ANTI-ARMOR MISSILE FLIGHT SIMULATOR

Albert Marshall
Dr. Herbert Towle
Bon Shaw
Gary Bond

Advanced Simulation Concepts Laboratory
Naval Training Equipment Center
Orlando, Florida

and

University of Central Florida
Orlando, Florida

ABSTRACT

This paper describes a missile flight simulator developed to train DRAGON gunners. It is also being adapted to a variety of similar anti-armor weapons. The system employs a terrain board with enemy armored vehicles moving in a variety of attack scenarios. When the gunner fires the missile he hears computer generated rocket sounds and experiences the weight loss, recoil and smoke of the missile launch. When the smoke clears he views the missile as well as the target. The gunner's aiming error is measured using a microprocessor controlled diode matrix array. The matrix detector senses an IR emitting diode which is located on the miniature target. The flight equations of motion for the missile are solved by a 16 bit microprocessor every 0.02 seconds in each axis using gunner aiming error, gravity, drag and side thruster accelerations as inputs. A second coordinated 16 bit processor controls a display that plots both vertical and horizontal aiming error for analysis of the gunner's performance. *Experienced DRAGON gunners have tested the system and attested to the realism and* training potential.

INTRODUCTION

Training in the firing of modern anti-armor weapons is expensive. Each live round costs thousands of dollars.

This paper describes a system that uses advanced electro-optics and microprocessor technology to enable training of DRAGON gunners at a reasonable cost.

The DRAGON is a command-to-line-of-sight guided missile system. Fired from a recoilless launcher, the missile is tracked optically and guided automatically to the target by electrical impulses transmitted via a wire link. Firing the missile is accomplished by depressing the safety and squeezing the trigger. No other action is required of the gunner except to keep the sight cross hairs on the target. However, to score a hit the trainee must overcome many perturbations that can spoil his track.

When the trainee fires the training device he hears the gyro wind-up noise and then the initial explosion of the rocket motor. He experiences a weight loss due to the rocket exiting the tube as well as a recoil force. Momentarily he is blinded in the sight by simulated smoke. The trainee must overcome such launch transients. He must then track the target smoothly and ignore the simulated missile which he can see in his sight. Thruster rocket firing sounds are included as well as the final hit or ground impact explosions. A visual indication of hit is also inserted into the gunners sight.

During missile flight the instructor can monitor two displays. These displays show:

1. The gunner's sight picture and the DRAGON's location

2. A plot of gunner aiming error versus time and the gunner error tracking limit envelopes. Thruster firings are annotated on the display.

This system uses a 16 bit microprocessor to solve the flight equations every 0.02 seconds in each axis using the gunner's aiming error, gravity, drag and thruster rocket acceleration as inputs. The solution also incorporates the dynamic performance of the tracker (See Artist's concept).

Key features of the system are summarized below.

- Smoke Obscuration
- Recoil
- Weight Loss
- Missile superimposed on gunner's view of scenario
- Sounds – thruster firings, launch, hit and miss explosions
- Gunner aiming errors versus time displayed in real time

- Can operate for night scenes to simulate a thermal sight
- Missile position versus time which can be recalled along with gunner aiming errors in azimuth and elevation for analysis
- Cost of expensive tank target and missile not required for training
- Target hit or miss distance determined by solving DRAGON flight equations in real time
- Number of thruster rockets ideal versus actual displayed for each scenario
- Portable
- Record and play back capability
- Can operate with and without an instructor
- Operator's pull down force on DRAGON launcher and eye cup pressure is measured
- Variety of target speeds and motions simulated
- Trainer flies like real missile because of computation of flight parameters

The system has been tested by both U.S. Army and U.S. Marine Corps DRAGON gunners. Further development of the trainer is now being accelerated.

SYSTEM APPROACH

The system is shown in Figure 1.

Targets in this system are miniature models. Models were chosen because they have better resolution than either computer generated imagery or a movie display. In DRAGON a 6X scope is utilized. In other weapons even higher power sighting scopes are utilized, thus demanding a high resolution visual scenario.

Models are moved on a terrain board using a stepper motor under the control of a single chip microprocessor. Located at the center of aim of the target is an infrared emitting diode (IRED). Engagement scenarios are stored in the Personnel Interface Processor (PIP) and one is selectable from the instructor's console by an input terminal. The stored scenario programs contain the tank target's velocity, direction and range. Located in the DRAGON launch tube is a photo diode array camera. This 100 x 100 matrix camera is boresighted to the gunner's sight and used to determine the gunner's aiming error (GAE) which is input to the DRAGON Flight Simulator Processor (DFS). This processor solves the DRAGON flight equations and provides DRAGON status to the Personnel Interface Processor (PIP). The PIP controls the graphics units which inserts the missile, smoke, hit, etc., into the gunner's sight. This processor also controls the Gunner Aiming Error (GAE) display on the Instructor's Console. This display plots GAE versus time, in real time. The DRAGON Flight Simulator Processor produces launch and target explosions, thruster rocket firings and gyro noises. The thruster rocket firings are delayed to allow for the speed of sound versus the visual phenomena of the rocket firing which is optically inserted in the DRAGON gunner's sight. Rocket thruster noises are attenuated as a function of distance.

A CCTV is located on the DRAGON tube and boresighted to the gunner's 6X sight. This TV provides the instructor the same view seen through the gunner's sight. The Gunner's Sight Picture Display is located on the instructor's console. The DRAGON rocket as seen by the trainee is also mixed into the gunner's sight picture visual display.

