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LASER HELICOPTER GUNNER TRAINER

Physical Sciences Laboratory
Naval Training Equipment Center
Orlando, Florida 32813

January 1976

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NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

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January 1976

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The objective of this effort was to demonstrate the feasibility of using small, low power, visible lasers to simulate weapon effect and tracers in a simulation system to train gunners in automatic weapon, direct fire techniques. The simulation of targets and background consists of a wide angle motion picture display. The trainee shoots from a simulated helicopter gun station. Laser produced spots on the display screen simulate incendiary hits and

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DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) tracers with appropriate time of flight, windage and ballistic drop. The position of the spots on the screen is controlled by mirror deflection systems which are controlled indirectly by the weapon position and the simulated time-of-flight. Training potential evaluation by Marine Corps personnel from The Aerial Gunnery School, New River, indicates that the system concept is a valid training tool to supplement or enhance current gunnery training.

PREFACE

This report describes the latest project in an on-going research effort which has previously led to the development of Device M-55 Laser Tank Gunner Trainer, Direct Fire Artillery Trainer, and a feasibility model of a Direct Fire Machinegun Simulator.

The assistance of the following personnel and organizations involved in the design and development of the feasibility model of the Laser Helicopter Gunnery Trainer is greatly appreciated.

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SECTION I

INTRODUCTION

The Laser Helicopter Door Gunner Trainer is a feasibility model of a training system which demonstrates a unique concept for training gunners to fire from a moving platform. This concept employs laser simulation of incendiary hit impacts and tracers, together with a wide angle motion picture display of targets and background, to train a gunner in proper observation methods, target acquisition, firing procedures, and fire correction procedures. Although the concept is applicable to a variety of situations, this development effort was directed toward satisfying an informal requirement for training Marine Corps helicopter door gunners.

This report will describe the requirement, the development of systems concepts, the system design, fabrication of the feasibility model, test and evaluation of the engineering feasibility model, and a training potential evaluation by Marine gunnery instructors.

SECTION II

STATEMENT OF THE PROBLEM

Current training of door gunners consists of several hours of classroom instruction followed by live-fire training flights. Due to curtailment of flying time and decreased availability of ordnance personnel and cleared ranges, there is a requirement for a training system to supplement or enhance the current training. This system should exercise the trainee in the various skills required of the door gunner during operational missions. The system should be a complete simulation system, rather than a weapon simulator, to reduce operational equipment needs such as aircraft and weapons.

Visits to the Marine Corps Air Station (MCAS), New River, North Carolina, were made to observe the classroom training and live-fire training flights conducted by the Aerial Gunnery School. The pertinent characteristics of the syllabus as applied to simulation system requirements were analyzed in terms of environment, mission, platform, target engagement, field of fire, and weapon systems. These are discussed below.

ENVIRONMENT

The trainee is in the noisy, vibrating and undulating environment typically associated with a helicopter. He is wearing a flight helmet and communicates with other crew members via a helmet intercom. He is stationed at a side window, looking out 90° with respect to the aircraft's forward direction. He is taught to concentrate his attention on certain terrain features which have high probability of concealing hostile weapons. An effective training system should include such terrain features as treelines, ridges, stream banks, roads, junctions, and manmade structures in the background scene. The helicopter platform simulation should generally resemble the aircraft interior.

MISSION

The door gunner's mission is primarily defensive. Most of the time, he will return fire on targets that are firing at his aircraft. Depending on how well hidden the enemy is, the hostile fire is usually visible as muzzle flashes. The ambient noise level in the aircraft is high, tending to mask sounds of hostile fire including some hits. The targets of most importance are those that have the greatest threat which, in general, comes from targets at the short-to-medium ranges of 100 to 1000 meters. In figure 1, a geometric description of the elevation angles required for line of sight to targets at various ranges for an aircraft flying level at 100 meters altitude above flat terrain. As can be seen in figure 1, the line of sight varies from 97° to 117° for ranges from 800 to 200 meters. All elevation angles are measured from vertical.

