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BRADLEY A2 OPERATION DESERT STORM VIRTUAL PROTOTYPE SIMULATOR DEVELOPMENT AND INITIAL VERIFICATION AND VALIDATION ACTIVITIES

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ABSTRACT

The Follow-On-To TOW (FOTT) was the Army's planned replacement for the aging TOW anti-tank missile. In support of the FOTT Program, the Program Manager, Close Combat Anti-armor Weapon Systems (CCAWS) focused the life cycle management of modeling & simulation (M&S) into four functional areas: Engineering Development, Combat Development, Test and Evaluation, and Training. The fundamental goals for using M&S in the FOTT program were to reduce time, resources and risk while improving the quality of information available to designers, users, and decision-makers. In support of these goals, a number of M&S activities were begun prior to Engineering and Manufacturing Development (EMD). One such activity was the development of a Bradley A2 Operation Desert Storm (ODS) Virtual Prototype Simulator (VPS). This VPS was intended to support Early User Assessments (EUA), design trades, operational test design, and to provide the User a tool for Tactics, Techniques, and Procedures (TTP) development, and training device requirements analysis. Although the FOTT program was terminated before entering EMD, Verification &Validation (V&V) activities for the VPS were already underway to ensure the simulator was ready to support early assessments of the man-machine interface appliqué kit design. This paper describes the Bradley A2 ODS VPS and gives an overview of selected initial V&V activities conducted in preparation for the EUA 1 to support the FOTT Preliminary Design Review.

INTRODUCTION

The FOTT Early User Assessment 1 was planned to support the system Preliminary Design Review. The BFVS A2 ODS VPS was to play a key role in the assessment of the FOTT appliqué kit during EUA 1. The appliqué kit is the hardware and software, which must be added to the existing Bradley A2 ODS platform to allow firing of the FOTT missile in its primary mode (fire-and-forget). To enable the assessment the AMCOM and System Prime Contractor would integrate the prototype appliqué kit designs following EMD contract award. The System Prime Contractor would certify the implementation to support User Assessments.

In addition to subject matter expert assessments, the FOTT Test Integration Working Group developed a number of measures to support the assessment of appliqué design(s). Baseline performance for the non-appliqué system was to be collected and compared with the appliqué system.

Measures of performance such as engagement timelines, gunner menu selection errors, gunner errors during primary/secondary mission engagements, and crew work load /system intuitiveness investigations could be analyzed to provide data for preliminary assessment of compliance to the FOTT system requirements. FOTT system specification requirements such as ready to fire time, primary and secondary mission capabilities, manpower /human factor appropriateness, engagement modes and appliqué kit man-machine interfaces could be addressed with the VPS.

In addition to man machine interface investigations, EUA was planned to allow the User investigations into the impacts of various missile concepts on system employment. Modular Semi-Automated Forces (ModSAF) would generate the scenarios for these investigations. The first EUA would flow into the Preliminary Design Review

(PDR) and focus the planning for the second EUA that was to precede the system Critical Design Review (CDR).

OBJECTIVE/ PROCESS DEFINITION

One of the key factors in the decision to develop the VPS was the need to assess the impacts of changes in the missile subsystem on the system level target engagement process early enough in the program to impact the design. The functional flow of the engagement process dictated the design goals of the VPS. Only those functions that would be impacted through the addition of an appliqué kit were examined.

The key subsystem functions that affect this phase of the process are Target Acquisition and Fire Control. Each of these functions is described by individual operations as depicted in figure 1. Although the Search and Assess functions were exercised during the V&V process they were not quantitatively evaluated.

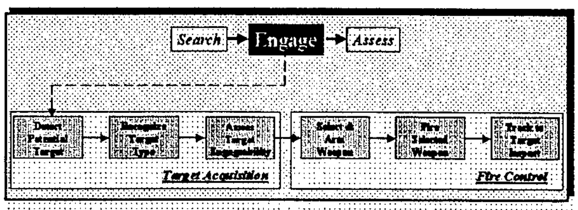

Figure 1: Target Engagement Process

THE SYSTEM

For the purposes of this assessment the Bradley A2 ODS system consists of three subsystems: the crew, vehicle platform, and weapon system.

