

Infrared Detection and Geolocation of Gunfire and Ordnance Events from Ground and Air Platforms

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ABSTRACT

The Naval Research Laboratory and Maryland Advanced Development Laboratory (MADL) have worked on the detection of small arms gunfire using land-based systems and on detection of larger ordnance using airborne-based systems. The primary detection mechanism is the sensing of the muzzle flash in the Mid-Wave InfraRed (3-5 μm band). Improvements in algorithms and sensors have enabled real-time detection from wide angle ($\sim 140^\circ \times 20^\circ$) cameras without loss of range performance. Shooting events are detected beyond the effective firing ranges of the weapons and with low false alarms. Post-detection imaging of shooters/snipers has been validated for day and night operations. The utility of these sensors is amplified by linking the data to other friendly forces. Network hardware and data protocols have been developed that permit the transmission of the sensor data at both local levels and to remote command stations in real time.

Under the sponsorship of the SwampWorks project office at the Office of Naval Research, this research in ordnance detection is being extended with the development of Gunfire Detection and Location units mounted on HMMWVs. These systems will be delivered to the 1st Marine Expeditionary Force in 2004. This effort will provide these Operational Experimentation Articles for small-arms muzzle blast detection together with EO/IR/Acoustic adjuncts to enable warfighters to rapidly validate gunfire events and to properly engage enemy shooters. Day and night cameras as well as lasers are mounted on a commanded gimbal. This configuration provides 24-hour situational awareness to the operator when not engaged in gunfire detection and location. The operational experimentation will aid in the development of new CONOPS (concept of operations) for the warfighter. Potential civilian-police and counterterrorism applications include employment of this equipment in hostage situations to detect, locate, image enemy positions, and to direct responses to dismounted police/counter-terror units. The system's capability to link hostile positions to other sensors and/or weapons enables a very rapid response to the counter the enemy. Further work in airborne detection and advanced systems is planned.

INTRODUCTION

The Mid-Wave InfraRed (MWIR) has been explored for detection of small arms fires from enemy snipers since the 1960s¹⁻². An early Advanced Concept Technology Demonstration (ACTD) of this, called VIPER, was done in 1996³⁻⁴. Some results from the VIPER ACTD are shown in Figure 1.

The VIPER program fired over 15,000 rounds of ammunition from various small arms (50 caliber and smaller). ACTD test results showed that all small arms could be detected at and beyond the maximum

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effective range of the weapon. These efforts were followed up by technology improvements, outlined in Figure 2. Capitalizing on improvements in mid-wave IR cameras and with the application of spectral filtering, we obtained significant improvements in Signal/Clutter ratio and a corresponding reduction in false alarms. We took advantage of the extra sensitivity in the infrared cameras and developments in wide-angle (anamorphic) lens technology to develop a system with more than 120° azimuthal coverage without loss of sensitivity. A track rejection filter was incorporated into the real-time software to further reduce false alarms resulting from motion within the background.

The efforts in MWIR detection were refocused to that of airborne detection of gunfire and ordnance in 2002. Two systems were designed to go onto tactical airborne vehicles flying beneath cloud layers. An initial proof of concept demonstration took place in 1997⁵. The first real-time airborne application of this technology came in October 2002 in response to the emergency created by the “Washington DC Sniper” incidents⁶. This resulted in the proposed *Forward Eyes* concept for a modest-cost tactical unmanned aerial vehicle (UAV), shown in Figure 3. The *Forward Eyes* payload is designed to detect large ordnance (mortars, howitzers, etc.) from relatively low altitude and provide coordinates of the shooting events and detailed video imagery back to a ground station. Additionally, *Forward Eyes* would detect and provide imagery of ground impacts of ordnance to confirm and/or correct friendly fire. A laser designator allows friendly forces to respond to hostile fire with greater accuracy while reducing the engagement timeline and leveraging the advantage of low altitude detection (even with a high altitude response).