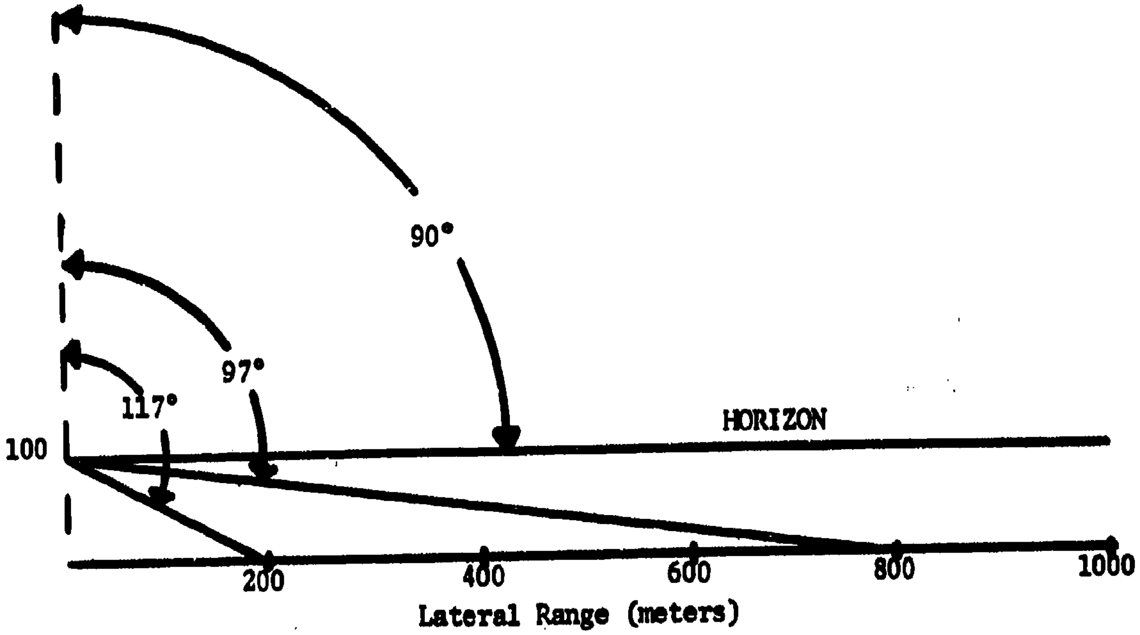

Figure 1. Line of sight elevation angles for 100 meter altitude

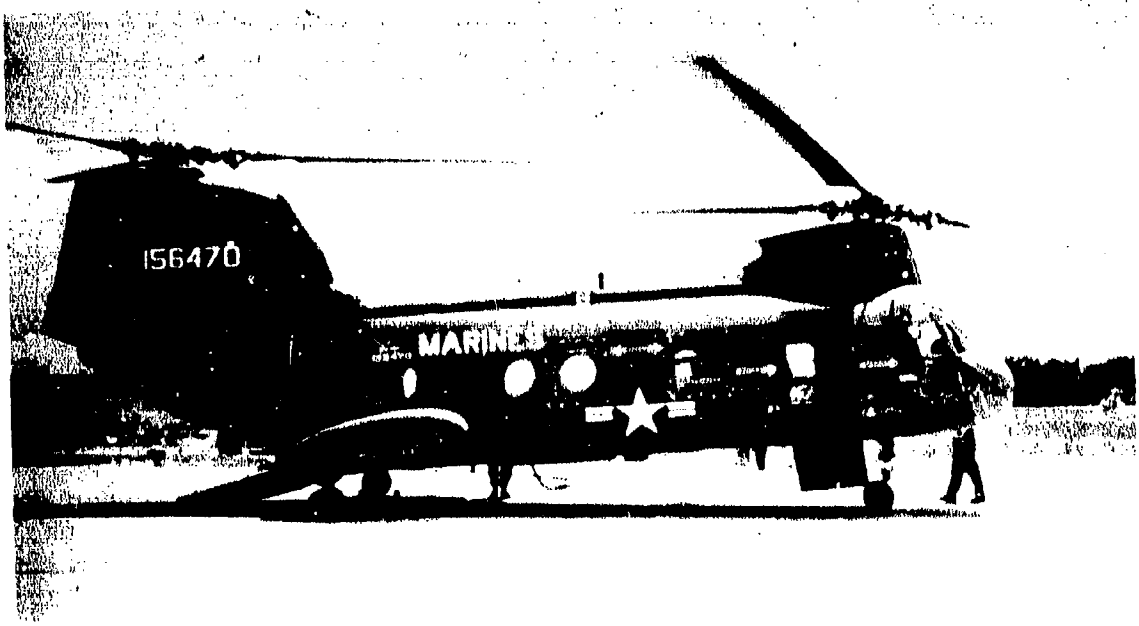

Figure 2. CH - 46 Helicopter

PLATFORM

The gunner's firing platform is a CH-46 aircraft. Figure 2 is a photograph of the aircraft. It is approximately 14 meters long and 5 meters high at the top of the tail section. On a typical mission, it will cruise at an airspeed of 40-50 meters/second (80-100 knots) at an altitude of 10-200 meters.

