# MINIATURE SMART MUNITIONS / GUIDED PROJECTILES FOR THE OBJECTIVE FORCE

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## ABSTRACT

This paper addresses technologies that would be applicable for smart munitions and guided projectiles for the Objective Force of the future and beyond. These smart munitions could be defensive or offensive, be vehicle-mounted on the various Future Combat System (FCS) manned and unmanned vehicles, and/or be carried by the Objective Force Warrior or future warriors. Quick reaction fire-and-forget miniature smart munitions would improve lethality against enemy vehicles and personnel and improve survivability by allowing rapid maneuvering and improved protection against enemy weapons. Force versatility and agility would be improved. Miniaturization and reduced cost per round would reduce the logistics footprint and replenishment demand leading to a more sustainable force.

## ACRONYMS

| Acronym | Definition |
|---|---|
| 3DANN | 3-Dimensional Analog Neural Network |
| ACS | Attitude Control System |
| ACT | Attitude Control Thruster |
| BLOS | Before Line of Sight |
| COTS | Commercial Off The Shelf |
| CV | Carrier Vehicle |
| DIT | Divert Impulse Thruster |
| DPS | Divert Propulsion System |
| dof | Degrees of Freedom |
| FCS | Future Combat System |
| GN&C | Guidance, Navigation, and Control |
| HMD | Head Mounted Display |
| IMU | Inertial Measurement Unit |
| IR | Infrared |
| LFLSP | Light Fighter Lethality Seeker Projectile |
| LOS | Line of Sight |
| LW | Land Warrior |
| MCM | Multi Chip Module |
| MKV | Miniature Kill Vehicle |
| OFW | Objective Force Warrior |
| TRL | Technology Readiness Level |
| UAV | Unmanned Air Vehicle |
| USA-SMDC | U. S. Army Space and Missile Defense Command |
| USA-TACOM | U. S. Army Tank and Automotive Command |
| ZEM | Zero Effort Miss |

## 1. INTRODUCTION

Commercial and defense technologies are following the miniaturization path long established by the electronics sector. Critical aircraft, missile, and spacecraft subsystems and components are being produced and integrated into smaller volumes with inherently smaller masses. For virtually all missile systems, a decrease in weight yields an increase in performance. A decrease in weight and size coupled with advanced manufacturing techniques will lead to reduced cost. As the development of miniature electronic components and inertial sensors matures, other critical interceptor subsystems are also following the miniaturization trend, such as propulsion and optical systems.

For the past several years, the U. S. Army Space and Missile Defense Command (USA-SMDC) has been developing miniature interceptor technologies and system concepts. These have focused on design, fabrication, and testing of miniature, hit-to-kill interceptors sized for strategic class engagements which utilize exo-atmospheric kill vehicles. However with the addition of an aero-shell, many of the technologies developed for these vehicles are applicable to endo-atmospheric systems and the Objective Force. In addition, atmospheric operation will allow aero control techniques to be used to maneuver the vehicles.

A significant reduction in size and weight of small arms without compromising effectiveness of the weapon system is capable only when the complete system is analyzed and trades are performed between multiple subsystems. Simple reduction in scale are applicable but technologies usually have limits beyond which scaling is no longer possible. Also, simplistic scaling to make parts smaller is often accompanied by loss in fidelity and performance. Therefore, miniaturization is best accomplished from a systems level where technologies can be traded to optimize both size and performance.

This system approach demonstrated in the development of lightweight, compact telescope for the MKV optical seeker. Conventional optical design and fabrication processes have been exploited to create incredibly small telescopes. However, the approach towards miniaturization has been to simply scale the processes to decrease the size of the system. This leads to complex alignment issues and over complexity in the structural system of the telescope. Therefore, an approach was taken to decrease the complexity of the telescope while maintaining the performance. The telescope was no longer considered a system of separate optical parts aligned and supported by an optical bench structure. Instead, the telescope system was investigated from the standpoint of a highly integrated optomechanical structure.

The U.S. Army Tank and Automotive Command (USA-TACOM) located at Picatinny Arsenal in New Jersey through their Joint Service Small Arms Programs look for ways to reduce the size and weight of small arms while increasing the effectiveness of the projectile or ammunition. Adaptation of components developed from the MDA technologies can apply to the Objective Force Warrior or Light Fighter to produce advanced projectiles that would increase the force projection capabilities of individual soldiers.