Two commercial helicopters, bearing MWIR ordnance detection payloads, have flown over Quantico Test Range during several Marine Corps ordnance and gunfire events. Targets seen from the air included rifle fire, mortars of various sizes, high explosive bombs (multiple types, machine gun, rockets, grenade launchers, practice bombs with smoke charges, white phosphorous explosions, illumination warheads, armor piercing impacts, high explosive impacts and cannon. The helicopters were employed in the manner of surrogate UAVs (e.g. all equipment was controlled from the ground). Video and data links provided event co-ordinates and video to a tactical user station from both helicopters. Events were detected at significant ranges, limited only by the geometry of the testing and the quality of the data links (e.g., not limited by the MWIR detection phenomenology).

ONR/NRL SWAMPWORKS GDL PROGRAM

NRL was implementing the *Forward Eyes* program for ONR-01 SW (SwampWorks shop). As part of this effort, NRL was instructed to coordinate operational warfighter input for operational application. Conversations with the Second Marine Expeditionary Forces indicated that land-based Gunfire Detection and Location (GDL) was a higher priority as current theater operations included repeated sniper events without the ability to locate the source of the threats. While GDL technology has been developed and improved by NRL over the last decade, there has been little operational testing by the warfighter. In order to transition this technology, it was recommended to perform detailed operational experimentation by Marine Corps warfighters. This has resulted in a rapid-prototyping SwampWorks GDL effort which will provide Operational Experimentation Articles (OEAs) to Marines from the First Marine Expeditionary Force in 2004.

NRL is developing, assembling, and testing 5 GDL prototype units. Four of these units will be delivered to the G-9 Innovation and Technology Group of the 1st Marine Expeditionary Force. These units can provide a complete 360 degree point defense posture and a complete "square" perimeter defense posture when accounting for internal blockage. The Marines will evaluate these units from the perspective of the warfighter in various missions. This evaluation can lead to the development of GDL concept of operations (CONOPS) as well as additional “spiral” development leading to early deployment of a combat-ready system.

The function of each individual GDL unit is to:

- **detect** hostile small arms and RPG fire rapidly and reliably
- **locate** enemy fire in azimuth, elevation, and range
- **image** hostile fire events for validation and documentation
- **display** event information to the operator in a useful manner
- **illuminate** firing events for dismounted warfighters response

This functionality has been endorsed by the operational Marine warfighters. In addition, the adjunct GDL gimbal and cameras will have the capability to function as a perimeter defense surveillance system.

To meet the experimentation requirements of the Marine Corps, NRL will provide four GDL systems, mounted in HMMWVs, containing:

- narrow band, wide-field of view IR camera for small arms detection
- digital signal processor
- tactical user display and tethered monocular display
- pan-tilt, retractable sensor and gimbal mount
- day/night video cameras and laser rangefinder on a slewable gimbal
- inertial orientation unit
- day/night illuminators to provide cues to dismounted warfighters
- acoustic sensor (for event confirmation and passive ranging)

as a baseline prototype. The OEAs are 6.3 engineering prototype items that have *not* been reduced in cost, power, weight, and size or have been sufficiently ruggedized for a productionized system. They are designed for warfighter experimentation prior to or during the development of CONOPS, operational requirements, and a 6.4 transition. In order to accompany rapid experimentation, the units will be delivered within months after start of this effort. The NRL team will provide user manuals, training, support, and assist in the development of CONOPS for the initial experimentation by the Corps.

EXPERIMENTATION PROCESS - BASIC CONSIDERATIONS

The GDL functionality (listed in the previous section) has been endorsed by the Operational Marine warfighters from MARFORPAC and MARFORLANT. The GDL systems will be tested while mounted on HMMWVs or on tripods detached from vehicle.

The GDL functions can be evaluated separately or in parts, depending upon the objective. It is expected that measuring the **detect** function will require live fire ammunitions, with a variety of weapon types. The weapons can be fired in Military Operations in Urban Terrain (MOUT) experiments to examine the impact of firing from room interiors, presence of optical reflections, etc. Firings in open ranges to determine weapon detection range by the GDL and validate previous detection performance findings by NRL. The testing will also examine tactics, integration, and employment issues. Also of interest will be performance a range of weather such as snow and rain. It should be observed whether degradation of detection performance matches degradation of the effectiveness of the hostile shooter. A goal for the OEA testing is to determine the effectiveness against both *amateur* harassment shooters (shooters/guerrillas with little or no training) as well as against more highly trained snipers (who can carefully choose their engagements to minimize effectiveness of detection and return-fire). An evaluation of the sensor's ability to rapidly detect multiple gunshots may allow it to provide information that improves responses to ambushes and coordinated offensive operations.