TARGET ENGAGEMENT

When the gunner sees muzzle flashes, he tells the pilot, who then takes evasive action. Meanwhile, the gunner directs fire at the target. He usually does not "aim," in the ordinary sense of sighting down the barrel, but uses the visual cues of ground effect or tracers to correct fire and bring it to bear on the target. Ground effect can consist of incendiary hit impacts, if the surface hit is hard, or may consist of kicked up dust, broken branches, or splashes in water. The incendiary hits are visible as small flashes of light. The tracers are visible as small points of red light which extinguish at impact. In daylight, the tracers from the M-60 (7.62mm) machine gun are almost invisible. The tracers from the M-2 (.50 caliber) machine gun are easily visible in daylight.

FIELD OF FIRE

The field of fire of the weapon is limited by stops on the pivoted swivel mount. In the right window (visible in figure 2) the field of fire is 28° to 155° (forward direction is 0° azimuth) in azimuth and 85° to 141° in elevation. The field of the left window is 309° to 226° in azimuth and 85° to 134° in elevation. The field parameters of the left window were chosen for the simulation problem since it has a smaller field of view and, therefore, less time is available to fire at a target making hits more difficult to obtain. The field of view available to the gunner at any one time is called the instantaneous field of view. When the gunner is in firing position, his eyepoint is approximately 1 meter from the pivot point of the weapon on a line passing approximately 10 cm above the pivot parallel to the weapon barrel. Figure 3 shows the approximate geometry in the vertical plane together with the instantaneous field of view at the two extremes of weapon motion. Figure 3 shows that the instantaneous field of view in the vertical plane varies from about 25°, when the weapon is at its greatest depression angle, to about 33°, when the weapon is elevated to its highest position. The total field available for the gunner to see is approximately 78°. This includes about 21° above the horizon which is essentially featureless sky and about 13° of field which is visible but depressed more than the greatest depression angle of the weapon. Figure 4 shows similar parameters for the horizontal plane. The instantaneous field of view varies from a maximum of 33° when the trainee is viewing straight out the window to 22° when he is viewing forward and 30° when he is looking aft. The total field available in the horizontal plane is 103°. Both figures 3 and 4 show parameters of a left window.

WEAPON SYSTEMS

The weapons which can be mounted in the aircraft are M-2 (.50 caliber) machine guns and M-60 (7.62mm) machine guns. The pertinent characteristics of the M-2 are listed in table 1 and of the M-60 are listed in table 2. The impact point of a bullet fired from a moving platform is influenced by many factors. These include: muzzle velocity; size, shape, and weight of bullet; aiming line or line of sight; speed and direction of moving platform; gravity; wind speed and direction; velocity drop due to air resistance; and location of moving platform with respect to location of target.

In operation, the weapon is pointed at the target and small corrections usually described in "mils" (1 mil = 1/6400 of a circle) are made to aim the weapon off the direct line of sight.

The two factors which have the greatest effect on aiming in azimuth from a moving helicopter are the effect of the helicopter forward motion and the effect of the relative wind due to the helicopter motion. At the relatively short to medium ranges of 100 to 1000 meters and the relatively slow airspeeds of 40 to 50 meters/second the predominat effect is the forward motion. Figure 5 shows the factors to be considered when aiming in azimuth. The forward motion of the aircraft causes the projectile to have a velocity componentin the 0° azimuth direction. If there were no air the weapon would have to be aimed behind the target (in direction indicated by aim line (motion only) in figure 5. If the aircraft were stationary and there was a wind blowing from the 0° azimuth direction, the weapon would have to be aimed in front of the target. Since the aircraft is moving in air, there is an effective wind blowing and both effects must be considered and the correct aim line is the sum of the two corrections. Values of the two corrections and the total correction required are given in table 3.

Note that the greatest effect occurs when firing straight out at 90° azimuth and amounts to approximately 20 meters at 500 meters actual and 25 meters at 500 meters with no wind. This implies that for short to medium ranges simulation of lateral drift due to forward velocity may be sufficient and that windage effects which become important at the longer ranges may be ignored at the ranges of most interest.

Aiming in elevation is primarily effected by the ballistic effect of gravity. Table 4 shows the elevation angle corrections necessary at various ranges. Note that the maximum correction is 7 mils at 1000 meters. Again, like the wind effect this is probably small enough to be ignored for this type of training.

