interdiction. Air, land, and sea components would reap many of the same benefits available in deep operations. Laser interoperability speeds up the target acquisition process, minimizes the exposure to enemy threat systems, enables a positive handoff of enemy targets, limits collateral damage, increases the probability of a kill, and most importantly, prevents fratricide. These advantages are even more important since the majority of engagements in close operations are against the more difficult to hit small and mobile targets. Because these targets can move and shoot back, any action that speeds up the targeting process and contributes to a first round kill is beneficial to US ground forces.

Consider a couple of scenarios: an actual legacy brigade composed of M-1A1 tanks and BFVs, and a theoretical, fully laser-interoperable IBCT. Such an ICBT would have approximately 350 LAV vehicles equipped with the basic package of a 1.06/1.54 micron laser designator and a laser spot tracker. Dismounted infantry and scouts would have an improved man-portable laser designator equipped with a laser spot tracker. In addition, these units would also have a reasonable number of vehicle-mounted Hellfire missile systems, improved Copperhead artillery LGWs, and laser guided mortar rounds. In addition to the systems organic to the brigade, the unit has access to laser interoperable UAVs, helicopters, and fixed wing aircraft for CAS.

As an A-10 and F-16 pilot, FAC-A, and former USAF Squadron Commander, this author had the privilege of providing close air support for seven rotations at NTC. The first scenario is the actual exercise engagement in which he participated. In December 1999 a brigade of friendly forces moved forward in the central corridor at 0430L. It was dark, and the enemy forces were dug-in approximately six kilometers in front of the friendly line of departure. The author was flying an F-16 block 40 with a LANTIRN targeting pod and operated as the FAC-A. The brigade was allocated two FAC-A sorties and eight F-16 Block 40 CAS sorties from 0430-0545. During this NTC rotation the friendly forces had no UAV or attack helicopter support.

As the FAC-A arrived on scene the ground forces were moving west and did not know where the enemy was. Using NVGs and his targeting pod, the FAC-A found four dug-in enemy positions, each with approximately eight vehicles (four tanks and four APCs). After a discussion with the Air Liaison Officer (ALO), the FAC-A determined that all four of these positions were enemy, based on a plot of the Forward Line of Own Troops (FLOT). At this point the FAC-A began directing non-precision artillery towards the dug-in armor. The artillery, though very accurate, did not destroy any of the enemy tanks. At that time a flight of four targeting pod equipped F-16s arrived on station. Because of training restrictions, the FAC-A could not shoot marking rockets at the enemy tanks to define the position, and a lengthy discussion of the four positions and the coordinates for each position ensued on the radio. In the mean time, the friendly ground forces were moving closer to the enemy tanks, and the tanks/APCs in one of the positions began repositioning to meet the friendly forces.

In this training engagement, none of the fighters or the FAC-A had a laser spot tracker, so the FAC-A used his targeting pod to talk the friendly fighters' pods onto the targets, a process that took approximately five minutes. In multiple passes the F-16s were able to completely destroy the vehicles in two of the positions; however, the other two positions evacuated, and those vehicles ultimately destroyed four friendly tanks and two APCs. During the entire engagement the FAC-A had awareness of the enemy positions, and he repeatedly warned the friendly tanks that they were driving into a potential ambush. Although three times he passed the coordinates of the nearest threat, friendly forces could not get their thermal sights on the enemy before being attacked and suffering losses. Even though the FAC-A had identified and maintained contact with the enemy and communicated their position to friendly forces, he was unable to precisely pass the target to friendly forces so they could kill it before suffering losses.

With laser interoperable aircraft/ICBT this scenario could have had a vastly different result. When the FAC-A contacted the enemy he could have quickly asked for precision ground fire and provided terminal guidance for the initial artillery actions, significantly increasing their probability of kill. Using ground-launched Hellfire missiles, improved Copperhead LGW, or laser guided mortar rounds, the ground-based precision indirect fire would have destroyed some of the tanks before they could move. Precision indirect fire has the additional advantage of limiting collateral damage. Rather than an entire barrage of unguided artillery rounds, the FAC-A could call for just the number of rounds he could control and direct them specifically into the targets he wanted destroyed.

