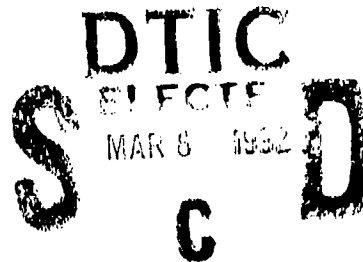


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SPECIAL REPORT SR 91-002

**ADVANCED LASER SEMI-CONDUCTOR
AIR TO AIR TRAINING DEVICE CONCEPT**

DECEMBER 1991

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PREFACE

**THE ADVANCED LASER SEMICONDUCTOR AIR TO AIR TRAINING
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INTRODUCTION

In 1975, NTSC developed an Laser Air-To-Air Gunnery Simulator (LATAGS). The LATAGS system was designed to simulate machine gun fire for either air-to-air or air-to-ground gunnery training in the T-2 aircraft against a cooperative (optically retroreflective) towed banner target. In the training mode of operation, a laser pulse is fired for each gun round. If the laser pulse hits the retroreflective target, the pulse is returned to the LATAGS receiver and counted as a hit. The LATAGS system consisted of two major subassemblies, a hit indicator assembly and a transmitter/receiver module. The LATAGS system counts and displays rounds fired and hits scored cumulatively and flashes a hit indicator lamp mounted on the gunsight to indicate hits while the pilot is firing the system. This indicator provides instantaneous hit feed-back information within the pilot's peripheral field-of-view. The LATAGS equipment is shown in Figure 1.

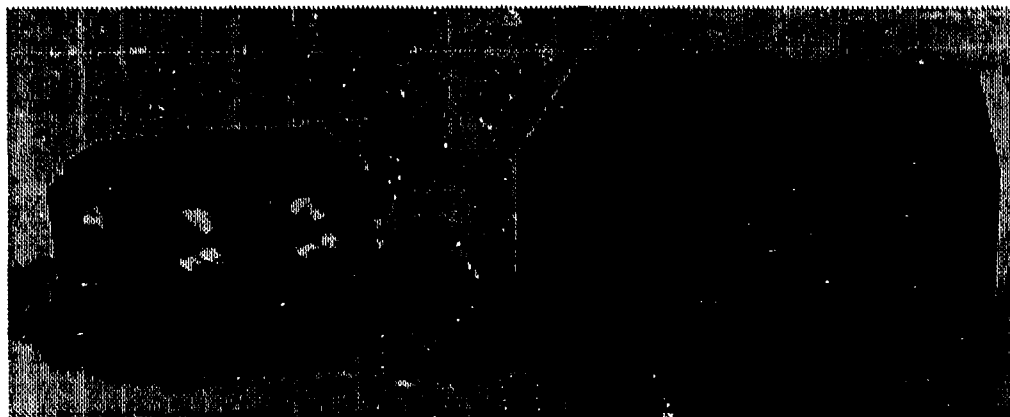


FIGURE 1. LATAGS EQUIPMENT

The current "squirrel-cage" gunnery pattern is similar to a circle. Four firing aircraft move around the periphery of this circle, equally separated, 90 degrees apart. The two aircraft and banner constitute a small chord at one side of the circle, with the starting or perch position on the opposite side. The plane of the circle is inclined to the horizon by the amount of altitude advantage of the perch position above the two aircraft and banner. This circle moves along relative to the speed and direction of the two aircraft.

The aerial gunnery pattern viewed from above is shown in Figure 2 .