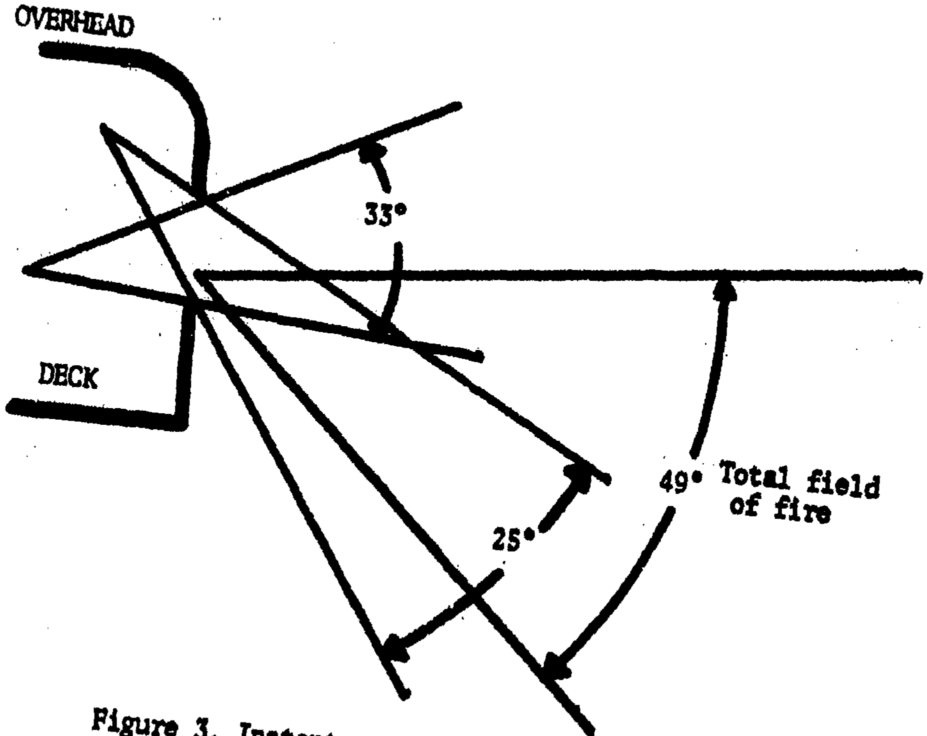

Figure 3. Instantaneous field of view: Vertical

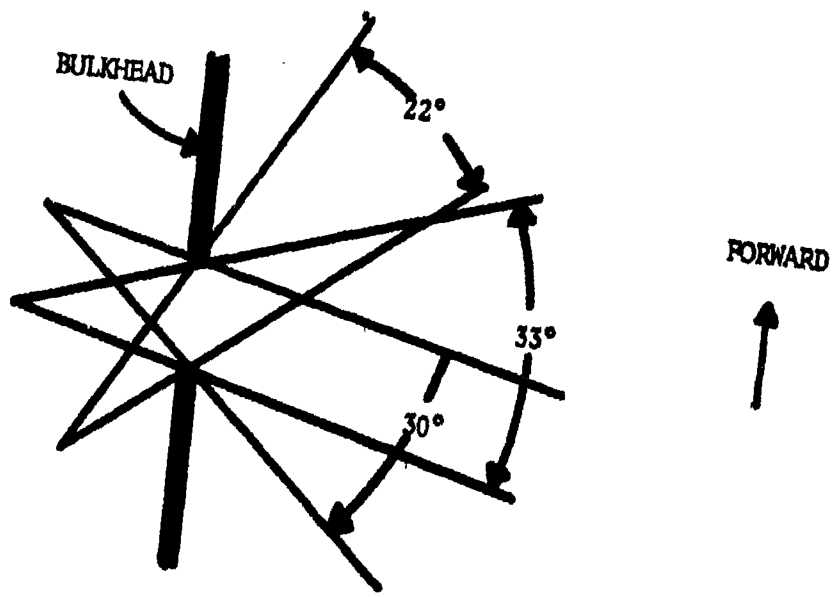

Figure 4. Instantaneous field of view: Horizontal

TABLE 1. CHARACTERISTICS OF M-2 (.50 CALIBER) MACHINEGUN

Description:	Belt Fed Recoil Operated Air Cooled
Data:	
Weight	37 kg (82 lb)
Length	1.6 m (65 in)
Maximum Range (Ball)	6.7 km (7400 yd)
Maximum Effective Range	1.8 km (2000 yd)
Tracer Burnout	300-1750 m
Muzzle Velocity	900 m/s
CyclicRate of Fire	450-500 rounds/minute