In August 2002 Schafer Corporation completed Phase I of the Light Fighter Lethality Seeker Projectile (LFLSP) Program. In Phase I the Schafer team conceptualized four different projectiles to satisfy the objective of being launched by an individual soldier to incapacitate an enemy soldier at a range of 150 to 500 meters. The LFLSP program was funded by the U.S. Army TACOM-ARDEC. The program was set to be conducted in three phases:. Phase I, a design phase; Phase II, a breadboard phase; and Phase III, a test vehicle stage. The end product of the three-phase program is to demonstrate that the LFLSP with an inert high explosive warhead and fuze can perform a flight path with a course correction to engage the target. The customer was very pleased with the results, but due to funding limitations only Phase I of the program was executed. Additional avenues for further funding are being investigated.

The MKV and LFLSP technologies and subsystems designed and tested can have considerable impact and applications in a variety of future missile defense systems, as well as the Future Combat System (FCS). For example, tiny divert and attitude control motors and propulsion assemblies have been designed, fabricated, and tested as part of the MDA MKV activities. Optical components have also been designed, fabricated, and tested. Six degree-of-freedom (dof) simulations have been conducted to assess overall performance against notional strategic class threats. Mechanical design efforts have addressed the integration of Inertial Measurement Units (IMUs), power and avionics components, and sensors including optical design constraints, and integration with the propulsion subassemblies. The development, integration, and test of miniaturized critical vehicle components and subsystems will ultimately provide substantial payoffs in overall mission effectiveness, in terms of responsiveness, agility, versatility, lethality, survivability, and sustainability.

The following sections provide details of each of the major investigation areas for MKV and LFLSP design and test efforts.

## 2. MINIATURE KILL VEHICLE TECHNOLOGIES

### 2.1 Technology Integration and Assessment

This focus area included system and subsystem analysis, functional requirement allocation, concept development, and general systems engineering activities. Prior to 2001, efforts were focused on Theater and Regional Missile Defense scenarios. Since 2001, the emphasis was shifted to strategic class systems and the sensor detection range and vehicle delta-V requirements were increased to be consistent with strategic class capabilities with respect to handover errors and operational timelines (Reference Marx et al, 2002;, Peters et al, 2002; Marx and Marquart, 2002; and Paschal et al, 2002). The Carrier Vehicle (CV), the system that carries and deploys miniature kill vehicles, was not considered in detail until 2002 and will not be discussed here. The operation and subsystem performance allocations were designed to be consistent with a dual-mode sensor package on board the CV. The strategic Miniature Kill Vehicle (MKV) concept, illustrated in Figure 1, has been fully modeled in a 6-dof simulation. All 200 divert motors and all 420 attitude control motors are individually modeled and controlled via flight software algorithms.

The 6-dof-simulation models on-board software as well as subsystem models and threat/engagement data. After simulated random ejection, the kill vehicle performs a series of alignment maneuvers, using divert and attitude control motors, for coarse and fine pointing. The vehicle subsequently enters a non-spinning acquisition mode. After target detection and track, measurements from the on-board sensor are used to estimate the current flight path zero effort miss (ZEM). Following completion of the ZEM estimate, the vehicle transitions to a spinning mode for optimal utilization of divert motors. After target re-acquisition, a modified version of proportional navigation is used throughout terminal homing. Monte Carlo analysis is used to ensure that the concept is robust to target handover uncertainties, pointing errors, thrust impulse variations and misalignments, etc.