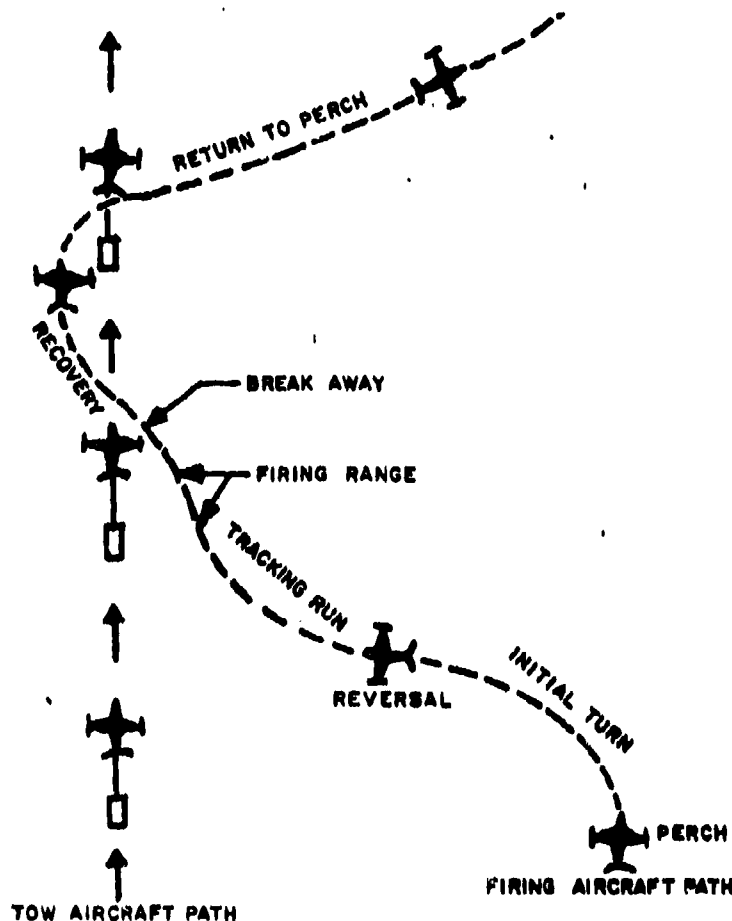


FIGURE 2. AERIAL GUNNERY PATTERN VIEWED FROM ABOVE

The LATAGS is boresighted at a fixed elevation angle and azimuth angle and is aligned with the fixed sight reticle of the gun sight prior to the training flight. This is commonly known as a fixed pipper.

Effective range of the LATAGS system is up to 5,000 feet utilizing retroreflective banner targets and up to 12,000 feet in the air to ground mode utilizing glass corner cube retroreflectors.

An adjustable range gate is used in the LATAGS system to only permit hits within the effective maximum range of the weapon. A boresight alignment kit is provided, which allows one-man alignment of the LATAGS to the gun sight pipper.

The LATAGS system is comprised of two major modules, the Transmitter/Receiver Module and the Electronics Module. The Transmitter/Receiver Module is mounted on the glare shield of the aircraft's instrument panel forward of the gunsight. A common mounting plate is utilized to provide a stable alignment of the laser and the gun sight. The Electronics Module is mounted in the forward pilot's map case location. The Electronic Module contains displays that show the cumulative rounds fired and the number of hits. The Hit Indicator is a small assembly that flashes when hits are being scored.

The transmitted beam has an angular width of 2.5 mradians at the 3 db points. The laser beam width closely approximates the dispersion of the weapons round.

The aircraft installation is shown in Figure 3.