TABLE 2. CHARACTERISTICS OF M-60 (7.62 mm) MACHINEGUN

Description:	Belt Fed Gas Operated Air Cooled
Data:	
Weight	10 kg (23 lb)
Length	1.1 m (43 in)
Maximum Range	3.7 km (4000 yd)
Maximum Effective Range	1.1 km (1200 yd)
Tracer Burnout	900 m
Muzzle Velocity	850 m/s
Cyclic Rate of Fire	550 rounds/minute

TABLE 3. AZIMUTH CORRECTIONS FOR 40 m/s AIRSPEED

Range (meters)	Aim Azimuth (degrees)	Motion Correction (mils)	Wind Correction (mils)	Total Correction (mils)
	45	+35	- 2	+33
200	90	+50	- 3	+47
	135	+35	- 2	+33
	45	+34	- 3	+31
400	90	+49	- 5	+44
	135	+34	- 3	+31
	45	+34	- 5	+29
600	90	+49	-10	+39
	135	+34	- 5	+29
	45	+34	- 6	+28
800	90	+48	-12	+36
	135	+34	- 6	+26

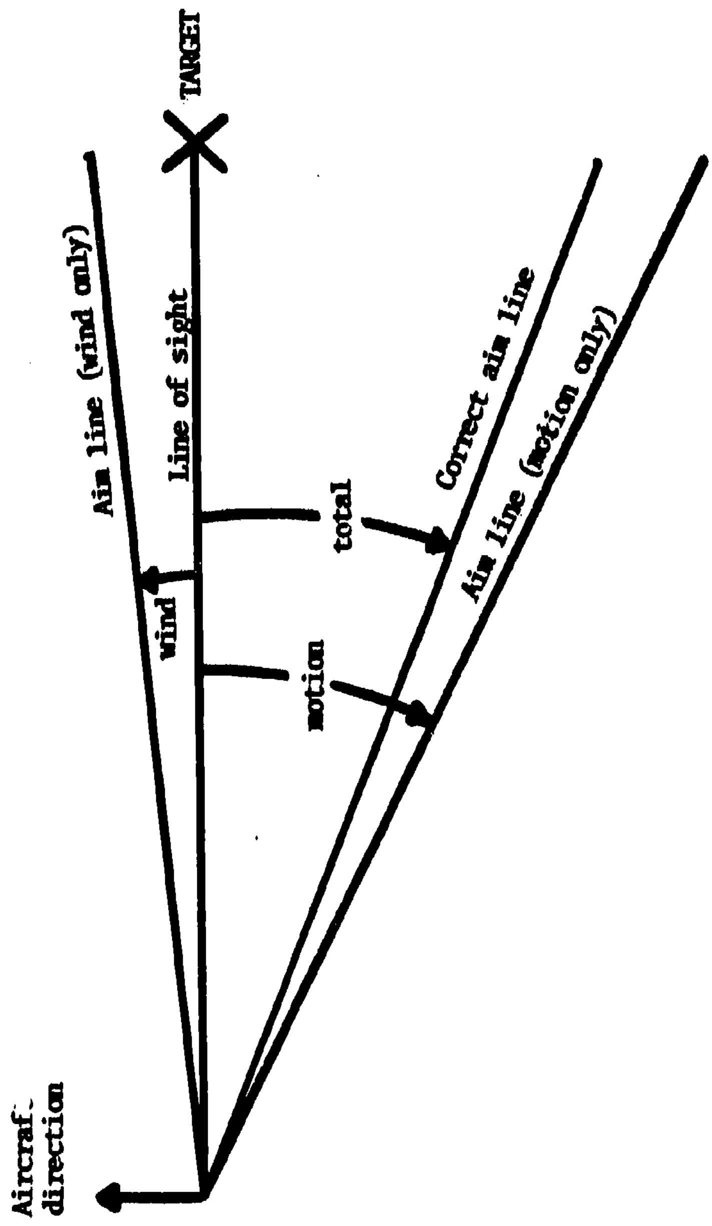

Figure 5. Azimuth correction

TABLE 4. ELEVATION AIM CORRECTIONS

Range (meters)	Elevation Angle (mils)
200	1
400	2
600	4
800	6
1000	7

SECTION III

DESIGN APPROACH

INTRODUCTION

The technology of simulating weapon fire by lasers has been developed and demonstrated for a variety of direct fire training systems at NAVTRAEQUIPCEN. The weapon fire simulation in these systems consists of using a shuttered-small, low-power, eye-safe, helium-neon laser to produce a red spot of laser light on a target at the point a projectile would have hit had an actual round been fired. Essentially, this technique provides immediate, visible feedback to the trainee and instructor as to how well the weapon was aimed when the trigger was pulled. The success of this training technology in other direct fire training problems led to its implementation in the helicopter gunner situation.