When the fighters arrived (assuming both the fighters and FAC-A had the Litening II targeting pod) the FAC-A could have used the *laze, spot, laze, confirm* technique; saving the time involved in the talk on, insuring the fighters had the correct targets, and destroying additional targets before they could move. The time when the FAC-A and the fighters were orbiting over the target area could be significantly reduced, minimizing the threat to friendly aircraft. Finally, the FAC-A could have passed his laser code to the ground unit and highlighted the enemy positions to the friendly ground forces via their laser spot trackers. At that point they could begin putting their own direct or indirect precision fires on the enemy.

It is important that the reader understands that this scenario is not limited to the players that were actually present. A UAV, helicopter, FAC-A, or a friendly fighter could have done the initial acquisition of enemy forces. For that matter an infantryman with a man-portable laser or a laser equipped LAV could have seen the enemy first and passed the targets to a LAV for direct fire or called in indirect-fire LGWs for his terminal guidance. In essence, this infantryman would have a whole arsenal of LGWs at his disposal in real time that he could immediately direct against the enemy he sees. His ability to designate a target as hostile and provide terminal guidance would save time and would help prevent fratricide because he would be guiding a weapon to a target he sees and not simply telling someone about that target, hoping they see the same thing.

The real advantage of laser interoperability occurs when the first friendly that sees the enemy quickly provides terminal guidance for his LGWs or another platform's indirect-fire LGWs, or positively passes the targets to a platform that has the killing power to destroy them. If ground forces have been on the defensive and are in contact with the enemy when the FAC-A arrives, they can just as easily use the *laze, spot, laze, confirm*, technique to pass the targets to him. Even in close proximity, the accuracy and small beam of the laser insures that enemy locations (and not those of friendly forces) are passed between platforms. Laser interoperability works for ground-to-ground, air-to-ground, and ground-to-air scenarios.

In the scenarios just discussed, for safety reasons neither the actual nor the laser interoperable scenario used live munitions. The enemy forces were real US Army soldiers trained to operate as the enemy. In the actual NTC battle in 1999 safety regulations prohibited the use of any non-eyesafe lasers.[95] Even though NTC is one of the US' premier combat training facilities, operators cannot practice like they would fight with their laser range finders and designators due to eye danger. These restrictions include tank, APC, and targeting pod lasers in combat mode. An advantage of laser interoperable forces equipped as outlined in this paper is that they can use their eye-safe lasers and 1.54 micron laser spot trackers to practice as they would operate in combat.

Laser interoperability also provides a significant advantage for ground forces in urban warfare. The USMC's Tele-operated vehicle, or a UAV could laze for a small LGW like a mortar round and precisely hit parts of buildings previously almost impossible to target without significant risk to ground forces.[96] These smaller munitions have the additional advantage of reducing collateral damage. In areas where deep or heavily fortified bunkers might exist, a ground laser system could designate for a much heavier LGW dropped from an aircraft or fired from a land or sea-based artillery piece.

Limitations

Like any military system or systems, Joint Laser Interoperability has its weak points. Some of these weaknesses are major and will limit the effectiveness of the concept, while others are less serious and can be overcome by training and innovation. Weather is the biggest problem for lasers and laser interoperability. Less serious and easier to solve are the limitations with communications and doctrine. And, of course, cost is always a factor that could be the greatest roadblock to laser interoperability—but hopefully not, if decision-makers see the importance of this investment in laser interoperability.

Lasers, and their associated aiming systems cannot see through clouds, heavy battlefield smoke, or visible moisture like rain. If the weather is between the laser and the target, a laser designator is unusable.[97] Thus LGWs from aircraft or other platforms, which require a trajectory that enters the weather, are useless. As previously mentioned, some LGWs have been outfitted with GPS backups that provide the weapon a less accurate precision capability for bad weather. One option for the ground forces and helicopters that typically operate below the weather is a flat trajectory direct fire LGW. The Hellfire missile has a low-trajectory option that keeps the missile from entering the weather, so this technology is available for future follow-on LGWs.[98] While there is no technology that will allow lasers to work through weather, a significant portion of a joint force could still use a flat-trajectory LGW on most days. Even with a flat-trajectory weapon, weather remains the biggest limitation to laser systems, and this problem will not be solved in the foreseeable future.