The BFVS A2 ODS carries three crewmembers: commander, gunner and driver and up to six fully equipped infantrymen (depending upon vehicle configuration. The vehicle consists of the hull and turret. The hull provides for vehicle mobility and contains the driver and troop compartments. The driver is equipped with three forward facing periscopes plus one periscope to the left. The turret contains the commander and gunner stations, and associated weapon system target acquisition and fire control functions.

The gunner is equipped with an Integrated Sight Unit (ISU) to augment target acquisition. The ISU includes a day/thermal sight of magnification 4x and 12x, and an optical relay to provide the image of the gunner's sight to the commander. The gunner and commander also have periscopes for forward and side observation. A daytime auxiliary sight system for the gunner or commander is also provided as a backup to the primary sight.

The BFVS is equipped with the TOW 2 Subsystem (T2SS). The T2SS is the fire control subsystem for the Bradley A2 ODS vehicle. This system provides the capabilities to acquire targets, aim and fire the turret mounted 25mm cannon and 7.62mm machine gun, and guide the TOW missiles to target under day, night and adverse battlefield environmental conditions.

The main armament is the 25-mm cannon. The gunner can select single or multiple shot modes. Different ammunition types can be fired which include either armor piercing (AP) or High explosive (HE) rounds. A coaxially mounted 7.62-mm machine gun is also provided.

The Bradley TOW subsystem components consist of missile guidance set (MGS), TOW missile launcher (TML) and associated turret cables. The ODS upgrade replaces the ISU unity window to provide for the Bradley eye-safe laser range finder (BELRF). The BELRF is used to provide accurate automatic ranging capability for the system. The MGS provides for built-in test (BIT), TOW missile guidance commands based upon the missile tracking error signals, and automatic super elevation of the 25mm cannon and 7.62mm machine gun. The TML provides the electro-mechanical link between the missile and the MGS, and accommodates the arming of two missiles.

VPS DESIGN

In preparation for the FOTT EMD program, the U.S. Army AMCOM began development of the DIS compliant BFVS A2 ODS VPS in FY 97. Significant portions of the hardware and software for this development were leveraged from existing simulations. Crew station mock-up and mobility models were leveraged from the AMCOM Bradley Stinger Fighting Vehicle (BSFV) (currently Bradley Linebacker) VPS. TOW missile system models were leveraged from the AMCOM TOW Improved Target

Acquisition System (ITAS) VPS and the high fidelity TOW 6-DOF simulation.

The BFVS A2 ODS VPS was designed to support the interaction of a three-man crew during the target engagement tasks. The VPS consists of two separate simulators and associated mockups; a Bradley Turret System (BTS) and a Bradley Driver Compartment (BDC). Secondary components of the VPS include a Global Positioning System Simulation (GPSS) and ModSAF station. Figure 2 provides a block diagram of each of the VPS components.