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False alarm testing can be done without live fire ammunition. It should be kept in mind that the system is currently designed for stationary employment. It is likely to have some functionality at low vehicular speeds in modest clutter (not a lot of near-field events). High speed motion with a lot of near-field clutter will require additional S&T (Science and Technology) investment to develop techniques to reduce false alarms. If solar glinting causes most false alarms in urban settings, the false alarms can be further reduced by additional spectral filtering in the camera (requires returning the camera to the manufacturer for a filter); however, such a switch will also reduce long range detection. For an urban mission with limited lines of sight, longer detection ranges may not be so important.

By testing the **illuminate** function, one also tests the **locate** capability of GDL. Both daytime and nighttime illumination capabilities are provided. Using the nighttime illuminator requires use of night vision goggles. The day illuminator may require a narrow band visor in periods of bright sunlight, but will work well in overcast, dusk/dawn, and nighttime operations. NRL will provide two of all necessary test articles per GDL as part of the OEA. Among things to be tested are: accuracy of the locator/illuminator, effective illumination range, and operational utility to dismounted warfighters. Other systems to provide information to nearby dismounted warfighters such as wireless links to D-DACT (warfighter computer/display) and/or aiming rings are not part of this effort but experimentation with these adjuncts could be done in subsequent efforts.

Some testing of the **display** functions may be done with blanks or paint ball training cartridges. This can be done at short range with some weapons or at somewhat longer range with shotgun blanks which will be bright enough to trigger detection. Some testing may be done with live ammunition if the OEA operators are located out of the firing zone and the GDL equipment is within line of sight. The reports will be seen by the user(s) at the primary display or with a tethered monocular display (and could be seen by remoted users over a local network on a D-DACT or I-PAQ). Parameters to be evaluated include the visibility, display layout, ease of interpretation, and operator workload. Also to be tested is the ability to involve dismounted warfighters in rapid counterfire via use of the day and/or night illuminators.

Testing the **image** function can be done with blank rounds or by using bullet traps if live rounds are used. The sensor can be positioned and running with record functions allowing personnel to be positioned in safe areas during the test events. The important issue is to be able to see both the shooter and the contextual environment around the shooter. The system will be capable of recording still frame or video imagery for law enforcement purposes or in a peacekeeping mission. It may be desired to have the information to relay via voice communication to remoted units. The GDL operator may be able to rapidly identify that this is indeed a hostile shooter and not a friendly accidental discharge of a gun. It is also important to determine whether the event is sufficiently validated to permit a counterfire engagement (via manually controlled or gimbal-slewed weaponry). CONOPS need to be examined whether the dismounted warfighters may engage illuminated targets or whether they also need to further validate the presence of the shooter. The ability of warfighters to hear (or not hear) the gunfire may impact the CONOPS for use of the imagery.

Another issue associated with the image function is whether the GDL system can be quickly slewed to the hostile shooter to see the sniper holding his weapon. This arises from concern over the ability to operate within varying rules of engagement during peacetime and wartime operations. This operation can be tested with various camera zoom settings, various shooter ranges, various shooter strategies, and varying the angle that the gimbal must slew to the event location. It involves gimbal speed, zoom camera speed, image blur, processing latency, and human factors. The GDL OEA will provide equipment capable of evaluating capabilities and determining operational requirements.

One of the most important aspects of the OEA may be the process of simulating an entire engagement. The purpose would be to assess the overall utility of the system in the engagement of the hostile shooters. Is counterfire more reliable and quicker with the GDL hardware than without? Also, how much of the

GDL capability is necessary (for example, GDL with or without the laser rangefinder; with or without the SWIR camera; or other variants)? Which GDL components are essential in the performance of the Marine missions? A critical type of experimentation testing will be to ascertain what components of GDL are most vital in providing improvements to the operator.

Since the gimballed cameras, rangefinder, and illuminator are provided as an adjunct to the basic GDL "detection" camera, these adjuncts are also evaluated in terms of additional functions such as perimeter defense surveillance. They may add value in general sentry operations and protection against such things as infiltrators (e.g. a truck bomber) initially detected from a long range.