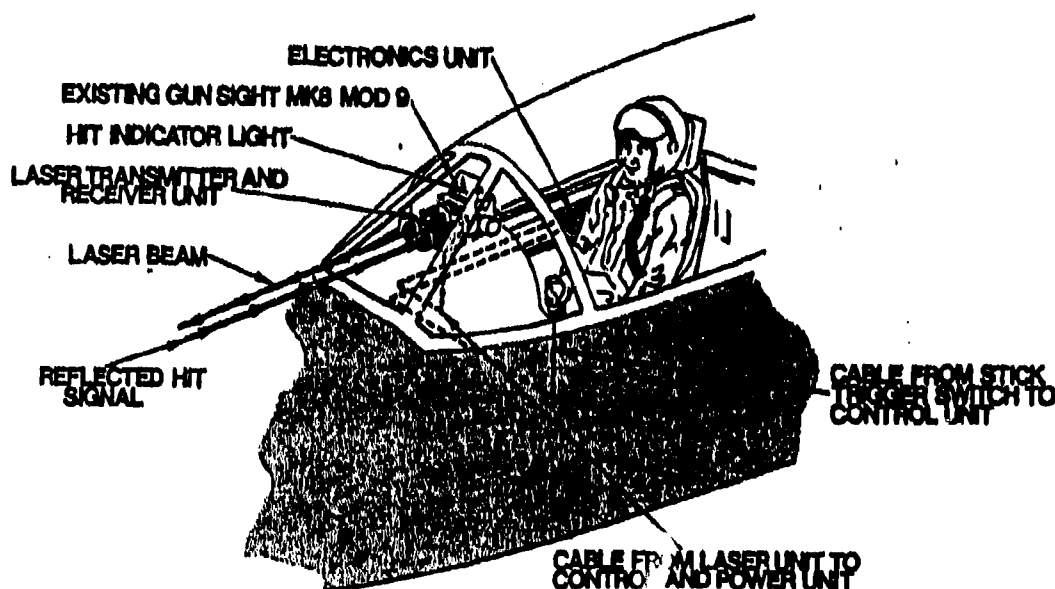


FIGURE 3. LATAGS AIRCRAFT INSTALLATION

LATAGS allows gunnery to be accomplished over inhabited land areas. Elimination of the aircraft's gun pods increases the fuel economy of the aircraft. Less ordnance personnel are required because the LATAGS uses no ammunition or guns. The cost of maintaining the LATAGS is also less than maintaining the operational weapon for training.

The Nominal T-2 attack parameters are shown below:

FIRING RANGE	600 TO 1,200 FEET
OFFSET ANGLE	27 DEGREES
ALTITUDE	11,000 FEET
ATTACK SPEED	300 KT TRUE
TARGET SPEED	200 KT
G LOAD	3.8 G

PROBLEM

A laser beam has a perfectly straight trajectory and travels at one foot per nanosecond or, has essentially zero time of flight from the laser transmitter to the banner and return. In the current LATAGS the laser beam is offset from the gun line by an amount equal in magnitude to the required lead angle and opposite in sign. Target hits are only indicated if the laser beam offset is suitably compensated by the attacking pilot by introducing the correct lead angle into the aircraft attitude. The required lead angle is not constant over the entire range of possible attacks, thus, the laser beam offset from the gun line should ideally be adjusted for each attack by an automatic control or equivalent. When the laser beam does not strike the target the system registers a miss. If the student only has misses there are no means of analyzing his tracking errors.

The target geometry for a fixed gun vs. a moving target is shown in Figure 4 . The basic fire control problem is the correct aiming of fixed forward-firing guns. Lead allowance is necessary for the target's motion during the projectile's finite time of flight and is called kinematic lead. The basic gunnery parameters are listed in the table below.

FIRE CONTROL PARAMETERS

FIRING RANGE	600 TO 1,200 FEET
BORESIGHT RANGE	1,000 FEET
OFFSET ANGLE	23-30 DEGREES
GUNNERY ALTITUDE	7,000 TO 15,000 FEET
TARGET SPEED	300 KIAS
MUZZLE VELOCITY	2,935 FEET PER SEC.
GRAVITY DROP	18 INCHES AT 1,000 FEET
DIVE ANGLE	10 TO 20 DEGREES
"G" LOAD DURING GUNFIRE	3.6 TO 3.8
GUN DISPERSION	3 MILS AT 1,000 FEET

Magnitude of the lead can be obtained by reference to the vector diagram shown in Figure 4.