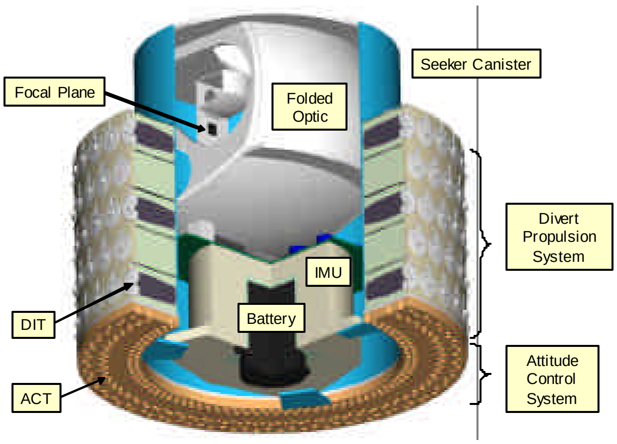


**Figure 1: Miniature Kill Vehicle Cut-Away Design**

### 2.2 Propulsion

The strategic MKV concept utilizes solid rocket motors for both the divert propulsion system (DPS) and the attitude control (ACS) system. The DPS has five rings of 40 single shot Divert Impulse Thrusters (DITs). The total delta-V for the vehicle was sized to be consistent with current and planned strategic and CV target handover errors. Multiple thrust profiles were examined. The aft end of the kill vehicle has an ACS "wafer" that contains six concentric rings of attitude control thrusters (ACTs). These thrusters are much smaller than the DITs and were sized to provide sufficient control authority for maintaining boresight within the field-of-view during target viewing opportunities. Both the DPS and ACS systems have been designed, fabricated, and tested. Figure 2 shows DPS hardware and Figure 3 shows ACS hardware.

Iterative analysis-test-evaluation design cycles were used to drive the DIT and ACT propulsion characteristics towards the required thrust profiles modeled in the 6-dof simulation discussed above. Commercial automotive airbag initiator technologies were leveraged to provide the small impulse characteristics required.

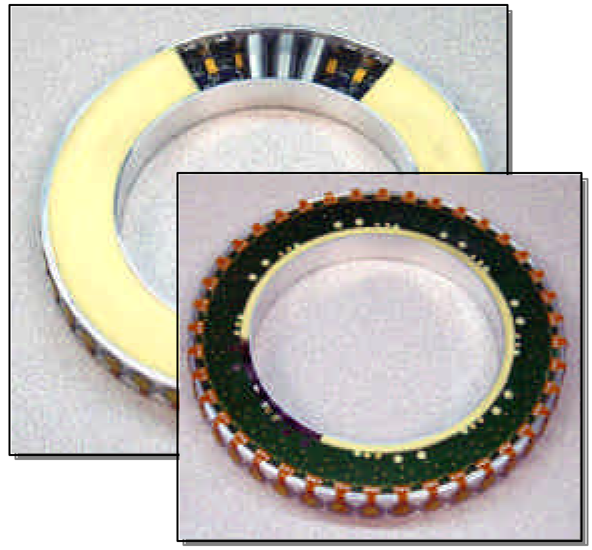

**Figure 2: Divert Thruster Ring Hardware**

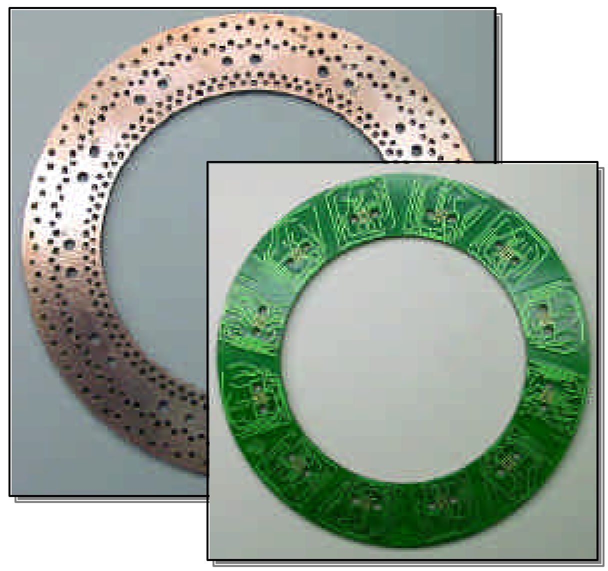

**Figure 3: Attitude Control System Hardware**

Initial DIT and ACT modeling efforts in the 6-dof simulation utilized square pulses for thrust profiles. As test data became available from the DIT and ACT tests, the square pulses were replaced by test data. After the test thrust profiles were added to the 6-dof simulation, performance was re-assessed. A variety of test profiles were analyzed using this method. Profiles were examined that utilized the nominal impulse for each motor, as well as excursions from the nominal, through either burn time or thrust magnitude variations. On-going sensitivity analysis will be used to specify requirements for continuing DIT and ACT motor development and testing.