SUBSYSTEM DESIGN APPROACH

Electro Optics Subsystem

Gunner aiming errors are determined using a 100 x 100 matrix camera. Functionally the camera is similar to a Vidicon camera except that the sensor has been replaced with a solid state photodiode array matrix having 10,000 pixels. The choice of lens determines the field viewed by the camera. Using a 125mm focal length lens and a model distance of 22 feet, the available field of view is 1.05 ft or 48 milliradians. This FOV will accommodate the maximum excursions allowed for DRAGON i.e., 32 mr horizontal and 22 mr vertical.

For a 1.05 ft FOV one pixel represents 0.126 inches on a terrain board.

Since the array is square the lengths in the X and Y axes are identical. The magnification of the camera is the ratio of the FOV to the length of the array:

$$\text{Magnification} = \frac{\text{FOV}}{\text{Array Length}}$$

where the array length is = 0.24 in. (0.60 cm total width/height) in both X and Y.

$$M = \frac{1.05 \times 12}{0.24} = 52.5$$

The static resolution is the array element spacing imaged into the object plane.

Resolution = Magnification x element spacing

Resolution = 52.5 x 0.0024 in = 0.126 in.

This is equivalent to ± 7.5 inch resolution on a real world tank at a scaled range of 2640 feet.

This means the smallest detectable change in a stationary object we can detect is 0.126 inches using a 125mm focal length lens. If a longer focal length lens is used the FOV is decreased and the resolution is improved.

Accuracy also depends on: image sharpness, contrast, vibration or movement of the object, light level and threshold setting of the camera.

The camera used is blemish free.

An IRED is located on the target and the center of the IRED's energy calculated to determine hit location.

Because the IRED produces uniform illumination, the threshold setting on the camera can be adjusted to a fixed level, thus eliminating background interference.

Data from the photodiode array are electronically scanned to produce a sampled-and-held video output signal. The amplitude of each pixel is proportional to the incident light intensity integrated over the interval of one frame period. The camera essentially detects light to dark transitions of the digital area. The scene present on the camera is a light circle on a dark background. Transition data from the camera, stored as a digital line-by-line picture of the array, is handled by an interface unit. The DRAGON Flight Simulator Processor determines the GAE from the transition data.

Microprocessor Subsystem

The microprocessor subsystem includes six units with five being housed in the system chassis. The principal function of each of the separate units is:

1. Personnel Interface Processing (PIP)
2. DRAGON Flight Simulation (DFS)
3. Sound Generation (SG)
4. Target Control (TC)
5. TV Display (TVD)
6. Photodiode Array Processing (PAP)

System I/O is processed by the PIP, which is covered in the Computer Graphics and Video Subsystem section.

Target control is detailed in the Miniature Target Board section.

Descriptions of the DRAGON Flight Simulator and the Photodiode Array Processor follow in the next two sections.

DRAGON Flight Simulator

The McDonnell Douglas Astronautics Company, Titusville Division, under Contract N61339-80-M-3518 provided a set of simplified equations and a computer program that approximate the DRAGON missile flight as directed by the gunner.

Six-degree-of-freedom equations are required to express the complete missile dynamics. Solutions of such equations were examined and simplified as much as possible by McDonnell while still maintaining a statistically accurate representation of weapon performance. Some of the simplifying assumptions were:

1. Missile dynamics should be represented by a point mass solution,
2. Small angle approximations to be used,
3. The effect of tracker sampling on missile trajectory while in the linear field of view to be neglected.

The six-degree-of-freedom equations thus modified were exercised and compared to results obtained from the complete equations of motion. Modification to the thrust level and guidance parameters were made to tailor the trajectory to the more exact results. Sufficient comparative analysis was conducted to assure that the simplified equations gave acceptable results over a range of crossing and stationary target conditions and with a variety of gunner aiming errors.

Figure 2 is the DRAGON simulation block diagram. The variables correspond with those of Figure 3 which defines the important horizontal angles. These, and a similar set of vertical angles, were used in the McDonnell BASIC program which iterates the differential equations of motion using a "Delta Time" of 20 milliseconds. Thus a 10 second missile flight requires the generation of 500 solutions of the equations of motion.

The BASIC program was rewritten for an Intel Microprocessor Development (MDS) System. The resulting program, while able to reproduce the McDonnell results, required several minutes to complete the 500 solutions for a simulated 10 second missile flight. It was, therefore, unsuitable for real time training.

An investigation of other floating-point-math techniques usable with Intel SBC-86/12, 8086, computers showed that real-time solutions of the missile flight could not be accomplished without using an 8087 coprocessor. The non-availability of the 8087 made it necessary to abandon the convenience of FP-math and recast the equations using integer arithmetic. This required close attention to the choice of suitable units for the variables because of the limited range of integer numbers: (-32,767, +32,767). Down-range distances, for example, are expressed in 2-inch units; 1000 meters (39,370 inches) being considered to be 19,685 "Down-range" units. Cross-range units are 0.05 inches for distances and 0.1 milliradians for angles. Unit selection is a compromise between the conflicting requirements of the desire to display variables over a wide range and the need to reduce the quantization distortion while not exceeding the allowable integer range. Many comparisons between the integer and BASIC program results have verified that good approximations to the DRAGON Flight characteristics are provided using integer arithmetic. Comments by experienced DRAGON gunners also support the validity of the approximations.

The DRAGON Flight Simulation Program includes five modules:

1. Main-DRAGON-Module: A "Driver" module which calls other modules.

2. DRAGON-utility: Includes a number of start-up and other general procedures.

3. DRAGON Flight Module: Includes the integer math missile dynamics, provides missile location information to the PIP, stores location data for possible reprise, and does the initialization of flight variables.

4. DRAGON IR: Analyzes the IR-spot data array provided by the DRAGON XF module.

5. DRAGON XF: Transfers line-by-line data provided by the photo-detector line array processor into a complete picture array.

The first three modules are written in PLM 86; an Intel high level programming language. The last two are in 8086 assembly language. Total program code require slightly under 4K of ROM memory. Variable memory requires about 1K of RAM.