If the US makes a concerted effort to implement Joint Laser Interoperability, communications will initially present a problem. Typically an aircraft or helicopter is not talking to a soldier on the ground with a laser designator unless the communication is planned in advance. Without doing a study of the entire DOD radio network, it is not possible to point out every case where a unit may or may not be capable of communicating with another due to radio incompatibility. Where issues of incompatibility arise, there will also be issues of the additional cost to provide interoperability. In addition, the *laze, spot, laze, confirm* technique will undoubtedly put more people on the radio nets that are compatible. This increase in radio traffic between parties who are not used to talking to each other can and will cause confusion until training and unit procedures insure operators are proficient. On the bright side, the procedures are already in effect in Joint Pub 3.09.1. Like any new capability, units will walk before they run in the laser interoperability business. The more units train together, the more joint they will become. This problem is solvable with committed work and training.

The doctrinal limitations of laser interoperability stem from the basic tactics, techniques, and procedures required to employ lasers in combat. Laser operations can be more complicated than operations with other fire and forget or direct fire weapons. To effectively employ laser systems operators have to know and adhere to a number of rules outlined in Joint Pub 3.09.1. The most critical rules involve a safety zone that extends +/- 60 degrees from the laser designator's sight line if he is lasing from a position on the ground.[99] This restriction limits available attack headings; however, violating this rule can result in a LGW guiding on a ground laser designator rather than the laser reflection off of the target. There are a number of other rules outlined in Joint Pub 3.09.1 that must be followed to insure safe laser operations. Fortunately, when the entire force is outfitted with eyesafe lasers for training, some of these restrictions will go away. For Joint Laser Interoperability to succeed, every soldier, airman, and seaman operating on the modern battlefield must train and become proficient in laser operations. This is another limitation that training can overcome.

Overall, weather is the only major limitation that cannot be overcome with hard work and commitment to Joint Laser Interoperability.

Conclusion

If the DOD is serious about JV 2020 and its goal of precision engagement, there is much work to be done in the next 19 years. This study outlined the DOD’s current laser systems and the precision engagement capability gained from those systems. As noted in Section II, many DOD systems have little, if any, precision capability. Further, current laser capabilities are certainly not joint, and several systems are not compatible within the same service. The concept of Joint Laser Interoperability offers the DOD a way to combine existing systems with a small amount of innovative new technology in order to achieve a significant precision engagement capability. This capability will make the individual services more joint in their application of combat power, and provide the precision weapons previously used by the air component to every serviceman and woman.

Precision weapons that rely solely on lasers for terminal guidance certainly have their limitations. Weather will always present a large problem for lasers, and there are those in the DOD who would abandon laser guidance because of those days when weather prevents its use. On the other hand, there is no 100% solution in warfare. Laser systems and the LGWs they guide have built an enviable record since Desert Storm. Laser systems may not be the weapons of choice in 2050, but they offer the best solution to a joint precision engagement capability by 2020. If lasers are not the answer in 2020, then the DOD is already behind in developing a fully joint alternative.

Should the DOD decide not to embrace this concept to modify existing aircraft and legacy forces for interoperability, then at the least these capabilities should be included in new systems such as the ICBT. If the DOD embraces the concept of Joint Laser Interoperability, it can provide a significant portion of JV 2020's precision engagement capability. Most of the hard work is already done, the doctrine is written, and the weapons are on the shelves. Now the DOD just needs to make Joint Laser Interoperability a reality.

Bibliography

Anderber, Bengt, and Dr. Myron L. Wolbarsht, ., *Laser Weapons, The Dawn of a New Military Age.* New York: Plenum Press, 1992.

US Assistant Secretary of the Army for Acquisition, Logistics, and Technology, *Army Science and Technology Master Plan 1998*, 1998 [Database on-line]; available from: http://www.sarda.army.mil/sard-zt/ASTMP98/vol_i/sec3/sec3n.htm; Internet; accessed 20 Sep 00.

Baker, Sue. "Predator Missile Launch Totally Successful,*" Wright Patterson AFB (Ohio) Aeronautical Systems Center Public Affairs,* 27 Feb 01, [Database on-line]; available from: http://www.fas.org/irp/program/collect/docs/man-ipc-predator-010228.htm; Internet; accessed 28 Apr 01

Biddle, Stephen, Wade P. Hinkle, and Michael P. Fischerkeller, "Skill and Technology in Modern Warfare," *Joint Forces Quarterly*, Summer 1999, 27.