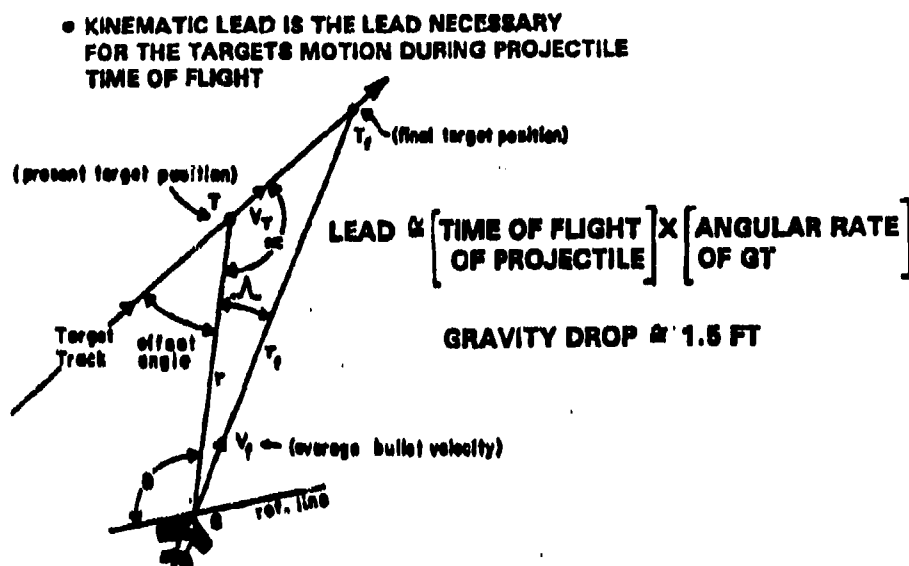


FIGURE 4. TARGET GEOMETRY FOR A FIXED GUN VS. A MOVING TARGET

The reference line in Figure 4, from which the angles are measured, points in a fixed direction in space. The origin about which the angles are measured is the pivot point of the gun platform, i.e., the center of gravity of the aircraft. Velocities shown in Figure 4 are considered as being measured relative to inertial axes fixed in space. Suppose that the target banner, T, traverses the line TT_f with a constant speed V_T. The point T_f represents the banner position at the time of bullet impact. V_f is the average bullet velocity over the firing range. Using the triangle GTT_f, and the Law of Sines

$$\frac{\sin \Lambda}{\sin \alpha} = \frac{V_T t_f}{V_f t_f} = \frac{V_T}{V_f} \quad (1)$$

or

$$\sin \Lambda = \frac{V_T}{V_f} \sin \alpha \quad (2)$$

Since α is not available as an input to the fire control system it is convenient to resolve V_T into components along and perpendicular to GT. The perpendicular components is given by,

$$V_r \sin \alpha = r\omega = r \frac{d\theta}{dt} \quad (3)$$

Where ω is the angular rate of the line GT given in rad/sec, and is its angular coordinate referred to a fixed reference line through G.

Combining equations (2) and (3)

$$\sin \Lambda = \frac{r\omega}{V_f} \quad (4)$$

$$\sin \Lambda = \frac{V_r}{V_f} \frac{r\omega}{V_r} = \frac{V_r}{V_f} t\omega \quad (5)$$

$$\frac{V_r}{V_f} \approx 1$$

$$\sin \Lambda = t\omega$$

Equation (5) essentially says the kinematic lead, Λ is approximately the time of flight multiplied by the angular rate ω of the sightline GT. To determine the time of flight, t , the range to the target is required. The bullet path is an extension of the instantaneous gun axis at firing if cross wind deflections and gravity drop are neglected. Cross wind deflections while important in some cases are considered negligible in forward firing guns. Gravity drop is about 1.5 feet at the maximum range. Gravity drop is a function of range and can be accounted for if the range is known. Range can be determined by measuring the time for a laser pulse to be reflected and returned to a receiver in the attacking aircraft.

The angular rate of the gun line can be measured with a gyro. Air resistance to the bullet is accounted for by using an average velocity, V_f , over the bullet path. This velocity is equal to the aircraft forward speed plus the bullet muzzle velocity minus an average slow down. The M2 muzzle velocity is 2,935 feet per second and at 300 knots true air speed, the gun is moving at slightly more than 505 feet per second relative to inertial coordinates. The initial velocity of the bullet is 3,400 feet per second. The previous figure of 1.5 foot gravity drop in 1,000 feet corresponds to an average bullet velocity of 3,270 feet per second which indicates an average slow down of 170 feet per second or five percent. Slow down is approximately proportional to range assuming a constant air drag force. Thus, a variation of between three percent

and six percent in average bullet velocity is predicted for target ranges of from 600 to 1,200 feet.