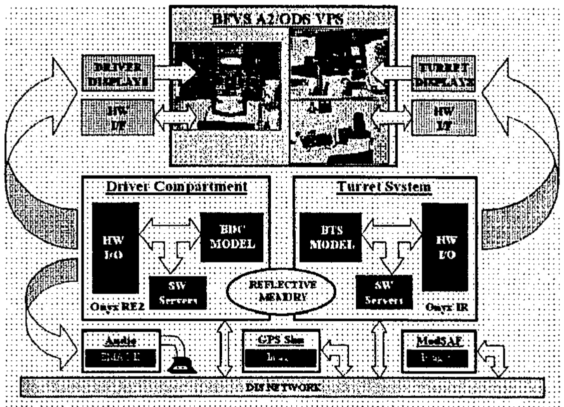

Figure 2: VPS Components

Hardware Architecture

The computer platforms used to implement the VPS architecture consists of four SGI computer systems. An ONYX Reality Engine II (RE2) workstation is used to perform all of the BDC tasks while an ONYX Infinite Reality (IR) workstation performs the BTS tasks. These two systems are physically linked by reflective memory to make possible the parsing of the BTS and BDC software. Each Onyx workstation has 4 CPU's to allow for real-time operation. An Indigo^2 hosts the ModSAF software, which provides the battlefield placement and function of red and blue forces. An Indigo is used to perform the GPSS tasks. The GPSS accepts information from ModSAF and the environment model to display the easting and northing coordinates, compass heading and "steer-to" indicator for the current location and orientation of the vehicle. This feature provides for additional situational awareness as the crew moves within the virtual database.

Each Onyx workstation is configured to provide multiple video channel output, which is utilized to display the individual gunner, commander, and driver views created by the computer image generator (CIG). In the BTS and BDC mockups, displaying the crew views are performed by the installation of both periscope vision blocks and ISU sighting system. Design, fabrication and installation of mirrors, optics and monitors were needed to emulate the tactical ISU, and associated periscopes. The VPS ISU, with attached commander's relay, include a tactical housing, and associated switches and eyepieces.

Electrical interfaces were designed and developed to provide communication between the VPS computer systems and the BTS/BDC mockup components to allow the simulator software to read tactical functions initiated by the crew. All ISU functions are implemented, with the exception of ISU bore-sight and focus functions.

Software Architecture

Reusable software modules were implemented to provide the building blocks needed to create the VPS. These building blocks, which are called "SW Servers", are shown in Figure 3. They enable the simulator to communicate with other simulators, render 3-D graphics, communicate with external hardware devices, and generate realistic battlefield sounds.

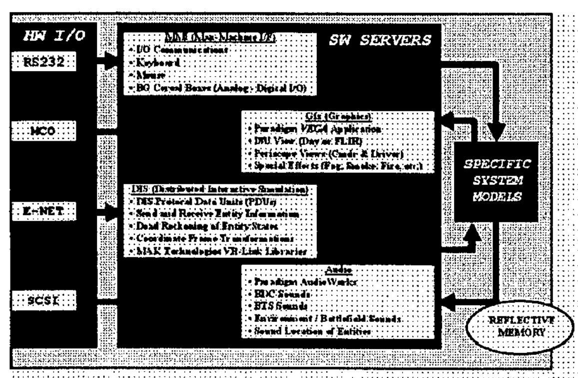

Figure 3: SW Architecture

Communication with entities external to the VPS is performed using DIS protocol. A DIS server was developed which sends and receives information contained in a DIS Protocol Data Units (PDU). The DIS Server accepts DIS PDUs from the network and ensures that each process receives the information it requires. The information is passed by function calls using a set of predefined structures, which reflect the DIS protocol. The DIS Server also dead reckons both local and remote entities, to determine if entity states need to be exported as local entities or timed out for remote players. Coordinate conversions from the DIS coordinate frame to a local coordinate frame are computed internal to the server. The DIS Server is currently built on top of MAK Technologies *VR-Link* library.

The Graphics (Gfx) Server is an asynchronous *Vega* application that runs parallel to the VPS and other servers. It is responsible for all graphical displays including visual and IR sensors of the ISU, and periscope views. The VPS determines the configuration of these displays through an interface structure (sgen) and a *Vega* Application Definition File (ADF). The Gfx Server is responsible for displaying the terrain database, environmental conditions (fog, cloud cover, time-of-day, etc.) and DIS information to display dynamic objects (DIS entities) and special effects (smoke, flame, trails, detonations, and fire). The Gfx Server is compatible with the U.S. Army Test and Evaluation Command (TECOM) Virtual Proving Ground (VPG) virtual range model database architecture.