Birker, John, Myron Hura, David Shlapak, DavidFreilinger, Gary McLeod, Glenn Kent, John Matsumura, James Chiesa, Bruce Davis, *A Framework for Precision Conventional Strike in Post-Cold War Military Strategy,* Santa Monica: NDRI, Rand Corporation, 1996, 6-9, MR-743-CRMAF

US Chairman of the Joint Chiefs of Staff, *Joint Vision 2020,* 2000 [Database on-line]; available from: http://www.dtic.mil/jv2020/jv2020a.pdf; Internet; accessed 20 Sep 00.

Crawford, Ian, engineer for Analog Modules Inc, and developed the Laser Spot Tracker hardware for the F-18. Interview by author via E-mail, Ft Leavenworth, Ks., 13 Sep 2000.

Federation of American Scientists, *AH-66 Electro Optical Target Acquisition System,* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/ac/docs/rah66_mep/img006.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Interim Armored Vehicle (IAV),* [Database on-line]; available from: http://sun00781.dn.net/man/dod-101/sys/land/mav.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Joint Strike Fighter,(JSF),* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/ac/jsf.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Litening, Advanced Airborne Targeting and Navigation Pod,* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/litening.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Medium Armored Vehicle (MAV) Operation Requirements Document, Appendix 4, Fire Support Vehicle,* [Database on-line]; available from: http://www.fas.org/man/ dod-101/ sys/land/docs/bct/Annex-A-Appendix-4-Fire-Support-Vehicle-31-Jan.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Pave Penny*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/pave_penny.htm; Internet; accessed 17 Feb 01.

Federation of American Scientists, *Precision Guided Mortar Munition ATD,* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/land/atd-pgm-fig18.gif; Internet; accessed 20 Sep 00.

Federation of American Scientists, *Summary of Military Handbook 828,Fire Control Laser Systems,* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/mil-hdbk-828.htm; Internet; accessed 20 Sep 00.

Federation of American Scientists, *Targeting Systems, ANNEX F Common Solution/Concept List (U) Air Force Mission Area Plan (MAP), TRGT-703 ,* [Database on-line]; available from: http://www.fas.org/man/dod-101/usaf/docs/mast/annex_f/part25.htm; Internet; accessed 20 Sep 00.

Field Manual (FM) 17-95, *Cavalry Operations*, Fort Knox: Headquarters, United States Army Armor Center, 1996.

Field Manual (FM) 6-30, *Tactics, Techniques, and Procedures for Observed Fire*, Washington: Headquarters Department of the Army, 1991.

Friedman, George, and Meredith Friedman, *The Future of War,* New York: Crown Publishers Inc., 1996.

General Dynamics Pamphlet, *F-16C/D Block 40 Systems Overview*, Fort Worth: 1992.

Hallion, Richard P., *Precision Guided Munitions and the New Era of Warfare,* Australia: Air Power Studies Center Working Papers, RAAF Fairbairn, 1995, APSC Paper #53, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/docs/paper53.htm#DELIBERATE; Internet; accessed 28 Feb 01.

Johnson, Lieutenant Colonel Robert, Former Artillery Battalion Commander in 25th Infantry Division, Interview by author, Ft Leavenworth, Ks., 7 Mar 01.

Joint Chiefs of Staff, *Joint Publication 3-09.1, Joint Tactics, Techniques, and Procedures for Laser Designation Operations,* 1999, [Database on-line]; available from: http://www.dtic.mil/doctrine/Jel/new_pubs/JP3_09_1.pdf; Internet; accessed 20 Sep 00.

Joint Chiefs of Staff, *Joint Publication 3-55, Doctrine for Reconnaissance, Surveillance, and Target Acquisition Support for Joint Operations (RSTA),* 1993, [Database on-line]; available from: http://www.dtic.mil/doctrine/Jel/new_pubs/JP3_55_1.pdf; Internet; accessed 20 Sep 00.

Keaney, Thomas A., and Eliot A. Cohen, *GULF WAR Air Power Survey Summary Report*, Washington D.C.: US Government Printing Office, 1993.

Kosiak, Steven and Elizabeth Heeter, *Unmanned Aerial Vehicles-Current Plans and Prospects for the Future,* Washington D.C.: Center for Strategic and Budgetary Assessments, 1997, [Database on-line]; available from: http://www.csbaonline.org/4Publications/Archive/B.19970711. Unmanned_Aerial_ Ve/B.19970711. Unmanned_Aerial_Ve.htm; Internet; accessed 17 Feb 01.

Lamb, Katie, "Northrop Grumman Lightning II Targeting Pods Demonstrate Successful First Flights," Northrop Grumman Press Release, 5 Oct 1999, [Database on-line], available from: http://www.northgrum.com/news/news_releases/109-136_litening2.html; accessed 20 Sep 00.