### 2.3 Telescope Design

The on-board sensor package includes an innovative, wavelength-independent telescope design. The telescope was designed and analyzed during 2001, was fabricated during early 2002 and is currently undergoing testing. The MKV telescope parts are shown in Figure 4 below.

**Figure 4: Electroformed Telescope Hardware**

The telescope is a lenseless design. The folded optics concept features 4 mirrors seeker canister. The telescope will be an electroformed nickel subsystem, fabricated in two pieces, to minimize part count and alignment processes. A detailed structural analysis was performed on the telescope and integrated vehicle design. Figure 5 shows our telescope structural finite element model.

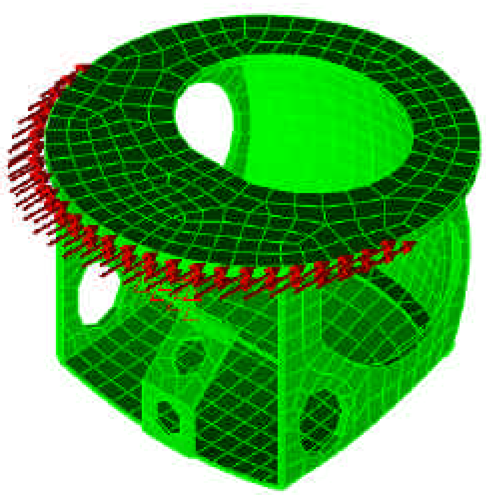

**Figure 5: Telescope Finite Element Model**

Static and dynamic structural analyses were conducted to verify structural integrity due to flyout and operational loads, as well as to assess optical performance metrics. Load cases were based on single and multiple divert motor firings, and a flyout vibration spectrum for a strategic class boost vehicle. Output from the 6-dof simulation was used to specify requirements for optics design parameters. Mass and volume allocations, detection range requirements, accuracy and structural damping requirements are based on integrated vehicle performance derived from the 6-dof simulation. These simulations show that the on-board flight control system maintains near-boresight pointing at the target during the entire engagement.

A comprehensive development and test plan to minimize risk has been developed. For example, DIT-induced jitter in the optics subsystem is tracked as a major technical risk. Future activities are focused on mitigating this risk and others through a series of progressively complex integrated seeker/propulsion subsystem tests.

## 3. LIGHT FIGHTER LETHALITY TECHNOLOGIES

The Light Fighter Lethality Seeker Projectile (LFLSP) program was funded by the U.S. Army TACOM-ARDEC located at Picatinny Arsenal. Phase I results were presented at Picatinny Arsenal on 29 August 2002. Four different solutions to the problem were discussed. The projectile is launched from 2 meters off of the ground at range 0 and the target is located 2 meters off of the ground at 500 meters. Figure 6 shows the four different solutions. For example, Option 4 weighs 0.57 lbs. and its Altitude vs. Downrange plot for different launch angles is shown in Figure 7. .

Technologies being developed by SMDC were used in the conceptual design for Option 4. Specifically, a variation of the MKV Divert Impulse Thrusters (DIT) and Attitude Control System (ACS) Thrusters can be used in projectile design to obtain large diverts over a small timeframe. In addition, The 3 Dimensional Analog Neural Network (3DANN) processor (see section 3.2) being developed by Irvine Sensors Corporation for the Jet Propulsion Lab (JPL) could be modified to add a focal plane array to develop an integrated sensor assembly.

### 3.1 Divert Impulse Thrusters – Concept of Operation

Utilization of a Divert Attitude Control System in a small projectile reduces weight and power requirements. The concept of operation is as follows:

- Objective Force Warrior (OFW) or Light Fighter Soldier Spots Enemy
- OFW or Light Fighter Soldier uses Launcher Fire Control System to determine Range to Enemy to within ± 2 Meters