A *Paradigm* Sound Engine II generates all sounds associated with the operation of the VPS including the vehicle engine sounds, BTS sounds and the environmental sounds. The Audio Server was designed using *Paradigm AudioWorks* to control the sounds necessary for the VPS. A "dat" information file is passed by the VPS to the audio server which includes a listing of the sounds to be used, the specific DIS entity with which the sound is to be associated, and the sound which is to be used upon receiving a fire or detonate PDU. A sound location, or ear position, may be specified in order to achieve the appropriate relative position of a sound with respect to the virtual location of the VPS.

The Man Machine Interface (MMI) Server is an application that runs in parallel to the VPS and other servers. It is responsible for communicating to all input/output (I/O) devices including the keyboard, mouse, BG Cereal Boxes and trackers. The MMI server also provides high-resolution timing that can be used by various processes in the same share group. BG Systems Cereal Boxes provide the data interface for the MMI. The Cereal Boxes read digital and analog inputs from the hardware, provide analog outputs to the hardware, and provide serial digital information to the MMI software located on the ONYX.

Unique software modules were developed to provide the user with the controls, sights, sounds and weapon system functionality available in the tactical system. The BTS and BDC functions implemented were based upon information found in system specification documents, technical manuals, and inspections of the tactical system.

Weapon system functions for the BTS consist of turret control, main gun operation, and TOW missile guidance. Multiple display devices are provided in the BTS for the periscope vision blocks and Integrated Sight Unit (ISU). The functionality of the BTS and associated TOW missile fly-out dynamics is accomplished through a closed loop system comprising actual and simulated tactical hardware, the operator, and 6-DOF missile simulation.

The BDC provides for the mobility of the BFVS A2 VPS within the virtual battlefield. The BDC is a separate enclosure simulating the environment of a BFVS A2 driver with the hatch in the down position. BDC functionality consists of the interaction with user controls such as the steering yoke, gas and brake pedals, transmission gear selector, and instrument panel switches and gauges. Display devices are provided in the BDC for the four "through the hatch" periscope views. .

V&V METHODOLOGY

A number of tests were designed to verify proper operation and validate the performance of the BFVS A2 ODS. The U.S. Army Infantry School provided Subject Matter Experts (Bradley Master Gunner Instructors) to support these V&V activities. Selected aspects of the Form, Fit and Function (FFF), Target Acquisition, and System Operational Performance Assessment tests are discussed in the following sections. The BFVS A2 ODS V&V Plan describes these tests in more detail.

Form, Fit and Function

The FFF of the VPS was evaluated to verify the design and layout of the BFVS A2 ODS VPS. The tests were to ensure that the simulator allows the crew to operate in accordance with the operational procedures of the tactical system. Tests were conducted to verify that the control/switch layouts and functions, gun firing (7.62 coax, High Explosive (HE) 25mm, Armor Piercing (AP) 25mm), gun reloading, missile firing, missile reloading, missile dynamics, system sounds, and vehicle intercommunications were adequately represented. When tactical functions were not physically achievable within the operational environment of the simulator, special provisions were made to provide the user a way to emulate the function. One example is the emulation provided to enable the reloading of weapon systems ammunition. A reload box was implemented to provide the user the ability to reload each of the munitions available within the Bradley A2 environment, given the proper turret to hull articulation criteria is met. Specific areas covered by the FFF tests performed were BTC/BDC station layout, switchology and associated sounds, sensor views, CIG realism, and crew intercommunications.

Verification of the VPS station layout, switchology, and sounds involved confirming that controls, displays, lights, instruments, placards, and handgrips were correctly placed, functioned properly and initiated the correct sounds. Verification processes familiar to the subject matter experts were used to quickly acquaint them with the VPS and to limit data contamination by test personnel. One example is the use of portions of the *BFVS Operator's Manual (-10)* to perform operator checks on the BTS and BDC to confirm proper system functionality. During these tests, the soldiers that participated in the exercise intuitively knew what was required of them and were therefore able to effectively accomplish VPS familiarization and checkout with limited test personnel intervention. Faults discovered during the inspection were recorded on DA Form 2404, *Equipment Inspection and Maintenance Worksheet.*

The computer image generation (CIG) capability of the BFVS A2 ODS was evaluated to ensure the terrain, cultural features, and icons for both the visual and thermal sensors sufficiently represented the battlefield environment. As a part of the FOTT M&S effort, the U.S. Army TECOM Redstone Technical Test Center (RTTC) and the AMCOM Missile RDEC jointly VPG synthetic range (SR) databases. The SR databases were developed to represent select test ranges, objects on those test ranges, and tactical ground vehicles. All simulated signatures were generated with the same level of fidelity and detail so that target acquisition would not be unfairly influenced.