Marquet, Louis C., and James A. Ratches, "Sensor Systems for the Digital Battlefield," In *Digitization of the Battlefield II*, Raja Suresh, Editor, Proceedings of SPIE-The International Society for Optical Engineering Vol, 3080, 1997.

McDaniels, Major Jeffrey R., "Viper FAC-A Effectiveness of the F-16 Block 40", Maxwell AFB, Alabama: Air Command and Staff College Paper, 2000.

Ministry of Defense, "Kosovo, Lessons From the Crisis," **Presented to Parliament by the Secretary of State for Defence by Command of Her Majesty, June 2000,** [Database on-line]; available from: http://www.kosovo.mod.uk/lessons/chapter7.htm; Internet; accessed 20 Feb 01.

NAVAIR Public Affairs, US Naval Aviation Systems TEAM News, *Litening II Pods Boost Harrier Targetin Capabilities,* 2000, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/docs/man-sm-litening-000900.htm; Internet; accessed 17 Feb 01.

Range Commanders Council, *Laser Range Safety, Document 316-98*, New Mexico: Secretariat Range Commanders Council, White Sands Missile Range, 1998.

Ruhl, Joseph W. Jr., Principle Physicist, Laser Safety Office Optics, and Laser Department, Raytheon Systems Company, Interview by author, E-mail, Ft Leavenworth, Ks., 12 Jan 2001.

Scheel, Captain Lynn I., "Improving FAC-A Effectiveness in a Killer Scout/Armed Recce Environment With Collateral Damage Concerns", Nellis AFB, Nevada: USAF Weapons School Paper, 1999.

Schwarzkopf, General H. Norman, *It Doesn't Take a Hero,* New York: Bantam Books, 1992.

Space and Naval Warfare Systems Command, *TeleOperated Vehicle (1985-1989*), 1989, [Database on-line]; available from: http://www.nosc.mil/robots/land/tov/tov.html; Internet; accessed 18 Mar 01.

Strain, Fredrick R., "The New Joint Warfare," *Joint Forces Quarterly*, Summer 1998.

The Website for Defense Industries-Army, *Kollsman, Inc.-Fire Control Systems,* [Database on-line]; available from: http://www.army-technology.com/contractors/fire/kollsman/; Internet; accessed 17 Feb 01.

Tirpak, John A., "Short's View of the Air Campaign," *AIR FORCE Magazine*, September 1999, [Database on-line]; available from: http://www.afa.org/magazine/watch/0999watch.html; Internet; accessed 20 Sep 00.

Tirpak, John A., "The State of Precision Engagement," *Air Force Magazine*, March 2000, [Database on-line]; available from: http://www.afa.org/magazine/0300precision.html; Internet; accessed 20 Sep 00.

US Army Command & General Staff College, *CGSC Preparatory Course,* CGSPC v1.06a, 1999, CD-ROM.

US Army Command & General Staff College, *CGSC Preparatory Course Lesson P920,* CGSPC v1.06a, 1999, CD-ROM.

US Army National Training Center Operations Group Team Werewolf, *Front Line Challenges for Today's Field Artillery Captains*, 2001, [Database on-line], available from: http://www.irwin.army.mil/Wolf/Pages/WOLF%207%20WHOLE.htm, Internet; accessed 1 May 01.

US Army Redstone Arsenal, *Hellfire*, [Database on-line]; available from: http://www.redstone.army.mil/history/systems/HELLFIRE.html; Internet; accessed 20 Sep 00.

Web Site for Defense Industries-Air Force Technology, *JSF*, [Database on-line]; available from: http://www.airforce-technology.com/projects/jsf/; Internet; accessed 17 Feb 01.

Williams, Walter, *Threat Update Krasnopol--A Laser-Guided Projectile for Tube Artillery,* Fort Leavenworth, Kansas: TRADOC DCSINT, 2000, [Database on-line];

available from: http://www.fas.org/man/dod-101/sys/land/row/krasnopol.htm; Internet; accessed 20 Sep 00.