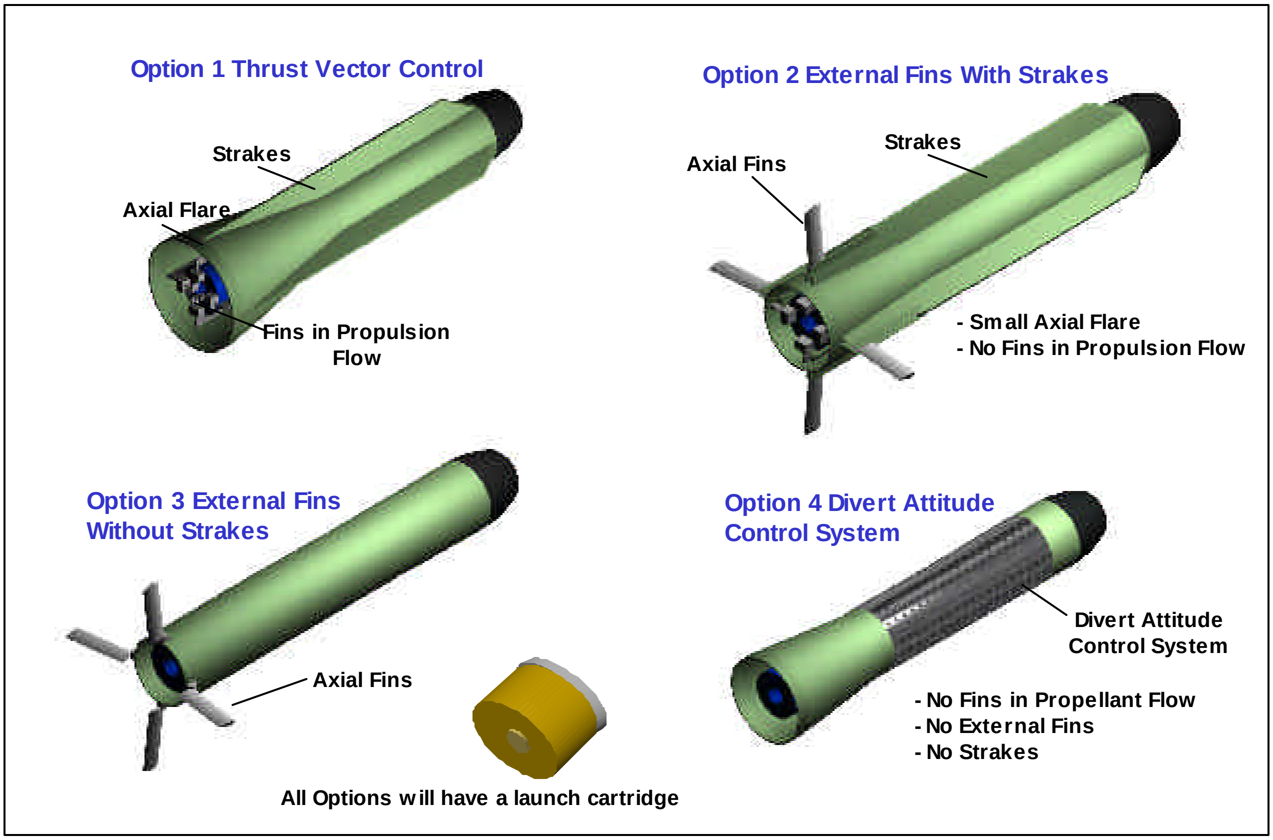


**Figure 9: Design Options for the LFLSP Vehicle**

- OFW or Light Fighter Soldier Aims and Fires Light Fighter Lethality Seeker Projectile (LFLSP) at the Enemy
- LFLSP is Soft Launched from Launcher putting the Vehicle under a Spin
- LFLSP Boost Motor Ignites 15-20 Meters Down Range
- LFLSP Maintains Unguided Flight until Target is within Seeker Detection Range
- LFLSP is Rolling and Guides to Target using Divert Thrusters
- Target Remains Visible for Entire Flight. Time of Flight < 4 Seconds
- LFLSP Detonates When Range to Target is 2 Meters or Less and Focal Plane Array is Filled

The Divert Impulse Thrusters must be controlled and fired in accordance with the Guidance, Navigation, and Control (GN&C) commands. The timing for guidance is critical. Therefore a very capable miniature processor is required.