The feedback to be gained from the experimentation process will include: (1) Basic detection performance evaluation, (2) Operator and operational issues, and (3) Production issues. The first type of evaluation is the most critical followed by (2) and (3) in order of importance to the ONR SwampWorks process. It is most important to know whether or not the GDL equipment was able to detect, locate, and transmit useful and timely information for Marines to respond. Of secondary importance is whether the operator would like more or less controls/options, larger displays, fewer buttons, etc. The basic components of GDL might not be affected by this type of testing; however, the GDL system's utility is likely to be limited by the ability of the operator to exploit its information. Thus improving the human factors and reducing operator workload must be considered. Lastly, issues that need to be resolved in a 6.4/6.5 production program such as durability, size, etc. can be addressed. These issues are not likely to be answered within the ONR process but would need to be addressed if the GDL system transitioned into a production item.

GDL SYSTEM DESCRIPTION

The GDL proposed configuration has been established based upon the sensor's current technical capabilities that have been adjusted to cover those warfighter requirements formalized during the study period. The GDL configuration proposed will not only allow for baseline detection, location and identification but also includes equipment and process alternatives that would be evaluated during the Test and Evaluation portion of the proposed SwampWorks program.

The current detection equipment from the Forward Eyes airborne counter-ordnance program is shown in Figure 4. A picture of the experimental vehicle-mounted GDL OEA system is shown in Figure 5 with an overview of the functionality of the basic subsystems.

Detection Suite

The detection Suite consists of a closed-cycle cryogenically cooled MWIR camera with a spectral band cold filter and anamorphic lens. The camera provides data to the GDL processor where algorithms determine detection and track events and declare this activity while eliminating potential false alarms. A higher operating temperature MWIR camera would be desired for ultimate use in a low-cost, low-weight, low-power system, but that technology is not available to meet the current GDL OEA experimentation schedule. An acoustic compliment to the IR detection system provides a confirmation of the gunfire detection for single shot events (where one shot is fired and the sound reaches the sensor before another shot is fired).

Location Suite

Locating gunfire detection or track (motion) events requires the need for GPS to determine the sensor's location. All event locations are based upon this knowledge. The sensor's attitude and pointing directions (magnetic heading) must also be known as a reference to locate events. A laser rangefinder provides range data along a bearing line determined by either the IR detection azimuth or an imaging sensor

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position. With a known offset and range from the sensor's own position, the system can determine the geo-coordinates of the event. Passive ranging can also be determined for single shot events by resolving time between the IR event and the acoustic event.

Imaging Suite

Several cameras are mounted on a fully articulating gimbal separate from the fixed position MWIR detection camera. These cameras provide 24 hour color imagery to the operator of the area of interest (the shooter and the nearby context). Optics have been designed to ensure robust capability against shooters at militarily useful ranges. Uncooled cameras were chosen in order to increase reliability and aid the transition to low cost production systems. The cameras that will be provided include a zooming visible camera, a Long Wave IR (LWIR) camera with a relatively wide field of view, a LWIR camera with relatively narrow field of view and a Short Wave IR camera with a relatively wide field of view.

Color fusion algorithms will be applied to give operator-selected images in day and nighttime ^{7,8}. Pre-recorded surveyed daytime visible imagery can be displayed and added to nighttime SWIR/LWIR imagery. Super-resolution imagery will be inserted as a technology upgrade at a later date ⁹⁻¹¹. Use of color fusion and super-resolution may provide a robust, low cost imaging function using smaller optics than would a monochromatic, "brute force" approach. This is especially critical with low f# uncooled sensor optics.

Laser illuminators for day and night can be used to involve dismounted troops in the return-fire functionality of GDL. Additionally, they can serve as a surrogate for return-fire and provide illumination for the imaging function. The entire day/night EO/IR gimballed suite also can function as a perimeter defense device. Such a system could perform surveillance against infiltrating guerrillas and truck bombers.

Tactical User Station

The tactical user station includes two display options, a keyboard and joystick controller. The main display is a large format plasma display consisting of a map or chart overlay with symbology, a scene context area for imagery, and a text based area (system status, user option, and history file section). A secondary display in the form of a monocular is tethered to the user display (wireless is a future option) and provides the same information. The monocular is designed to eliminate screen glow for night operations. The keyboard is used to adjust appropriate defaults and options not normally changed during tactical operations. The joystick controller is used to manually slew the gimbal, fire the LRF (Laser Range Finder), zoom the visible camera, initiate a recording mode, select among imaging cameras and fire the illuminators.