As noted previously, the program ROM is located on an Intel SBC 86/12 board. This board, along with four others are housed in an Intel SBC 86/12 system chassis which provides eight card slots, power supply and ventilation. Cards within the chassis can communicate via the multibus motherboard. An SBC 86/12 provides dual-port RAM which can be accessed by both the on-and-off-board processors. Missile position data resulting for the solution of the missile equations of motion are transferred to the PIP via the multibus for further processing and output. Data status bits are also read and written across the multibus as required.

Target motion is provided as described in the section on Miniature Modelboard. It is programmed via a stepper motor controller into which the desired target maneuver is input from a suitable menu item located in program memory of the PIP. Identification of the selected maneuver is posted within dual-port memory and therefore may be read by the DFS in order to make possible appropriate target position calculations as required by the missile equations of motion.

The DFS also provides control signals to the sound generator for side-thruster pops, ground explosion and target hits. It also provides signals for weight loss in response to trigger pull.

Photodiode Array Processor

Line scan data from the 100 x 100 photodiode array are initially stored in a set of ping-pong memories on a Reticon RSB 6020 board housed within the system chassis and attached to the multibus. Data are alternately read into ping or pong memory under control of a clock located within the Reticon RS 520. Data within the memory units gives the location of light level transitions and indicates whether it is a light-dark or dark-light transition. The stored data also indicate when the last scan line is read.

After initialization, a last-line flag is output across the multibus to the DFS which causes the DRAGON XF program to begin the transfer of data from each line of the next 100 x 100 photodiode array frame. The data read-out is then halted by the next occurrence of the last-line flag. The 100 x 100 frame data are ignored during the next frame data analysis. New frame data are thus provided every other frame.

The frame rate of the Reticon camera is 100 frames per second so new IR-spot position data are provided 50 times a second or with a 20 millisecond period. Occurrence of the last-line flag acts as the master system clock with all data processing starting with its assertion.

Computer Graphics and Video Subsystem

The DRAGON computer graphic visual presentation is prepared by the Personnel Interface Processor. In addition to this processor a computer graphics board, a phase-locked-loop sync board, and an EIA composite sync generator is used. Figure 4 shows the complete graphics and the video subsystem.

Computer generated graphics provide two major functions:

1. Real-time video graphics are generated for the gunner sight. These graphics include a simulated missile which includes thruster firings, smoke obscuration during initial launch and a final explosion.

2. Real-time graphics are generated for the instructor which indicate both vertical and horizontal gunner aiming errors. Also, for follow up analysis, graphics may be presented for gunner aiming error versus time and missile position versus time.

Gunner's sight computer graphics are generated on a 256 x 256 x 4 graphics board. Sixteen levels of gray scale provide for a full range of visual intensity which allows for smoke generation which varies from fully transparent to completely opaque. The computer generated graphics are passed directly to the gunner's sight through a one and a quarter inch closed circuit television (CCTV) monitor. The optical arrangement is shown in Figure 5. The television screen appears at infinity along with the viewed scene through the 6x scope. The CCTV is mounted inside the DRAGON IR tracker housing and electronics for the CCTV are located where the IR tracker electronics were located at the bottom of the tracking unit.

The instructor console graphics subsystem is composed of two units, a television representation of the gunner's sight picture and a graphical plot of gunner aiming error versus time and/or gunner aiming error versus missile position.

The television representation of the gunner's sight is accomplished by mixing the gunner's sight TV camera, which is boresighted to the 6x gunner sight, with the video graphics presented to the gunner's sight. The composite picture presents to the instructor an image of the gunner's sight which includes the target, missile, smoke, crosshairs and final explosion.

The graphical plot of the gunner aiming error (GAE) versus time for both horizontal and vertical error are presented in real-time during the missile flight. The graphs indicate the actual gunner aiming error during the flight as well as the limits for a 95% probability of hit performance. The guidance rocket thruster firings are shown when they are fired as well as a final actual count of the thrusters fired versus the ideal number of thrusters that would have been fired for a given target distance with perfect aim. At the end of a flight displayed results show the miss distance, in feet, where the missile passed the target. If the missile strikes the ground before passing the target, a message is displayed stating "ground impact" as well as the remaining distance to the target when grounded. If a hit is scored a hit message is displayed to mark the event.

After a missile flight a reprise of the flight may be called. A horizontal reprise replays the horizontal GAE and the horizontal missile position versus time. Likewise the vertical reprise replays the vertical GAE and the vertical missile position versus time. The reprises indicate all the hit/miss summaries of the first real-time plot.

Any of the computer graphic plots may be made into a hard-copy printout. The hard-copy may include the gunner's name or other pertinent data as desired by the instructor.

Computer Generated Sound System

Simulation of sounds produced during an actual DRAGON missile firing is accomplished by interfacing an Intel 8748 microcomputer to a General Instruments AY-3-8910 Programmable Sound Generator (PSD). Data necessary for the PSG to reproduce sounds is acquired from the permanent memory of the microcomputer. During missile flight time the DFS processor simply selects the sound to be made and communicates its choice to the microcomputer. This approach allows the processor to handle sound-making decisions with minimum time taken from its primary functions.

The choice of sounds available to the DFS processor are:

1. Gyro start-up
2. Missile launch explosions
3. Rocket thruster motor firing
4. Target missed explosions
5. Target hit explosions.

The General Instruments Programmable Sound Generator (PSG) is a 40 pin, eight bit device with microprocessor compatibility. The device features three independent analog channels each with access to its own tone generator. A 16 control register array communicates to the microcomputer through an eight bit bi-directional port. Four lines are allotted for bus control logic (read and write). Each tone generator looks to two registers within the array for a 12 bit tone period. A range of frequencies covering the full eight octaves of the equal tempered chromatic scale is available.