Views in the VPS system were validated. The Subject Matter Experts assessed the level of fidelity, unrealistic cues, and special effects for each view. Verification of each view involved confirming that missile and round trajectories, as well as the movement of other entities in the virtual environment appear in all sensor views correctly. During testing, the BFVS crew confirmed that missile and round trajectory, and target impact signatures properly appeared in all simulated views.

During V&V testing, the BFVS crew communicated with each other and external ModSAF operators and test conductors via a TELEX intercom system. The system is comprised of a 2 channel Master Station and associated belt pack units. Each crewmember was provided a belt pack unit capable of providing 2 separate audio channels. Each belt pack unit provides the user with a volume control, headset, and a dual function talk button. The talk button has a momentary talk feature as well as a hands-free talk or "open mike" mode. The TELEX unit in the BDC was modified to interface to the steering yoke mounted talk button to emulate the tactical system. The belt pack units in the BTS were also modified to interface with talk button switches provided in the form of the gunner's floor switch and the commander's 7.62 ammo reload door handle switch. Verification of the intercom system involved the testing of each unit in a crew / test conductor environment to confirm all functionality goals were met. During the operator checks and operational exercises, the crew confirmed proper operation of the intercom system.

Target Acquisition

One of the most important tests conducted in the V&V was verification of the target acquisition capabilities of the ISU. The target acquisition tests conducted with the VPS consisted of the ability to detect and recognize (DR) targets that have been presented to the gunner by the CIG. For target detection, data was collected for the DVO and FLIR views under low magnification, or wide field of view (WFOV). For target recognition, data was collected for the DVO and FLIR views under high magnification or narrow field of view (NFOV). A description of the DR levels are defined as follows:

▪*Detect*: A target can be seen
▪*Recognize*: A target can be seen and its form can be recognized such as tracked or wheeled
▪*No Target*: A target was not seen

BFVS A2 qualified gunners were used to perform the DR tests using six CIG targets. Two targets were chosen from each of three target classes: tank, APC, and wheeled vehicle.

The ISU view for target detection was separated into four quadrants from left to right, so that the quadrants could be identified as quadrant one, two, three or four. Quadrant separation was achieved by utilizing the CIG to overlay vertical lines upon the battlefield scene, evenly dividing the scene into four sections. Within a quadrant, a target was presented at five ranges. The target type, range, and quadrant selections were randomly generated by a target acquisition test tool (TAT2).

During the DR testing, the gunners were individually instructed to look through the sight and attempt to acquire the target to the highest level possible. Prior to testing, the target models were made available for the gunners to view for familiarization. At the moment the gunner acquires a target, a verbal message was then announced and recorded. The data recorded during the target acquisition tests were collected by the test conductor utilizing a graphical user interface (GUI) provided by the TAT2. The following information was recorded:

- Sight used (DVO or FLIR)
- Field of View (WFOV for Detection, NFOV for Recognition)
- Type of Test (Detection or Recognition)
- Acquisition level
- VPS position and heading
- Target position, heading and type
- Target range
- Gunner's declared and actual acquisition quadrant (for detection only)
- Scoring statistics

The results of these tests were compared to NVESD model estimates under nominal conditions. Figures 4 and 5 show the DVO and FLIR results respectively.