Notes

1. Ibid, 6.
2. Ibid, table 2.1, 6.
3. Chairman of the Joint Chiefs of Staff, *Joint Vision 2020.*
4. George and Meredith Friedman, *The Future of War* (New York, Crown Publishers Inc., 1996), 273.
5. Bengt Anderber and Dr. Myron L. Wolbarsht, *Laser Weapons, The Dawn of a New Military Age* (New York, Plenum Press, 1992), 44.
6. Ibid, 44.
7. Ibid, 44.
8. Ibid, 23.
9. Ibid, 44-45.
10. Ibid, 44.
11. Federation of American Scientists, *Summary of Military Handbook 828,Fire Control Laser Systems,* [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/mil-hdbk-828.htm; Internet; accessed 20 Sep 00.
12. General Dynamics Pamphlet, *F-16C/D Block 40 Systems Overview*, (Fort Worth, 1992), 6-7.
13. Anderber, 45.
14. Ibid, 45.
15. Ibid, 45
16. General Dynamics, 6-5.
17. Ibid, 50.
18. Anderber, 49.
19. Ibid, 50.
20. Joint Chiefs of Staff, *Joint Publication 3-09.1, Joint Tactics, Techniques, and Procedures for Laser Designation Operations,* 28 May 1999, B-B1, [Database on-line]; available from: http://www.dtic.mil/doctrine/Jel/new_pubs/JP3_09_1.pdf; Internet; accessed 20 Sep 00.
21. Ibid, 1-2.
22. Katie Lamb, Northrop Grumman Press Release, "Northrop Grumman Lightning II Targeting Pods Demonstrate Successful First Flights," 5 Oct 1999, [Database on-line], available from: http://www.northgrum.com/news/news_releases/109-136_litening2.html; accessed 20 Sep 00.
23. Joint Pub 3-09.1, p. A-4, figure A-4.
24. Ibid, A-5.
25. Ibid, C-1.
26. Ibid, A-2.
27. Birker, 7.
28. Joint Pub 3-09.1, A-2.
29. Assistant Secretary of the Army for Acquisition, Logistics, and Technology, *Army Science and Technology Master Plan 1998*, 1998, vol I, section N. "Fire Support,"

[Database on-line]; available from: http://www.sarda.army.mil/sard-zt/ASTMP98/vol_i/sec3/sec3n.htm; Internet; accessed 20 Sep 00.

30. Richard P. Hallion, *Precision Guided Munitions and the New Era of Warfare*, (Australia: Air Power Studies Center Working Papers, RAAF Fairbairn, 1995), APSC Paper #53, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/docs/paper53.htm#DELIBERATE; Internet; accessed 28 Feb 01.
31. Ian Crawford, interview by author, E-mail, Ft Leavenworth, Ks., 13 Sep 2000. Mr Crawford is an engineer for Analog Modules Inc, and developed the Laser Spot Tracker hardware for the F-18. He believes it is possible to build a Laser Spot Tracker in the eye-safe 1.54 micron wavelength.
32. Lamb.
33. Sue Baker, "Predator Missile Launch Totally Successful,*" Wright Patterson AFB (Ohio)Aeronautical Systems Center Public Affairs*, 27 Feb 01, [Database on-line]; available from: http://www.fas.org/irp/program/collect/docs/man-ipc-predator-010228.htm; Internet; accessed 28 Apr 01.
34. Federation of American Scientists, *Litening, Advanced Airborne Targeting and Navigation Pod*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/litening.htm; Internet; accessed 17 Feb 01.
35. Joint Pub 3-09.1,A-3.
36. NAVAIR Public Affairs, Naval Aviation Systems TEAM News, *Litening II Pods Boost Harrier Targetin Capabilities*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/docs/man-sm-litening-000900.htm; Internet; accessed 17 Feb 01.
37. Federation of American Scientists, *Joint Strike Fighter,(JSF)*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/ac/jsf.htm; Internet; accessed 17 Feb 01.
38. Web Site for Defense Industries-Air Force Technology, *JSF*, [Database on-line]; available from: http://www.airforce-technology.com/projects/jsf/; Internet; accessed 17 Feb 01.
39. Federation of American Scientists, *Summary of Military Handbook 828,Fire Control Laser Systems*, table A-2,[Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/mil-hdbk-828.htm; Internet; accessed 20 Sep 00.
40. The Website for Defense Industries-Army, *Kollsman, Inc.-Fire Control Systems*, [Database on-line]; available from: http://www.army-technology.com/contractors/fire/kollsman/; Internet; accessed 17 Feb 01.
41. Federation of American Scientists, *Pave Penny*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/smart/pave_penny.htm; Internet; accessed 17 Feb 01.
42. Ian Crawford, interview by author, E-mail, Ft Leavenworth, Ks., 13 Sep 00.
43. Federation of American Scientists, *AH-66 Electro Optical Target Acquisition System*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/ac/docs/rah66_mep/img006.htm; Internet; accessed 17 Feb 01.
44. Steven Kosiak and Elizabeth Heeter, *Unmanned Aerial Vehicles-Current Plans and Prospects for the Future* (Washington D.C.: Center for Strategic and Budgetary Assessments, 1997), [Database on-line]; available from:

http://www.csbaonline.org/4Publications/Archive/B.19970711.Unmanned_Aerial_Ve/B.19970711.Unmanned_Aerial_Ve.htm; Internet; accessed 17 Feb 01.

45. Joint Chiefs of Staff, *Joint Publication 3-55, Doctrine for Reconnaissance, Surveillance, and Target Acquisition Support for Joint Operations (RSTA),* 14 April 93, II-4, [Database on-line]; available from: http://www.dtic.mil/doctrine/Jel/new_pubs/JP3_55_1.pdf; Internet; accessed 20 Sep 00.
46. General Dynamics, 6-7.
47. Military Handbook 828.
48. Joint Pub 3-09.1, A-L-1.
49. US Army Command & General Staff College, *CGSC Preparatory Course,* CGSPC v1.06a, 1999, CD-ROM.
50. Joseph W. Ruhl, Jr., interview by author, E-mail, Ft Leavenworth, Ks., 12 Jan 2001. Mr. Ruhl is the Principle Physicist, Laser Safety Office Optics, and Laser Department, Raytheon Systems Company, and previously worked for Hughes Inc. He worked on the laser rang finders for the M-60, M-1, the Mule and the G/VLLD.
51. US Army Command & General Staff College, *CGSC Preparatory Course Lesson P920,* CGSPC v1.06a, 1999, CD-ROM.
52. Ian Crawford.
53. Federation of American Scientists, *Interim Armored Vehicle (IAV),* [Database on-line]; available from: http://sun00781.dn.net/man/dod-101/sys/land/mav.htm; Internet; accessed 17 Feb 01.
54. Ibid.
55. Federation of American Scientists, *Medium Armored Vehicle (MAV) Operation Requirements Document, Appendix 4, Fire Support Vehicle,* [Database on-line]; available from: http://www.fas.org/man/dod-101/ sys/land/docs/bct/Annex-A-Appendix-4-Fire-Support-Vehicle-31-Jan.htm; Internet; accessed 17 Feb 01.
56. Military Handbook 828.
57. Louis C. Marquet and James A. Ratches, "Sensor Systems for the Digital Battlefield," In *Digitization of the Battlefield II*, Raja Suresh, Editor, Proceedings of SPIE-The International Society for Optical Engineering Vol, 3080, (1997), 14.
58. Space and Naval Warfare Systems Command, *TeleOperated Vehicle (1985-1989*), [Database on-line]; available from: http://www.nosc.mil/robots/land/tov/tov.html; Internet; accessed 18 Mar 01.
59. LtCol Robert Johnson, Former Artillery Battalion Commander in 25 ID, interview by author, Ft Leavenworth, Ks., 7 Mar 2001.
60. Joint Pub 3-09.1, A-B-1.
61. John A. Tirpak, "The State of Precision Engagement," *Air Force Magazine*, March 2000, [Database on-line]; available from: http://www.afa.org/magazine/0300precision.html; Internet; accessed 20 Sep 00.
62. Federation of American Scientists, *Targeting Systems, ANNEX F Common Solution/Concept List (U)Air Force Mission Area Plan (MAP), TRGT-703* , [Database on-line]; available from: http://www.fas.org/man/dod-101/usaf/docs/mast/annex_f/part25.htm; Internet; accessed 20 Sep 00.
63. Ibid.
64. Field Manual (FM) 6-30, *Tactics, Techniques, and Procedures for Observed Fire,* (Washington: Headquarters Department of the Army, 1991), 6-29.