Psuedo-random noise may be mixed to any or all channels from a noise generator with basic frequencies of 4 KHz to 125 KHz. Two modes of output control are available for each channel. The fixed level amplitude mode selects an amplitude specified in the array by the microcomputer. For use in this system the variable amplitude mode is selected, forcing an envelope generator to control the shape and cycle of all outputs. Controlling the envelope generator is a 16 bit tone period within the array allowing for frequency ranges of 12 Hz to 7812.5 Hz and a five bit shape/cycle control register. Three D/A converters supply 0 to 1 volt signals to the output channels.

To accurately represent the flight of a DRAGON missile as it moves down-range two sound phenomena must be simulated:

1. Time delay due to the difference in the speeds of light and sound, and

2. Logarithmic sound amplitude decay due to distance sound must travel through air.

Software developed for the microcomputer closely approximates these conditions within a 1000 meter range.

As shown in Figure 6, the outputs of the PSGs are input to circuits which function to control the amplitude of the sound. These circuits consist of operational amplifiers with closed loop gains under direct control of the microcomputer. The DRAGON Flight Simulator processor initiates a timer within the microcomputer upon request of a launch explosion. Thereafter, each request for a sound by the processor causes the microcomputer to inspect the timer. Assuming the missile travels at an average speed of 280 feet per second the microcomputer is able to approximate the distance covered and set the appropriate gain. For rocket thruster firings, the microcomputer selects one of thirteen levels of amplitude, decreasing logarithmically from a gain of ten to one over a time span of 11 seconds corresponding to a distance of 1000 meters.

Time delay associated with distance covered by the missile is accomplished upon inspection of the timer for each requested sound after launch. Before signals are passed to the PSG to create a sound, software completes a sequence of three delays. The first delay represents the real-time between requests from the DFS processor. This timeout occurs only when two or more requests are made before the first request is serviced by passing signals to the PSG. The real-time between any two requests represents distance traveled by the missile and is decoded into the second time delay as determined by the time required for sound waves to travel this distance. The incremental time delays are accumulated in the microcomputers data memory. The third time delay before a sound is made is the cumulative total of all the second time delays that have already been decoded. The complete algorithm produces a series of logarithmically decaying, time delayed, sound waves that approximate the actual conditions within a 1000 meter range.

Miniature Target Board

Because most anti-armor devices use high power telescopes to view the targets, a miniature model was chosen. The target model has an IRED located at the center of the target mass. The model is moved using a stepper motor. The stepper motor controller is a stand-alone intelligent controller that is independent of the host computer, the Personnel Interface Processor, except for loading the scenario. The stepper motor controller uses a high level language for control of the stepper motors direction, position, speed and acceleration. Scaled to the real world the tank location is known to 0.9 inches.

Weight Loss and Recoil Mechanism

Launch effects of the DRAGON simulator are a very important facet of the training mission. Two of the launch transients which must be overcome by the DRAGON gunner are the weight loss due to the missile leaving the launch tube and the recoil of the launcher due to slight uncompensated differences in the pressures at launch. Weapon launch effects of weight loss and recoil are simulated via mechanical attachments to the DRAGON bipod.

The recoil mechanism is a sliding platten upon which the DRAGON bipod and gunner's feet are supported. The platten is covered with a rubber and steel hybrid material that allows the gunner to firmly plant the bipod legs in position and stabilize the launcher using his boots to press against the bipod supports. At launch the platten is given an impulse from a pneumatic solenoid thus imparting a sensation of recoil to the launcher.

The weight loss simulation is accomplished by a weight mass that is attached to the bipod via a pivot and pneumatic cylinder. When the DRAGON simulator is armed for launch, the pneumatic cylinder is energized which in turn raises the weight and places an additional equivalent weight of the DRAGON missile on the shoulder of the DRAGON gunner through mechanical leverage. When the simulated missile is launched, the pneumatic cylinder is relaxed, thus releasing the weight and effectively removing the equivalent missile weight from the gunner's shoulder.

CONCLUSION

This simulator has undergone preliminary evaluation by a United States Marine Corps Fleet Project Team of experienced DRAGON gunners. All gunners were favorably impressed with its realism and teaching attributes. Testing of the device is planned for the fall of 1981 by both the United States Marine Corps and the United States Army. Results of these tests will be reported at the conference.

The authors wish to gratefully acknowledge the support of both the Marine Corps and United States Army, PM TRADE on this program. We specifically wish to thank Major Don Head, USMC and A. J. Boudreaux - PM TRADE for their valuable suggestions and help.