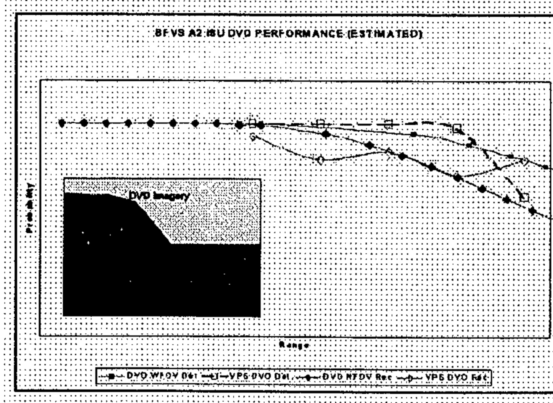

Figure 4: DVO Performance

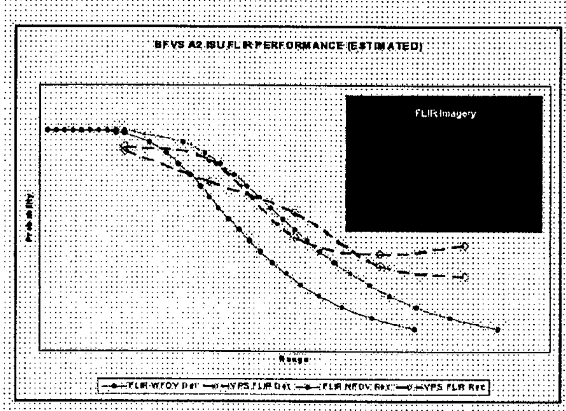

Figure 5: FLIR Performance

Operational Performance Assessment

In addition to the assessments described previously, a series of crew level engagement exercises were conducted to gain insights into the ability of the crew to perform the engagement function from target detection to impact on target. The engagement scenarios used for these exercises were derived from the Bradley Crew Qualification Tables. A number of factors were systematically varied to examine which ones most affect engagement timelines. Factors varied in the engagements include crew, crew station from which fire control was conducted, sight used, range to target, target motion, target aspect, target type, and weapon type used. Engagements were scored using Army qualification table standards.

The scatter plot in Figure 6 shows the time from target detection to impact for all TOW engagements that resulted in a hit. The shaded region denotes those engagements that would result in a score of 70% or higher using current U.S. Army standards for conducting a TOW engagement.

Approximately 85% of the successful TOW engagements scored at or above the 70th percentile. Similar trends occurred in the cannon and coax machinegun engagements.

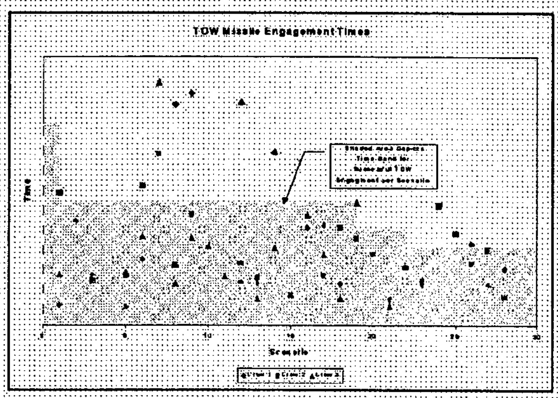

Figure 6: TOW Target Engagement Timelines

In addition to providing insights into the engagement process, the crew gunnery exercises provided data to certify proper TOW and gun performance in the following areas:

- Targets in hull defilade can be engaged
- Targets beyond maximum range cannot be successfully engaged
- Targets within a minimum range cannot be successfully engaged

The accuracy and fly-out performance for the simulated TOW missile and 25mm projectile were compared with system test results and model estimates. Portions of an all-digital high-fidelity six degree-of-freedom (6-DOF) TOW missile simulation were incorporated in the VPS to provide missile responses that accurately respond to the VPS gunner tracking rates. These models include missile guidance, kinematics, aerodynamics, thrust/mass, missile beacon tracker, and Monte Carlo routines. The VPS has the capability to simulate fly-outs of all five TOW missile types. The delivery accuracy tests focused on the TOW 2A and TOW 2B combat missiles.