### 3.2 Miniature Processor

The 3DANN-Revised Processor under development by the Jet Propulsion Lab/Irvine Sensors is shown in Figure 8. It is and expected to be in prototype form in FY 2010 to provide a compact processor design using 3-dimensional Multi Chip Module (MCM) stacking techniques. The processing technology will provide the next step beyond High Density Interconnect technology. Therefore, the growth path of development from current integrated circuits to Multi Chip Modules and Hybrids to High Density Interconnect to finally three dimensional MCM devices will provide designers many choices to trade component availability, cost, and size. Additions to the processor technology would include a Miniature, Smart CMOS Active Pixel Sensor, Advanced Image Algorithms, and GN&C Algorithms to control the projectile.

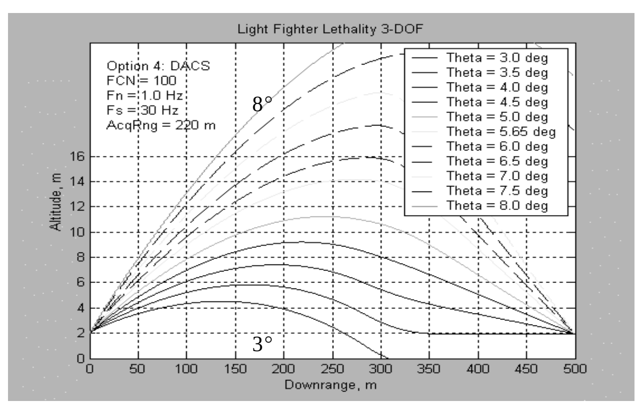


**Figure 10: Altitude vs. Downrange for Projectile**

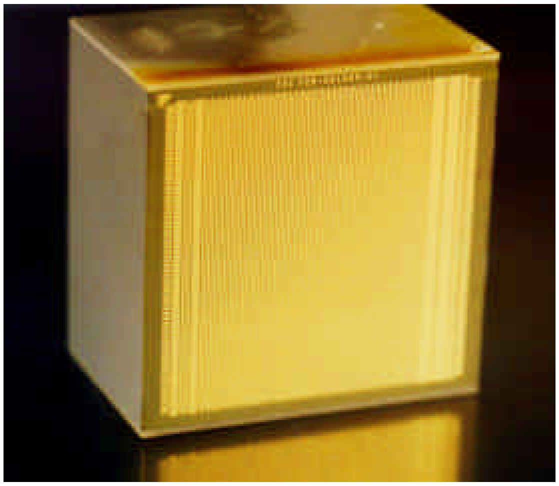

**Figure 11: 3DANN-R Processor**

### 3.3 LFLSP Internal Design

The conceptual design for the Light Fighter Lethality Seeker Projectile consists of an optical system to gather the target signature, a focal plane array as a sensor, a scaled down 3 DANN-R Processor, a Super Capacitor to provide power, a power conversion system, a Guidance and Control, and a fuse with a warhead to provide an air bursting munition capability. The LFLSP program concept provides a self-guided, autonomous weapon that can be launched at a target by a soldier to provide that soldier the advantage of moving on to the next objective without being occupied by the weapon in flight. This provides the soldier the capability to launch multiple weapons that pursue and engage different targets simultaneously.

## 4. APPLICATIONS FOR CURRENT AND FUTURE ARMY PROGRAMS

The Objective Force Warrior program is embracing an alternative approach in which individual equipment is not central to the warrior's mission. Rather, force integration including the soldier and his sensors and armament is the foundation for the OFW concepts of the future. The Land Warrior system adds new capabilities to the current system of field gear via electronic equipment soldiers will carry. The OFW system integrates the soldier's electronic capabilities. Night vision or infrared viewing capabilities, other thermal sensors, video cameras, and chem/bio sensors will be fully integrated within the soldier's helmet. Figure 9 below shows an illustration of an OFW, including weaponry consistent with our Light Fighter Lethality Seeker Projectile system.

**Figure 12: Objective Force Warrior Armed with Light Fighter Lethality Seeker Projectile Equipment**

The Objective Force Warrior would utilize an Integrated Head Mounted Display (HMD) that would be linked to the Light Fighter Lethality Seeker Projectile Launcher. This link would allow LFLSP fire control and other critical information to be displayed directly to the soldier through the HMD. When preparing to fire the LFLSP the warfighter approaches a firing position and surveys the battle field. The warfighter spots the enemy soldiers, takes aim and range finds the target as shown in Figure 10. The warfighter then fires the Light Fighter Lethality Seeker Projectile.