SYSTEM CONCEPT

The basic concept is to simulate tracers and ground effect by small spots of projected laser light. Simulation without operational aircraft or weapons requires a visual display which should be dynamic and contain both targets and background. The simulated motion of the aircraft requires some trajectory simulation and a time of flight delay between trigger squeeze and hits. The trainee is shooting down most of the time which dictates a platform fairly high off the ground for a display screen of reasonable size. Figure 6 depicts the general layout of the system concept. The trainee stands within an enclosure which simulates the moving aircraft interior environment. Through his window he observes the simulated real world on a wide viewing screen. His weapon is mounted in the window and is capable of pivoting in elevation and azimuth. He observes targets which are in the simulated passing terrain and engages them. When he activates the trigger the weapon fire simulation system causes spots of laser light to appear on the display screen at positions corresponding to where tracers and incendiary hits would have been observed had actual rounds been fired at real world targets.

SUBSYSTEMS PRIORITIES

The general system concept was divided into several component subsystems and the requirements and efforts were adjusted based on priorities, manpower estimates, and equipment costs. The laser simulation of weapon firing from a moving platform was given first priority since this was the prime purpose of the project. The display was given second priority since wide angle motion picture displays are common to many types of visual simulation and such a display is not a unique requirement. Third priority

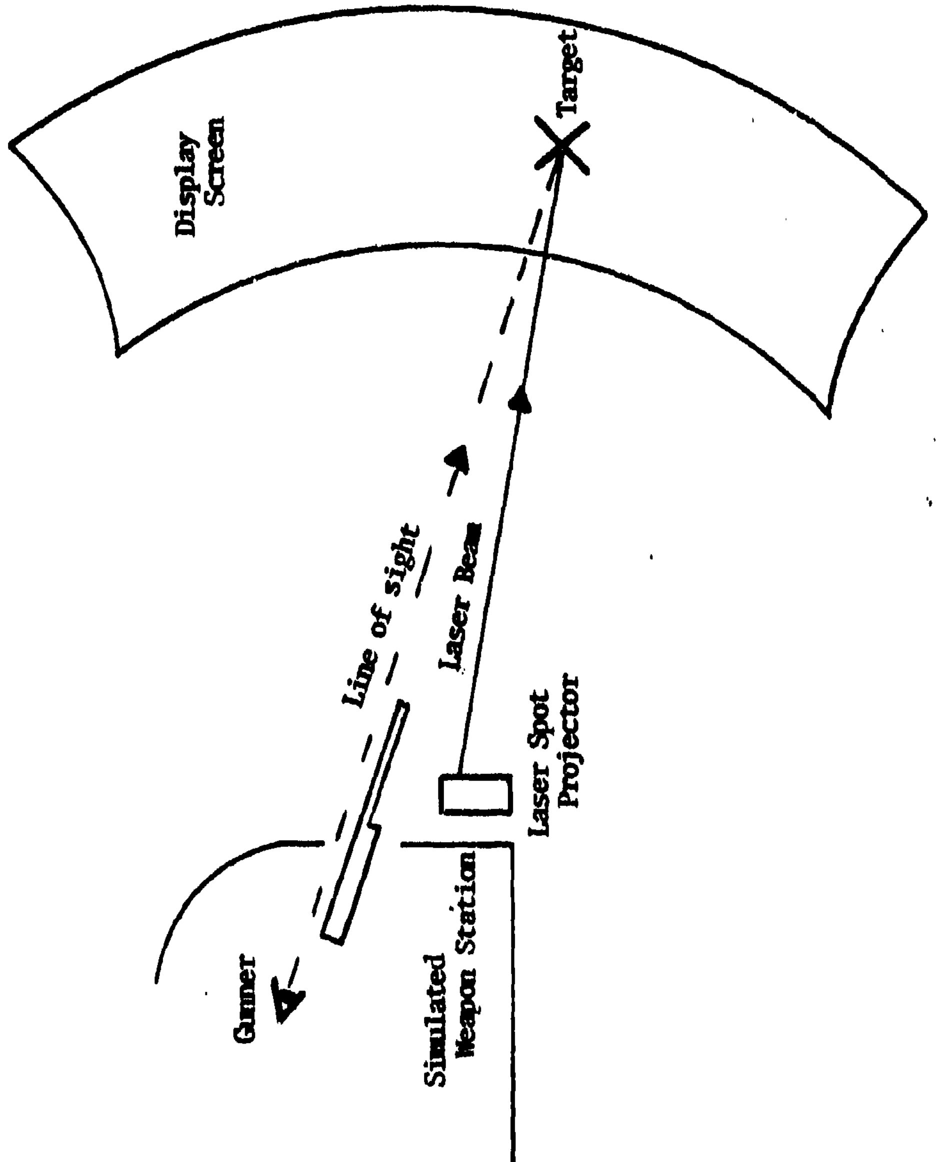

Figure 6. System concept

was assigned to the platform simulation since accurate simulation of the motion and interior of the helicopter does not play an important role in the skills to be taught in the training system.