The 25mm cannon was modeled using a dynamic table look-up routine. The data used in the table originated from the Department of the Army firing table. Trajectories of the Armor Piercing (AP) or High Explosive (HE) rounds are implemented in the VPS.

Data reduced from the crew gunnery exercise engagements was used to verify correct flight times for the TOW and 25mm cannon weapons. Figures 7 and 8 below compare the logged gunnery table data to accredited TOW 6-DOF simulation data and the gunnery table data respectively. The results indicate that the virtual weapons show proper agreement with the comparison data.

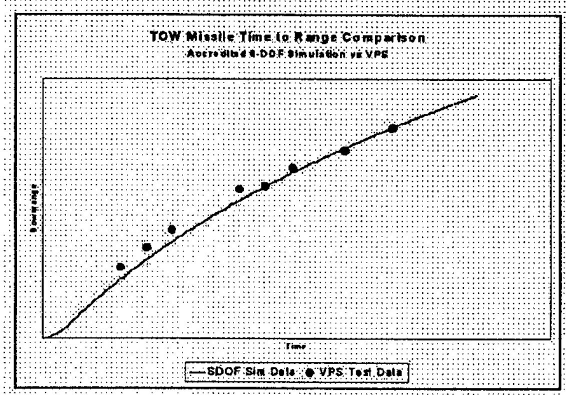

Figure 7: TOW Performance

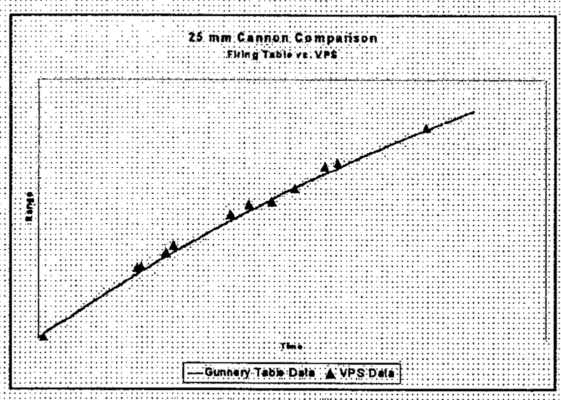

Figure 8: 25 mm Cannon Performance

Future Technology Insertion

The Bradley A2 ODS VPS was developed for the FOTT program to support Early User Assessments, design trades, and operational test design. Although the FOTT program was terminated before entering EMD, initial V&V activities were begun to ensure the simulator would be ready to support the assessment of FOTT appliqué kit early in the design process.

Early V&V activities focused on the target acquisition process. Component level assessments verified Form, Fit, and Function and target Detection/ Recognition performance. Data from system level engagement exercises was used to validate subsystem performance.

These activities provided insight into the methodologies needed to perform V&V of manned simulators intended for use in the evaluation of future weapon system operational performance. Successful implementation of subsystem models is key to providing this type of analysis. The Bradley A2 ODS VPS has successfully demonstrated a methodology that may be used to realize this goal.

The Bradley VPS technology developed at AMCOM is being used as a test bed for future programs. Software and hardware technology is being leveraged for the development of a low cost Bradley Linebacker Trainer (BLT). This next generation VPS design utilizes lower cost Intergraph TDZ personal computer (PC) systems to provide for the computational and 3-D graphics rendering for the Bradley sight views. The BLT mockup incorporates a modular multiple box tabletop design that provides for ease of transportation, mobility and setup.

Additionally the Bradley A2 ODS VPS was used for examining new approaches for allowing legacy DIS compliant simulators to become High Level Architecture (HLA) compliant. The Bradley A2 ODS VPS successfully completed an HLA Federate Conformance Test by utilizing an HLA Gateway approach. The Bradley A2 ODS VPS was HLA certified, via this approach, by the Director of Defense Modeling and Simulation Office.

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U.S. Army Technical Manuals TM-9-2350-10-1 and TM-9-2350-10-2

U.S. Army Field Manual 23-4, *Bradley Fighting Vehicle Gunnery*

Department of the Army firing table, FT 25-A-2

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