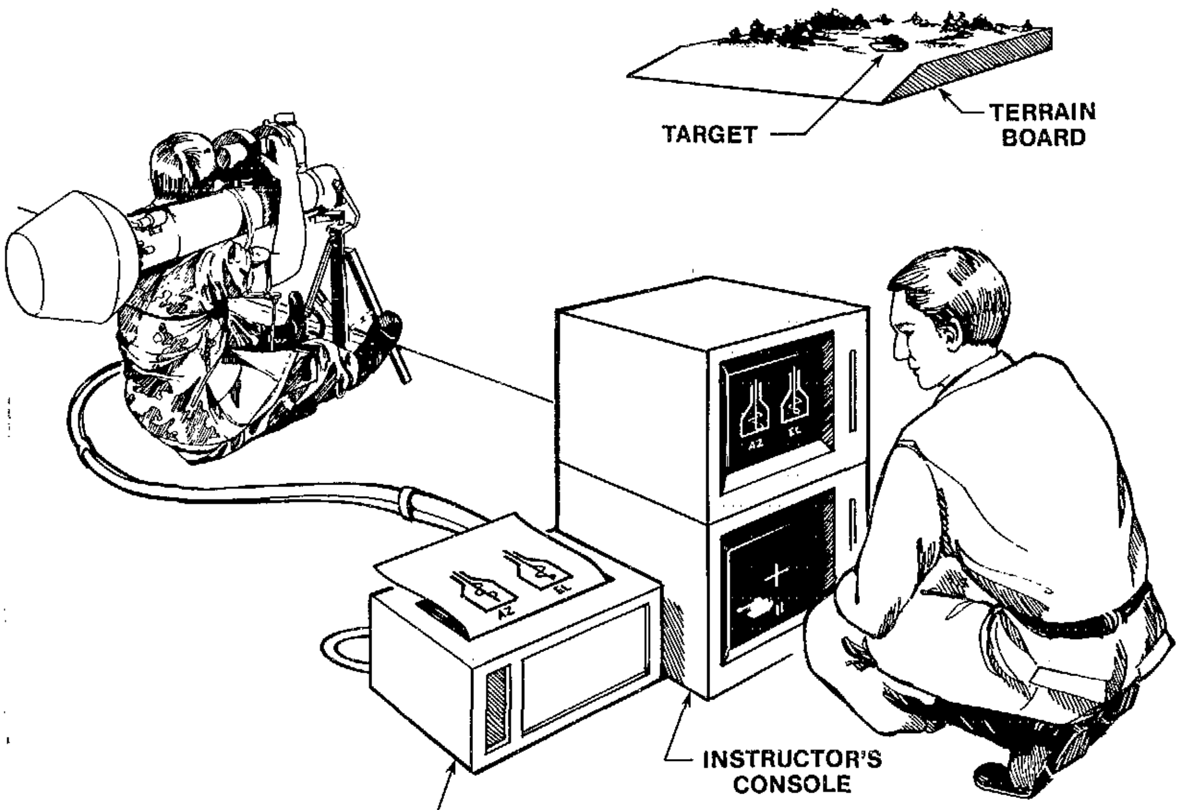
ABOUT THE AUTHORS

MR. ALBERT H. MARSHALL is a Research Physicist at the Naval Training Equipment Center. He has specialized in developing weapon fire simulators using lasers, electroptics and microcomputers. He holds ten U. S. patents. He has Master's degrees in both physics and Electrical Engineering from Brown University and the University of Central Florida.

MR. BON F. SHAW is an Electronics Engineer at the Naval Training Equipment Center (NAVTRAEQUIPCEN). Since joining NAVTRAEQUIPCEN, he has participated in several projects including Thermal Signature Targets for Live Fire Training with Thermal Sights; Air-to-Air Gunnery Simulation; Infantry Weapons Trainer; Marksmanship Potential Evaluation; and the Anti-Armor Missile Flight Simulator.

MR. GARY M. BOND is an Electronics Engineer at the Naval Training Equipment Center. He holds a B.S. degree in Electrical Engineering from the University of Central Florida and is currently working on his Master's degree. Since joining NAVTRAEQUIPCEN, he has participated in such projects as the Infantry Weapons Trainer, Marksmanship Potential Evaluation, and the Anti-Armor Missile Flight Simulator.

DR. HERBERT C. TOWLE is a Professor of Engineering at the University of Central Florida and a consultant to Mr. Marshall at the Naval Training Equipment Center in microcomputer development. He has many years of engineering experience at both the Republic Aviation Corporation and the General Electric Company. He received his Ph.D. degree from the University of Michigan.