LASER WEAPON EFFECT SIMULATION

The prime skill the gunner must be taught is to observe tracers and ground effect and correct his fire into the target. The helium neon laser can simulate tracers as small red spots of relatively long duration and can simulate ground effect, limited to incendiary hits, by a series of short bursts or spots of red light. The limitation to incendiary hit simulation is not considered significant since ground effect lets the trainee know where his rounds are hitting, and the means for letting him know should have little effect on his proficiency. Previous development of this technology was implemented by having the laser affixed directly to the weapon. This means of simulation would not be applicable to the helicopter gunner problem due to the requirement for a simulated moving platform. Fixed deflection with respect to line of sight, which can be accomplished with the laser mechanically attached to the weapon, does require the trainee to lead and superelevate. However, the time of flight of the projectile is not taken into consideration in this case and the fire correction procedures would be unrealistic. In order to simulate time of flight the laser weapon effect simulation cannot be mechanically coupled to the weapon.

The solution to the helicopter gunner's training problem proposed in this concept is to use mirror deflection techniques to position the laser spots at the proper screen locations and to control the mirror deflection by the angular positions of the weapon. The electronic control of the mirror deflectors and laser shutters allows manipulation of laser spot position as required by the system without mechanical coupling between the lasers and the weapon.

TRACER SIMULATION. The characteristic properties of the tracer important to the simulation are:

a. The tracer spot appears instantaneously with the discharge of a tracer round from the weapon.

b. The time duration, or length of time the tracer spot exists after firing, is equal to the time it takes the round to reach the ground in the direction fired.

c. The motion of the tracer spot in the horizontal plane is approximately equal to the lateral speed of the aircraft.

d. The ballistic drop due to gravity at the ranges of interest is negligible.

These characteristics lead to the following requirements on the tracer deflection system:

When a simulated tracer round is fired the tracer shutter opens and allows a laser beam to enter the tracer deflection system. This system projects the laser spot onto the screen at the point on the screen which intersects the line of aim. At the same time the tracer deflection system is decoupled from the weapon so that no motion of the weapon can affect the "flight" of the tracer. The tracer spot stays stationary with respect to the screen. Consequently, it appears to be moving laterally with respect to the target in the projected motion picture display. After a time duration equal to the time of flight at the range to the target, the shutter closes, the spot disappears, and the tracer deflection system returns to the coupled state with the line of aim of the weapon.

To prevent the problem of simultaneously simulating two tracers a tradeoff must be made between time-of-flight and tracer frequency. This was chosen to be a maximum tracer duration, or time-of-flight, of one second representing a maximum range of approximately 800 meters and a corresponding tracer frequency of one per second. This limits the tracers to approximately one-round-in-eight assuming a normal firing rate of 450-500 rounds/minute. The weapon mount fields of fire characteristics are such that a horizontal range of approximately 100 meters is minimum. This corresponds to a time-of-flight of approximately 0.2 seconds for an altitude of 100 meters.

The characteristics required of the tracer system may be summarized as follows:

The shutter must open when a tracer round is fired and stay open for a time varying from 0.2 to 1.0 seconds depending on the range to target. The tracer deflection system must be capable of tracking the weapon over its entire field-of-fire and holding on a fixed point on the screen when a tracer is in flight. The entire sequence must be repeated at a one per second rate when the weapon trigger is continuously activated.

HIT SIMULATION. The characteristics of incendiary hits pertinent to the simulation are:

a. The incendiary hit appears as a small red spot on the ground at an instant incorporating a time of flight delay after an incendiary round is fired.

b. The position of the spot in the horizontal direction is primarily affected by the lateral speed of the aircraft at the short to medium ranges (up to 800 meters).

c. The effect of relative wind is negligible at short ranges.

d. The elevation position deflection due to gravity effects is negligible.