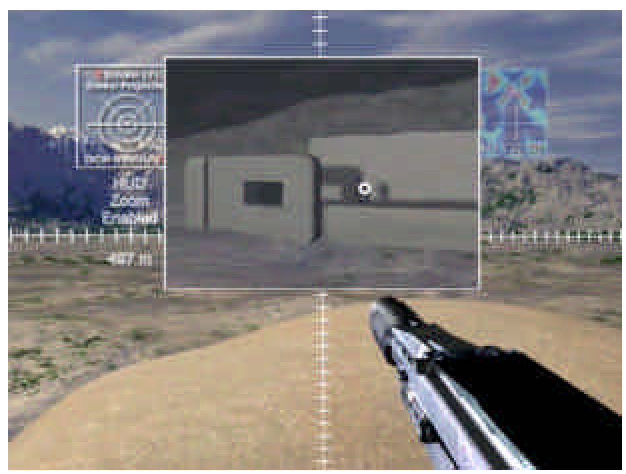

**Figure 13: Objective Force Warrior Head-Mounted Display View Concept with LFLSP Equipment**

The Seeker Projectile is initially soft-launched out of the launcher. After the projectile is launched the warfighter is free to move to the next target because the LFLSP runs autonomously to pursue and engage the target. When the Projectile is a safe distance downrange, an axial boost motor is ignited to bring the projectile to flight velocity.

The internal components of the Light Fighter Lethality Seeker Projectile will vary upon the particular design. For design Option 1 the boost motor burns quickly to accelerate the Projectile. The Projectile then coasts until the target is detected. The sustain motor then ignites to maintain flight and provide exhaust for thrust vector control. A control system moves the control fins within the exhaust flow of the axial Sustain Motor. This redirection of the flow by the four independently controllable fins allow for thrust vector control of pitch, roll, and yaw for the Projectile. Control of the projectile could also be obtained through the use of divert motors as in Option 4 mentioned earlier. A super capacitor provides the power for all of the Seeker Projectile's onboard electronics. The advantages of using a Super Capacitor over other power sources are: long-term storage, small size and weight, and the ability to power-cycle the Projectile multiple times. Power control circuits provide the power to the Projectile's Control System. Conditioning circuits provide the power for the onboard Processor and Electronics. The fuze and warhead make an air-bursting munition that detonates when directed by the onboard Processor. The onboard processor and DSP contain a Focal Plane Array, Detection Algorithms, an Autopilot, and other necessary software to autonomously guide the Projectile to its target. An optical system is designed to collect the target signature and focus the target energy onto the Sensor Focal Plane Array. A sensor focal plan array collects the image provided by the Optics and converts it into signals to be analyzed by the Processors to determine the target position. Target recognition is used to detect the target. This allows the Seeker Projectile to "see" to maneuver to the target. When the Processor has determined from the Sensor data that the target is within the lethal radius, a signal is sent from the processor to the fuze to detonate the warhead.

Through the use of the advanced technology in the Light Fighter Lethality Seeker Projectile, the typical soldier can rapidly engage multiple targets in a short period of time. The soldier aims close to the target and fires. The Seeker Projectile finds and tracks the target to make each shot more accurate see Figure 11. When a warfighter is surprised, and immediate precise action is required, the Seeker Projectile's advanced technology also allows the warfighter to fire LFLSP in the general direction of a target. The Projectile will then search for a target in its field-of-view and autonomously guide itself to the target.

Option 1 details a vector thrust control system and Option 4 utilizes modified miniature divert propulsion systems developed for the MKVs to provide attitude control. It is possible to develop small, smart, guided munitions, like the LFLSP using other applications of the technology. The small size and impulse levels of these miniature motors are consistent with the design needs for Line-of-Sight (LOS) or Before-Line-of-Sight (BLOS) munitions desired for the Objective Force Warrior. The telescope and sensor technologies and subsystems are potentially applicable for the family of sensor vehicles (e.g., robotic mules, dogs, eagles) within the Future Combat System, as well as classes of Unmanned Air Vehicles (defensive, offensive, and reconnaissance). Visible, Infrared (IR) and dual-mode sensor configurations are being investigated through our MKV Technology Development Program.