ARTIST CONCEPT
DRAGON TRAINER

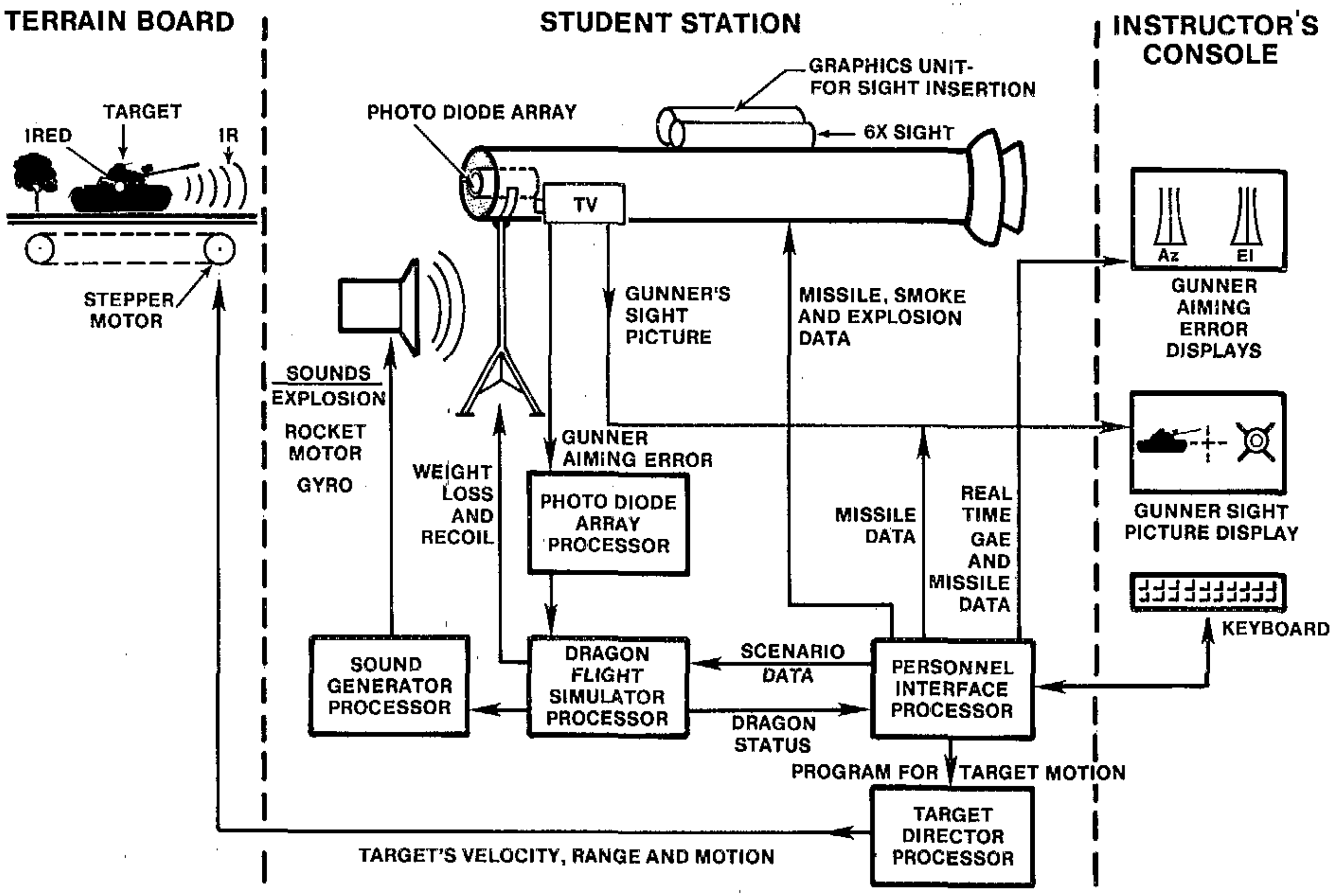


FIGURE 1. SYSTEM BLOCK DIAGRAM

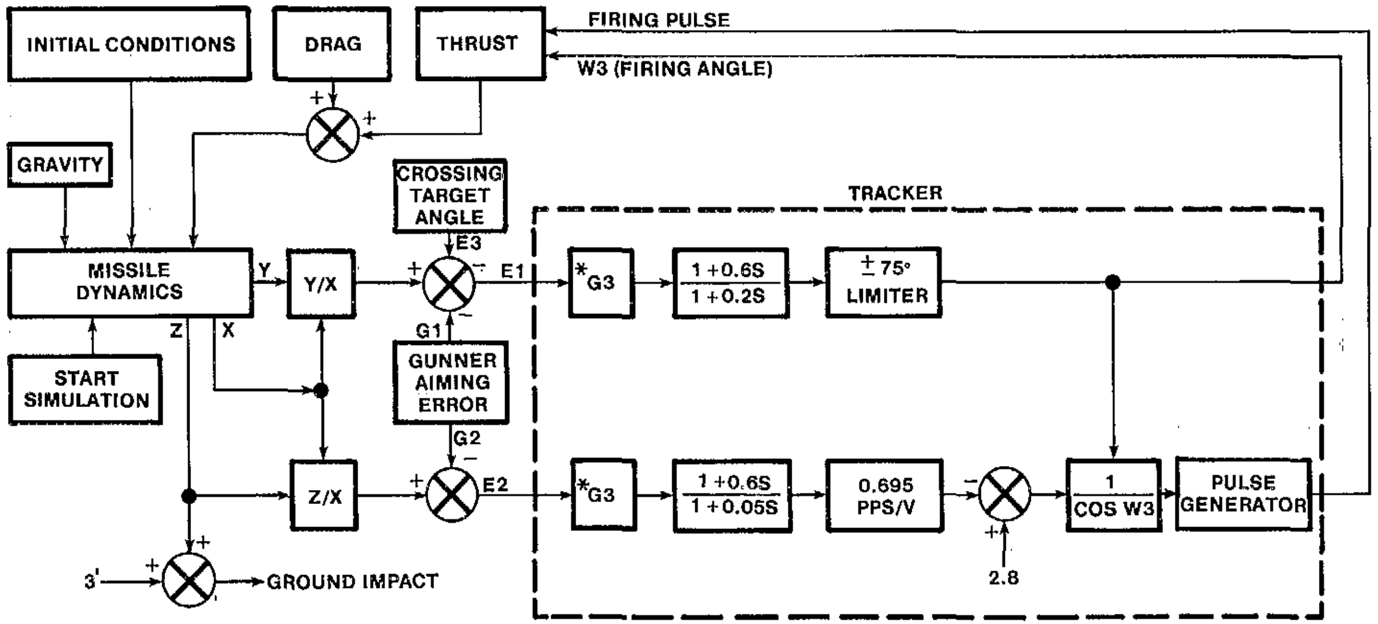


FIGURE 2. SIMULATION BLOCK DIAGRAM