For the firing parameters of

V_f = 3,500 feet

V_T = 150 knots (true)

Offset = 25 degrees

Lead = 31 mils

The current LATAGS system has the following characteristics :

HIT OR MISS SCORING ONLY

NO BALLISTIC COMPENSATION

NO AIRCRAFT MANEUVER COMPENSATION

FREE PLAY NOT POSSIBLE

DURING AIR TO GROUND STRAFING LATAGS DOES NOT SCORE MISSES

OBJECTIVE

The objective of this research program is to research the development of an advanced LATAGS system that can compensate for variations of the flight path and also score the rounds location, in the plane of the target, if the student trainee misses or fires when the pipper is not on the target.

The system will also be capable of recording the pipper location during the tracking run.

The new system will also be capable of analyzing the students tracking efficacy using an expert system. Advantages of a new LATAGS system is shown in the table below.

ADVANTAGES AND NEW FEATURES OF NEW VS OLD LATAGS

OLD LATAGS	NEW LATAGS
NO FREE PLAY MANEUVER SCORING	FREE PLAY SCORING
NO PLAY BACK	PLAYBACK
NO MISS DISTANCE DETERMINATION	MISS DISTANCE DETERMINATION
NO EXPERT SYSTEM ANALYSIS	EXPERT SYSTEM ANALYSIS

APPROACH

The OLD LATAGS has a 2.5 mradian beam at the 3 db points. At a range of 1,500 feet the beam diameter is 3.75 feet. In the new approach, the transmitted beam will be approximately 20.0 mradian at the 3 db points. At a range of 1,500 feet the beam will have a 30 foot diameter. See Figure 5. This beam diameter will allow the system to determine the pipper location within plus or minus 25 feet from the center of the towed target. The return from towed retroreflective banner is be focused on a vertical and horizontal detector array in the tracker assembly. See inset in Figure 5.

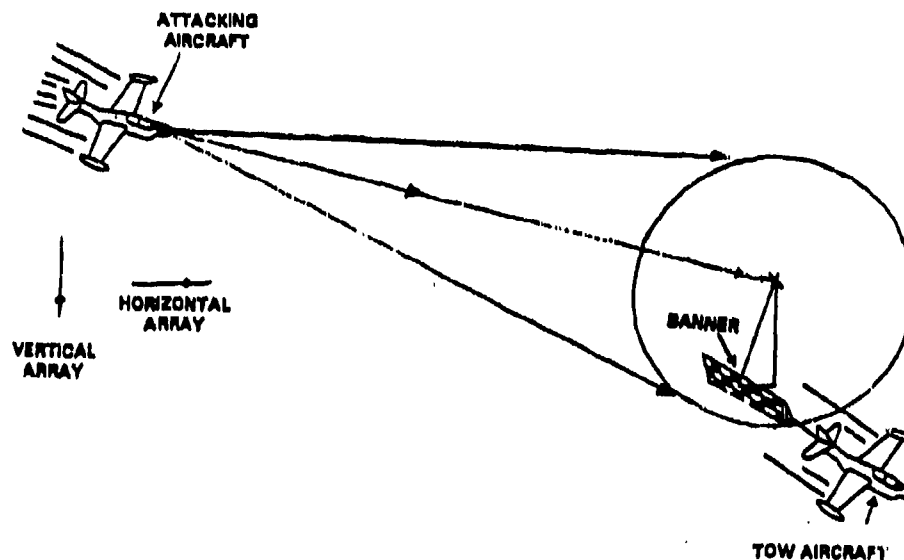


FIGURE 5. LASER BEAM GEOMETRY

Cylindrical optics are used to focus the retroreflected laser beam on a 25 element avalanche photo-diode, APD, array. The lens layout is shown in Figure 6.

The detector is a 25-Element Silicon Avalanche Photodiode Linear array. The detector used is an RCA C30985E array. The detector is made using a double-diffused "reach through" structure. This structure provides high responsivity at 904 nm as well as fast rise and fall time characteristics.

The responsivity of the C30985E is independent of modulation frequency up to about 200 MHz. Using this 25 element array we can resolve the pipper location within 2 feet. This is well within the CEP of the weapon.

Key APD characteristics are shown below:

RISE AND FALL TIME	2 NSEC
RESPONSIVITY	31 AMPS / WATT
QUANTUM EFFICIENCY	85 % AT 904 NM

A pulsed Ga-As laser is used to determine both the range to the target, and the pipper location or aircraft orientation with respect to the towed banner target.