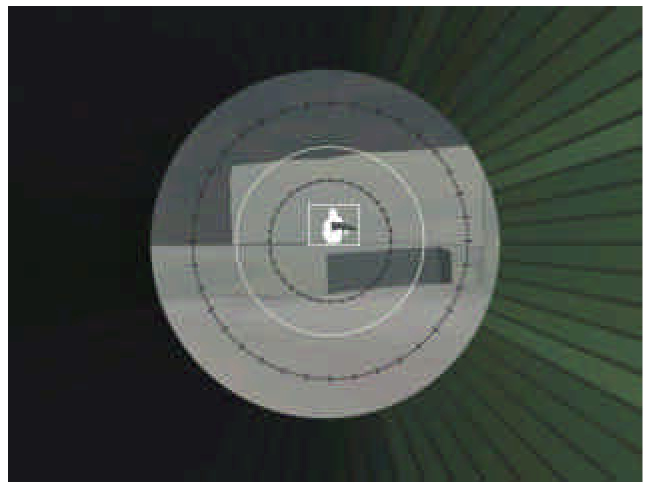

**Figure 14: Acquisition View from the LFLSP**

In addition to individual technologies, refinements are being made in the process by which technology is developed, matured, and inserted into military programs. Emphasis has been placed on identifying commercial-off-the-shelf (COTS) hardware that has potential and may be rugged enough for military field applications. There are several commercial business sectors, especially components employed by the automobile industry, that have specifications comparable with aerospace and defense applications. By creatively recognizing the potential of the commercial devices, along with the ability to model and analyze system performance, it is both cost-effective and practical to consider incorporation of commercial technologies into developing systems and for proof-of-concept demonstrations. Furthermore, by understanding the critical performance parameters and the implications of these parameters on overall integrated system performance, it is possible to construct a minimal number of selected tests and demonstrations that exercise the desired parameters. Since qualification of any new component is both time consuming and expensive, one wishes to make sure the effort is well spent.

By integrating the testing of the current state-of-the-art components and using the data to anchor simulations that can then validate the overall system performance against computer based models, the government customers are able to run multiple scenarios at minimal cost. Interoperability, miniaturization, and lower procurement costs can be realized by fully exploring the commercial market and capitalizing on research and development already in motion. However, the military or aerospace customer must be assured that the enabling technologies and components are robust enough to serve in fieldable systems. Therefore, continued funding of technology integration and demonstration efforts are needed so that the government agencies are able to quickly identify enabling technologies, determine the technology readiness level (TRL) of the components, and establish performance requirements for actual fieldable systems in a more rapid and affordable manner

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## CONCLUSION

The MKV Program is a critical part of a layered missile defense architecture. It offers an affordable, effective means of addressing sophisticated countermeasures. The technologies being developed have application to the Objective Force and the Objective Force Warrior. Although much work remains, it is clear that potential solutions exist for smart munitions and guided projectiles for the Objective Force of the future. These smart munitions could be defensive or offensive, be vehicle-mounted on the various Future Combat System (FCS) manned and unmanned vehicles, and/or be carried by the Objective Force Warrior. Quick reaction fire-and-forget miniature smart munitions would improve lethality against enemy vehicles and personnel and improve survivability by allowing rapid maneuvering and improved protection against enemy weapons. The objective force versatility and agility would be improved. Miniaturization and reduced cost per round would reduce the logistics footprint and replenishment demand leading to a more sustainable force.

Technologies such as the Miniature Kill Vehicle, and results from programs within the Army such as the Light Fighter Lethality Seeker Projectile can serve as a baseline to adapt advance technologies to increase the warfighter' s capabilities. A weapon that can be launched at a target that operates autonomously provides that warfighter the advantage of moving onto the next objective without being occupied by the weapon in flight. This provides the warfighter the capability to launch multiple weapons that pursue and engage different targets. Rapid precision fire on target by individual warfighters and coordinated operations among teams of warfighters multiplies force capabilities and brings effective firepower against the objective. Further development of advanced technology will bring a rapid precision fire capability to the warfighter to allow the pursuit and engagement of multiple targets.