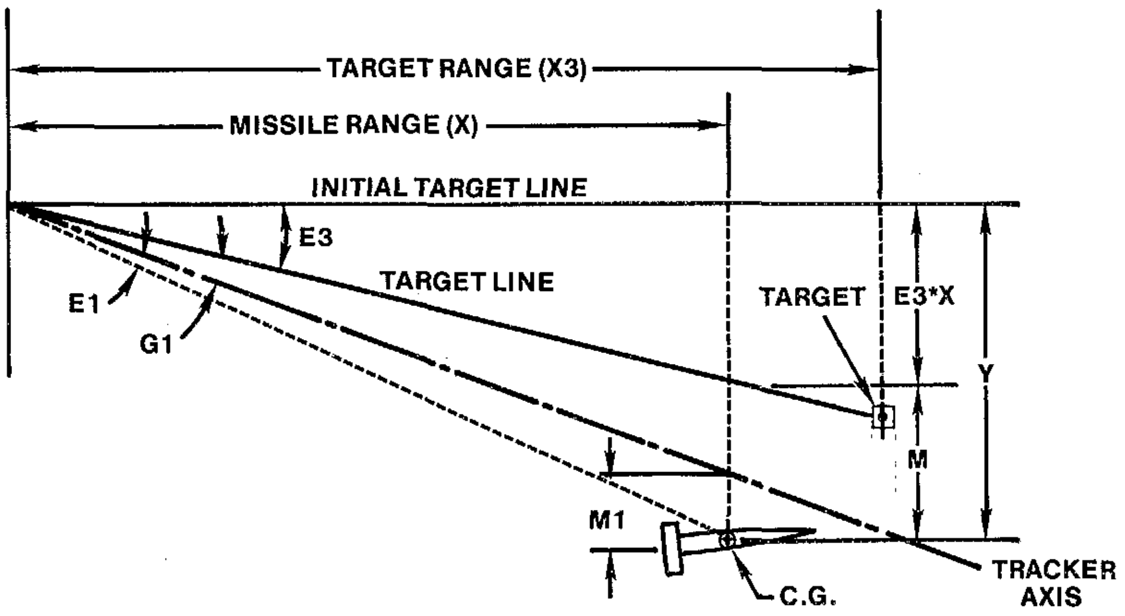


FIGURE 3. HORIZONTAL PLANE GEOMETRY

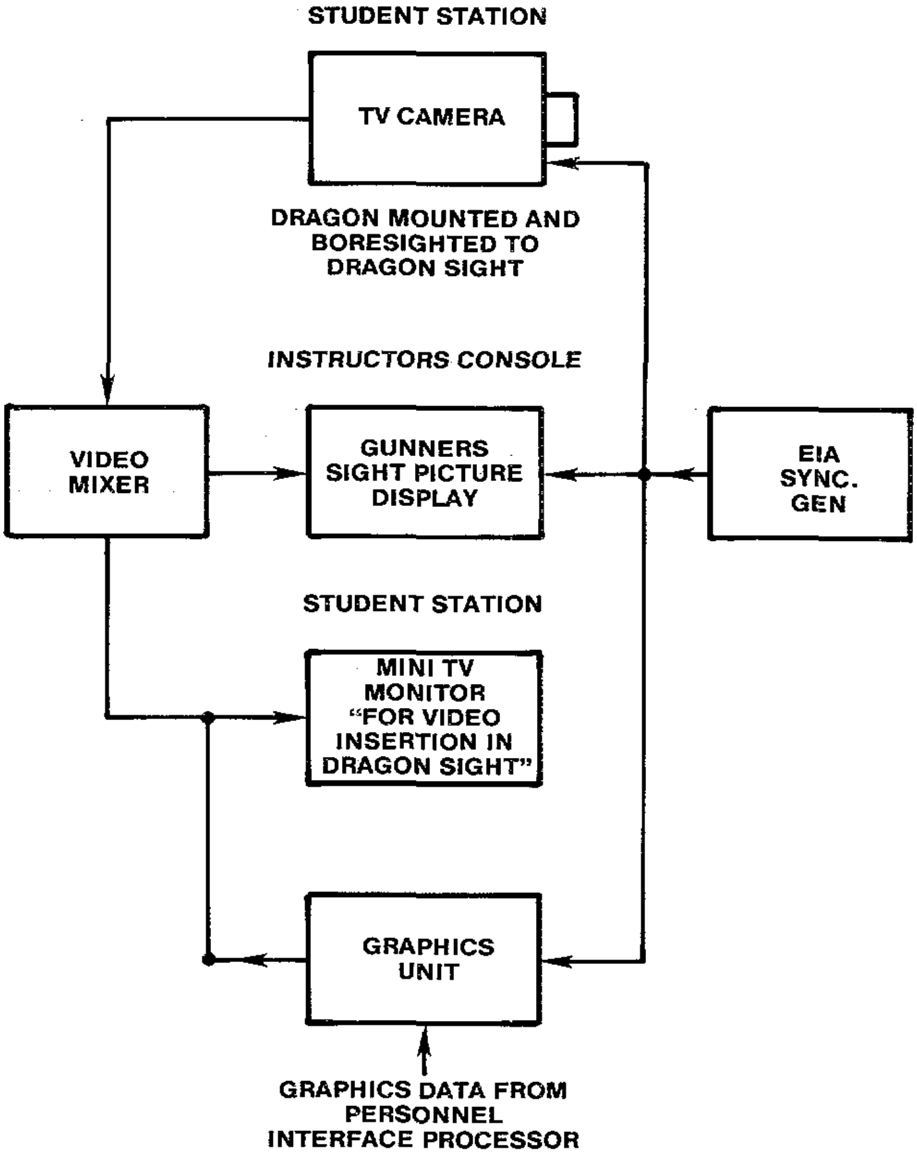


FIGURE 4. COMPUTER GRAPHICS AND VIDEO SUBSYSTEM