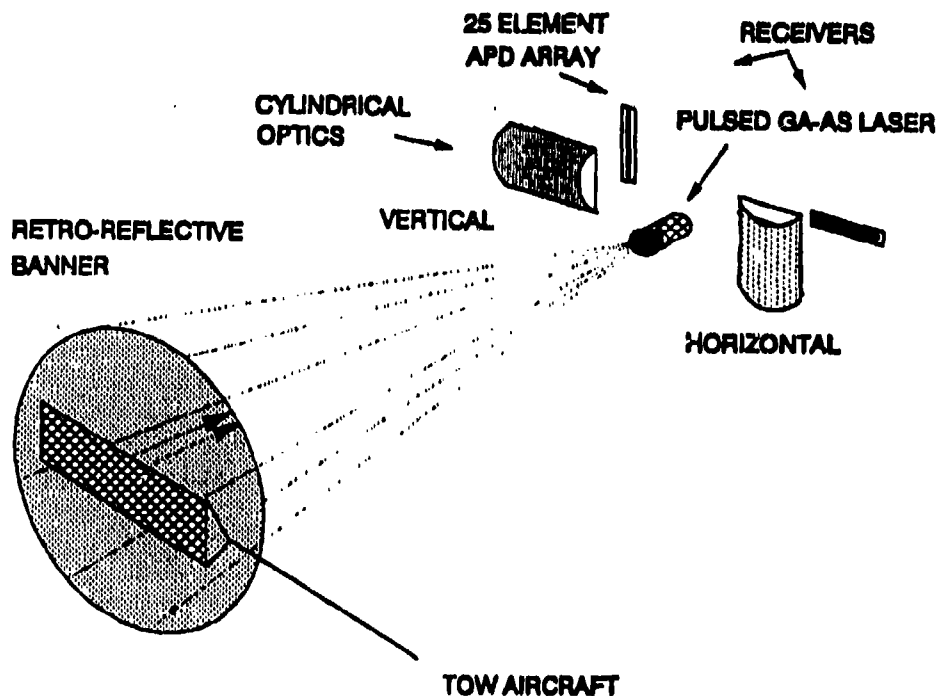


FIGURE 6. OPTICAL SYSTEM CONFIGURATION

Cylindrical optics are used to focus the retroreflected laser beam into a line on the 25 element APD array. Cylindrical lenses condense the received light in one axis to form a line. Notice the two optical channels are orthogonal to each other. The focused returned laser line will move up and down the array as the pipper location changes. One set of cylindrical optics are used to determine the vertical position of the banner and the other set of cylindrical optics is used to determine the horizontal position of the pipper. An aircraft attitude sensor determines the roll axis. Using this system no moving mechanical parts are necessary for the scanner, which is used to determine the banners coordinates. This system can replace a rotating mirror laser scanner which would be both expensive and difficult to implement in an aircraft environment.

Figure 7 shows the equipment located in the training aircraft.