65. US Army National Training Center Operations Group Team Werewolf, *Front Line Challenges for Today's Field Artillery Captains*, [Database on-line], slide 17, available from: http://www.irwin.army.mil/Wolf/Pages/WOLF%207%20WHOLE.htm, Internet; accessed 1 May 01.
66. LtCol Robert Johnson, Former Artillery Battalion Commander in 25 ID, interview by author, Ft Leavenworth, Ks., 7 Mar 2001.
67. Stephen Biddle, Wade P. Hinkle, and Michael P. Fischerkeller, "Skill and Technology in Modern Warfare," *Joint Forces Quarterly*, Summer 99, 27.
68. Ibid.
69. US Army Redstone Arsenal, *Hellfire*, [Database on-line]; available from: http://www.redstone.army.mil/history/systems/HELLFIRE.html; Internet; accessed 20 Sep 00.
70. Ibid.
71. Space and Naval Warfare Systems Command, *TeleOperated Vehicle.*
72. Federation of American Scientists, *Precision Guided Mortar Munition ATD*, [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/land/atd-pgm-fig18.gif; Internet; accessed 20 Sep 00. Also see Assistant Secretary of the Army for Acquisition, Logistics, and Technology, *Army Science and Technology Master Plan 1998*, 1998, vol I, section N. "Fire Support," [Database on-line]; available from: http://www.sarda.army.mil/sard-zt/ASTMP98/vol_i/sec3/sec3n.htm; Internet; accessed 20 Sep 00.
73. Field Manual (FM) 17-95, *Cavalry Operations*, (Fort Knox: Headquarters, United States Army Armor Center, 24 Dec 1996), Section III.
74. Walter Williams, *Threat Update Krasnopol--A Laser-Guided Projectile for Tube Artillery* (Fort Leavenworth, Kansas: TRADOC DCSINT, 2000), [Database on-line]; available from: http://www.fas.org/man/dod-101/sys/land/row/krasnopol.htm ; Internet; accessed 20 Sep 00.
75. Lieutenant Colonel Fredrick R. Strain, "The New Joint Warfare," *Joint Forces Quarterly*, Summer 98, 17.
76. Ibid., 22.
77. Birker, 28-31.
78. Thomas A. Keaney and Eliot A. Cohen, *GULF WAR Air Power Survey Summary Report*, (Washington, D.C.: US Government Printing Office, 1993), 36.
79. Ibid.
80. Birker, 16-17.
81. John A. Tirpak, "Short's View of the Air Campaign," *AIR FORCE Magazine*, September 1999, Vol. 82, [Database on-line]; available from: http://www.csbaonline.org/4Publications/Archive/B.19970711.Unmanned_Aerial_ http://www.afa.org/magazine/watch/0999watch.html; Internet; accessed 20 Sep 00.
82. Ministry of Defense, "Kosovo, Lessons From the Crisis," Presented to Parliament by the Secretary of State for Defence by Command of Her Majesty, June 2000, [Database on-line]; available from: http://www.csbaonline.org/4Publications/Archive/B.19970711.Unmanned_Aerial_ http://www.kosovo.mod.uk/lessons/chapter7.htm; Internet; accessed 20 Feb 01.
83. Birker, 16-17.

84. Captain Lynn I. Scheel, "Improving FAC-A Effectiveness in a Killer Scout/Armed Recce Environment With Collateral Damage Concerns" (Weapons School Paper, USAF Weapons School, Nellis AFB, Nevada, 1999), 2.
85. Ibid.
86. To limit confusion over the terms FAC-A and Killer Scout, a FAC-A can control air in close proximity to friendly troops or Close Air Support (CAS) missions. A Killer Scout can only control air on the enemy side of the FSCL, and is not trained to control in close proximity to friendly troops. In deep operations the two missions are essentially the same, and for purposes of this study the term FAC-A will be used.
87. Ibid., 10.
88. Ibid., 21.
89. Ibid.
90. Jeffrey R. McDaniels, "Viper FAC-A Effectiveness of the F-16 Block 40" (ACSC Paper, Air Command and Staff College, Maxwell AFB, Alabama, 2000), 19-20.
91. Tirpak. The State of Precision Engagement.
92. Ibid.
93. H. Norman Schwarzkopf, *It Doesn't Take a Hero* (New York: Bantam Books, 1992), 418.
94. Joint Pub 3-09.1, p. III-1
95. Range Commanders Council, *Laser Range Safety, Document 316-98* (New Mexico: Secretariat Range Commanders Council, White Sands Missile Range, 1998), 1.6.
96. Space and Naval Warfare Systems Command, *TeleOperated Vehicle.*
97. Birker, 13.
98. Joint Pub 3-09.1, III-15.
99. Ibid., III-3