Sensor Support

Each GDL OEA will be mounted on a HMMWV which provides transport and power. An alternative is to mount the GDL on tripods or buildings where electrical power is available. Each vehicle provides needed logistic support for the operator as well as cooling for the processing electronics. DC power derived from the HMMWV's alternator can fully power to the system. Alternatively, 120 volt AC power can be used for a tripod-mounted GDL unit. Mounted on the vehicle is a mast system that raises or lowers the sensor suite as needed/desired. A pan and tilt mechanism at the mast's peak allows for manual positioning of the IR sensor field of view in azimuth and elevation. This assists in aiming the detection FOV to correct for position changes of either the scene or sensor position. A removable roof on the vehicle allows for testing counterfire alternatives such as a Marine operating a bi-pod mounted machine gun from the vehicle. The vehicle also provides the space for the Tactical User display and an acoustic isolation from the environment allowing for clearer radio communications when needed. As this system can be dismantled,

a tripod is included as a support item. This provides the ability to relocate the sensor, processor and displays to locations that the vehicle can not be positioned such as on a building roof. Additional cables will be provided for this configuration. Recording devices are used in experimentation and in post-event reconstruction for intelligence uses.

FUTURE DEVELOPMENTS

The SwampWorks land-based GDL program will enable the warfighter to assess the utility of MWIR-based sniper detection as well as the efficacy of EO/IR components used in establishing situational awareness for returning fire. The same suite also is capable of performing 24-hour perimeter defense. These OEAs will assist in the development of CONOPS.

Additional work in 2004-2006 in the area of rejection of near-field false alarms is required for a more robust system which can handle complex vehicle motions (or human motions). It is especially important to reduce false alarm events if this concept is to be employed on autonomous unmanned fixed sites or autonomous unmanned ground vehicles.

There is also a need by military warfighters for a man-portable “backpack” counter-sniper system. Such a capability could be obtained from a networked system where the warfighter merely gets information from a remote set of IR and acoustic sniper detectors. There still is a need for a man-portable stand-alone counter-gunfire system. That system will have to be low-cost, lightweight, and inexpensive to be deployed on a rifle or a helmet. Development of uncooled MWIR cameras may provide technology breakthroughs needed to make this concept a reality. Uncooled MWIR cameras may also be useful on vehicle-mounted and fixed-site systems.

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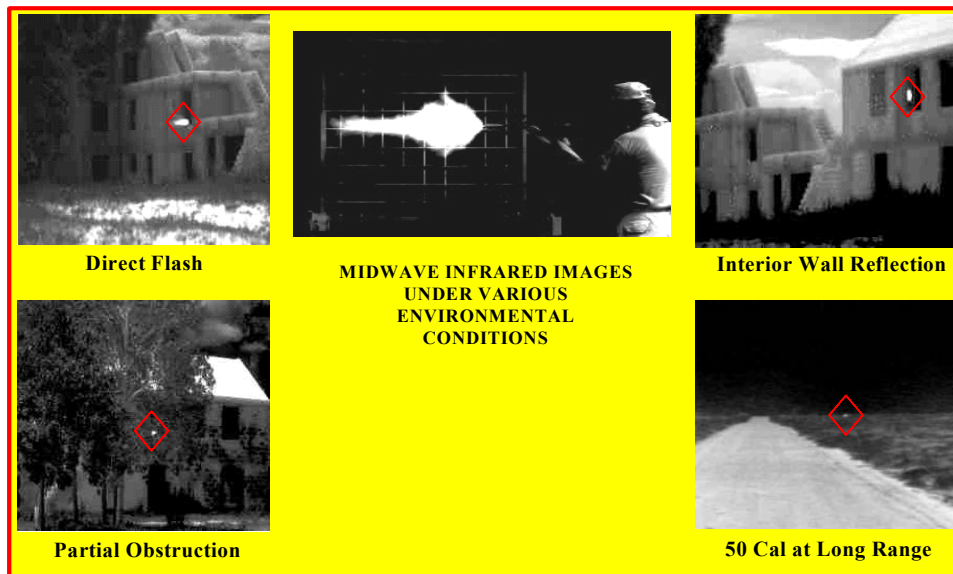