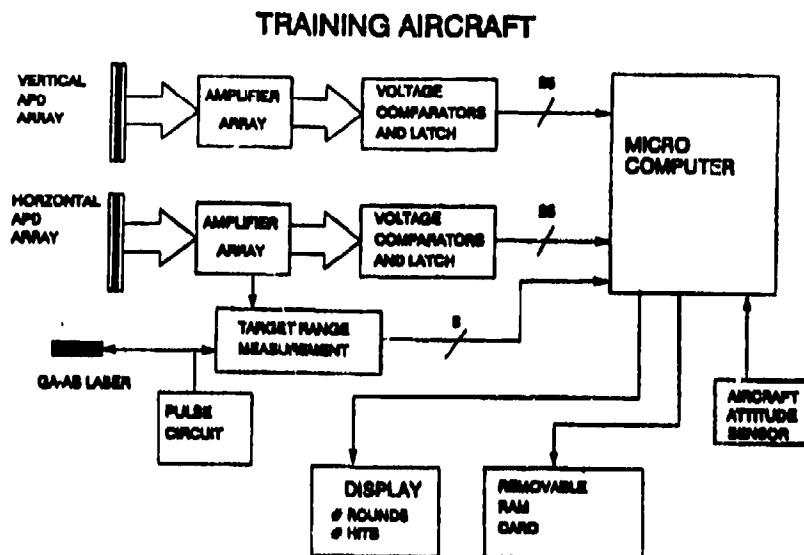


FIGURE 7. TRAINING AIRCRAFT EQUIPMENT

Equipment in the aircraft consists of two optical systems: vertical and horizontal systems. The array amplifier consists of a transimpedance amplifier for each detector and a voltage comparator and latch for each channel. The output is digital and represents the location of the banner. The outputs from the latches are read by an Intel 80960 Microcontroller.

Range to the target is determined by measuring the round trip time for the pulse to transit from the aircraft to the target and back. The aircraft has a display for the rounds fired and the number of hits.

The movement data for the piper is stored on a removeable ram card. Figure 8 shows the microcomputer.

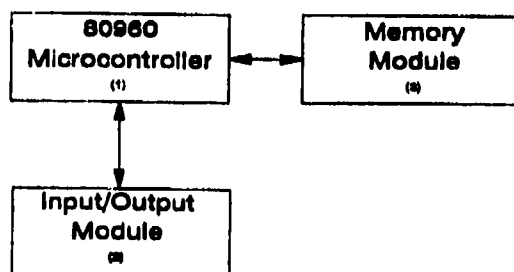


FIGURE 8. MICROCOMPUTER

Figure 9 illustrates the playback system located in the ready room. A PC in the ready room would be used to play back the pipper location and run an Expert System to coach the pilot.

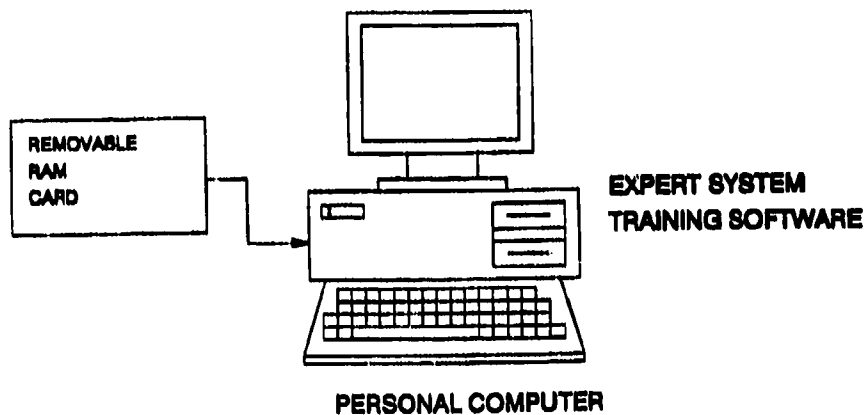


FIGURE 9. PLAYBACK SYSTEM

BENEFITS

The following benefits would be accrued by using this improved LATAGS system:

FREE PLAY RATHER THAN FIXED PIPPER GUNNERY

BETTER STUDENT DIAGNOSTICS USING AN EXPERT SYSTEM

RESULTS

This system will allow aerial gunnery training over inhabited areas with no live ammunition. The system will also allow free play of the aircraft and calculate the bullets hit and miss distances from a towed aerial banner. In the old system the laser is pointed to a point in space for the lead expected in a typical gunnery run. The old system does not compensate for variations in g's, range, angular rates or attitude of the aircraft. The new system measures the ranges, angular rates, pipper location and calculates the actual lead required for a hit. An expert system will play back the sight picture and show where each round impacted (hit or missed) in the plane of the towed banner. The data, stored on a removeable RAM card ,will be transported to the ready room where it will be analyzed by an expert system software program in a PC.

The old LATAGS system only scored hits and misses and did not score where the round impacted if a miss occurred.

A tracker has been invented that has no moving parts. This allows better miniaturization and lower cost.

A single channel of the tracker system was successfully breadboarded.

A system patent was submitted.

Remaining problems are: breadboard the entire system, aircraft interface and further minimization of the equipment size.

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