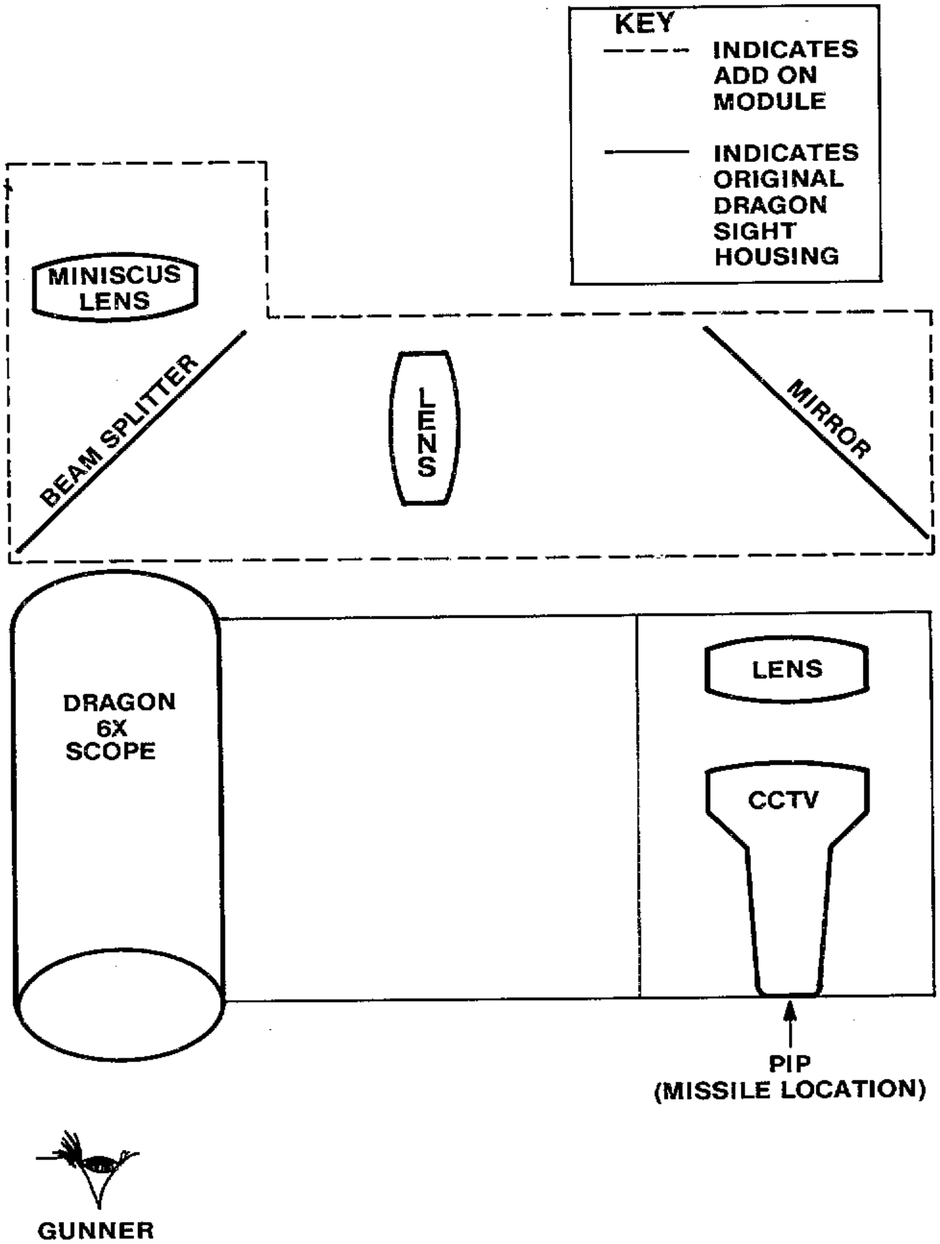


FIGURE 5. DRAGON GUNNER'S SIGHT SYSTEM

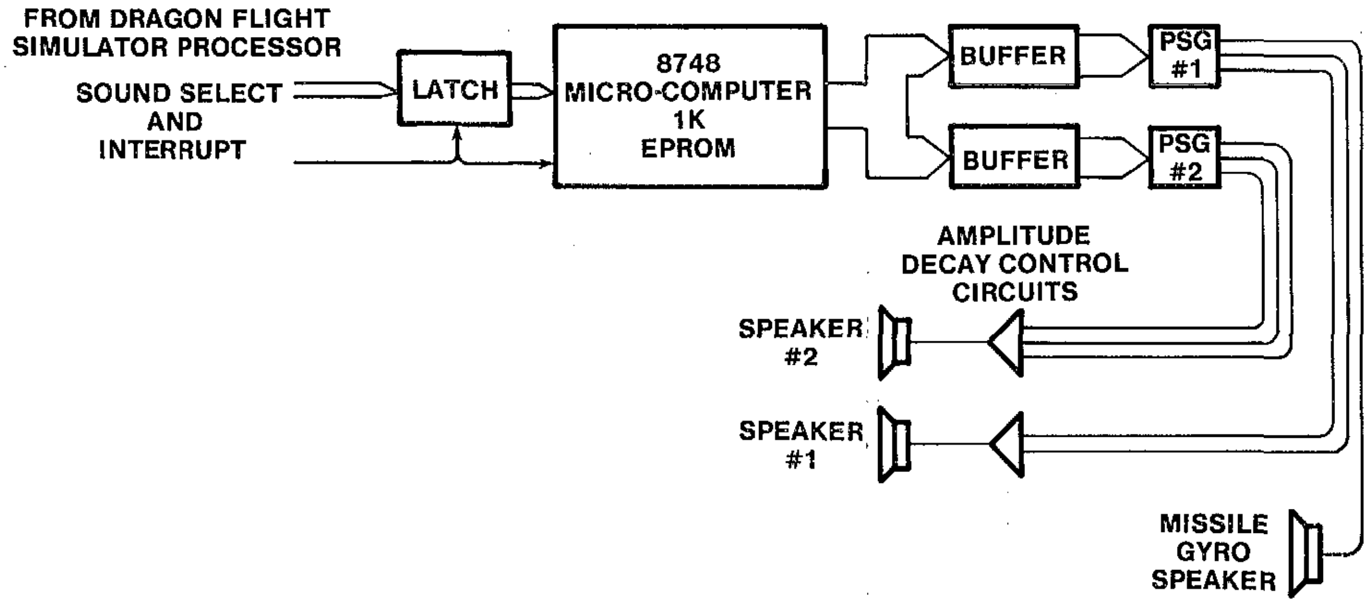


FIGURE 6. SOUND GENERATOR HARDWARE LAYOUT