Figure 1 - VIPER ACTD Testing



SwampWorks Gunfire Detection/Location

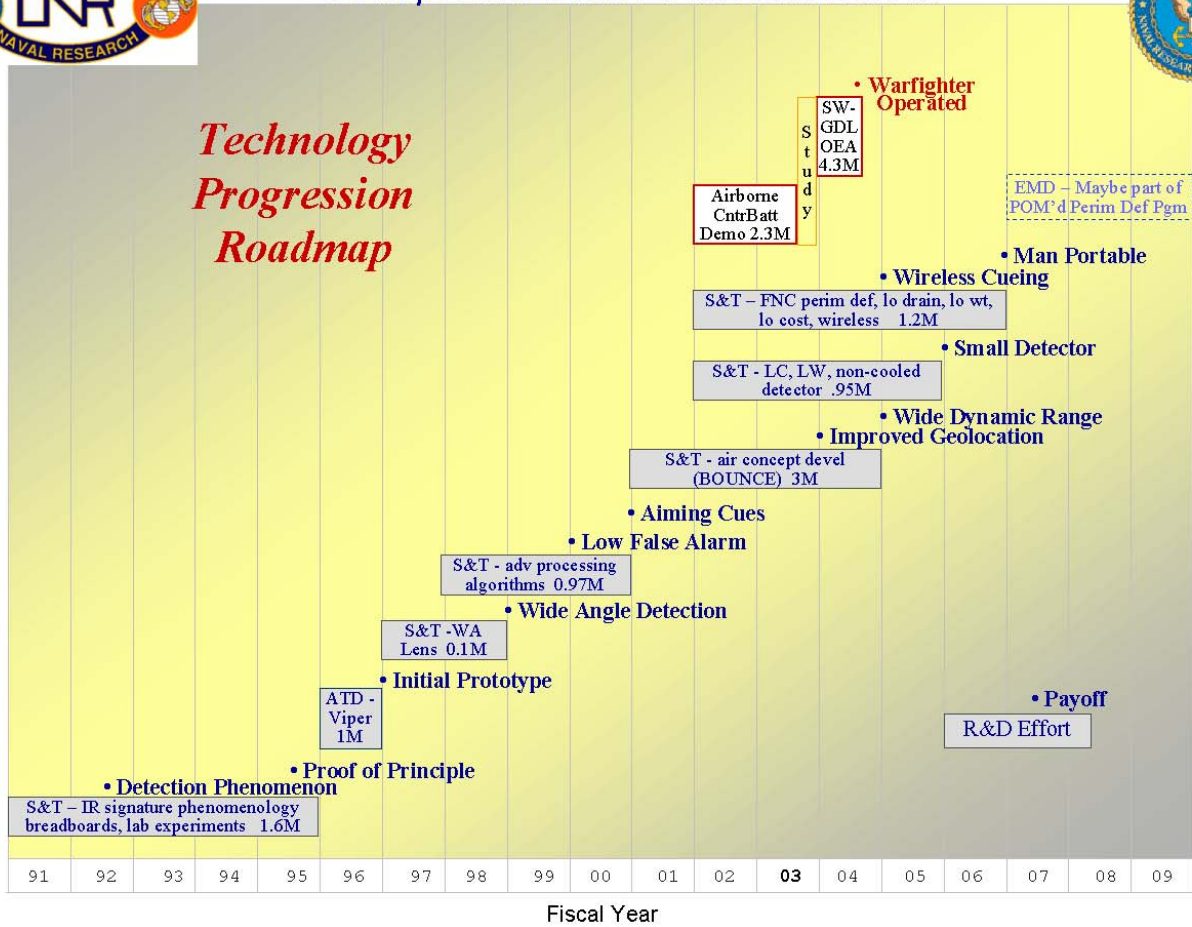


Figure 2 - Relevant ONR/NRL Science and Technology Programs

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Figure 3 - Forward Eyes UAV Concept



Figure 4 - Forward Eyes Test Equipment



Figure 5 - GDL Operational Experimentation System



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