These characteristics lead to the following requirements for the hit deflection system:

(1) The laser hit deflection system must continuously point to the spot on the screen at which the weapon was pointing incorporating a time of flight delay before the round appears on the screen. In other words, the line of aim of the laser follows the line of aim of the weapon delayed by a time-of-flight duration.

(2) The angular coverage of the hit indication deflection system must be at least equal to the field of fire of the weapon.

(3) The shutter must serve two functions. It must open at a delayed time after the trigger is depressed and close at a delayed time after the trigger is released. The shutter must also repetitively shutter the laser at approximately the cyclic rate of fire of the weapon in order to produce a spot on the screen for each incendiary round (assumed to be every round). In order to simplify the shutter design, the two functions will be performed by two shutter systems. One shutter will perform the repetitive function to break up the continuous laser beam into individual spots and the other to allow the broken up beam to proceed to the hit deflection system. In this simulation as in the tracer simulation, the small effects of relative wind and gravity drop can be neglected since the trainee does not sight down the barrel of the weapon but essentially "shoots from the hip" and corrects his fire by watching tracers and hits. The small discrepancies introduced by the inaccurate trajectory simulation are negligible when this method of fire is used. The time of flight simulation cannot be neglected since there must be a realistic delay in ground effect in order for realistic fire correction techniques to be taught. The delay also results in the requirement for the gunner to compensate for his simulated motion, which is the major correction factor in the real world.

DISPLAY

Since the gunner does not control the flight of the aircraft, he plays a passive role in observing the passing terrain. This allows a programmed or canned simulation of the aircraft's flight path and speed to be used in the training system. The concept employed in this system is to record a motion picture from the side window of a moving helicopter. The resultant motion picture is then played back to the trainee in the simulator. The choice of background and targets contained in the motion picture is discussed in the next section.

ENVIRONMENT

The trainee should have the feel of being in a helicopter. Some simulation of a gun station inside a helicopter together with a weapon mounted in a window is necessary. Simulation of the helicopter motion (other than visual) would be interesting but probably of little relative importance for the training of gunners. The vibration of the helicopter, however, does have an effect on ability of the gunner to track evenly. The rotor induced vibration should be simulated to some degree. Weapon noise and recoil simulation was reduced to a requirement for noise simulation only, since the complex effect of recoil on the pivoted weapon is difficult to simulate accurately.

SECTION IV

EXPERIMENT

The design approach described in the previous section indicated several problem areas and trade-offs to be made before fabrication would commence. The investigations into these areas are developed in this section. These will be discussed in the system classification scheme outlined in the previous section but not necessarily in the order of priorities.

DISPLAY SYSTEM

The design approach calls for a wide angle motion picture display containing a view of passing terrain as seen from the side door of a flying helicopter. The display should contain targets which the trainee can see and engage. The field of view should be approximately $83^{\circ} \times 49^{\circ}$.

As previously noted the display was given a low priority and was to be accomplished at low cost. Based on this, the decision was made to use existing laboratory equipment and in-house personnel to make the motion picture. The same reason led to the decision to insert targets by animation techniques rather than coordinate a major motion picture production involving substantial use of military personnel, equipment, time, and expense. The display requirement was then resolved into the following problem areas and solutions:

FORMAT - The choice of motion picture film format involves several trade-offs. Motion picture film is commonly available in 8mm, 16mm, 35mm and 70mm. The large formats have capability of recording more information than the small formats. However, the expense of the equipment necessary for recording and projecting the large formats is much more than the expense of the small format equipment. The dimensions of recorded image size for the commonly used film formats are given in table 5. Since the amount of information projected in the vicual display is directly proportional to the format area, the last column of table 5 indicates the relative value to be considered in the trade-off. The relative accessibility of 16mm filming and projection equipment and the relatively low priority of the display led to the selection of 16mm format.

FILM - Choosing the type of film to utilize in making the motion picture was based on several considerations: The display should be in full color; it should be as high a resolution as possible; it should be relatively low noise, and it should be readily available. These considerations led to the selection of a commercially available color transparency film. This film has an inherent resolution capability of approximately 100-125 lines/mm. Combining the resolution capability with the projected format size of a 16mm frame leads to an image having approximately 1000 hori-

TABLE 5. PROJECTION FORMATS

Film type	Film width (mm)	Perforation pitch (mm)	Format width (mm)	Format height (mm)	Format area (mm^2)
8mm cine	7.98	3.81	4.37	3.28	14.3
Super-8	7.98	4.23	5.36	4.01	21.5
16mm cine	15.95	7.62	9.65	7.21	69.6
35mm cine	34.98	4.75	20.95	15.24	319
70mm cine	69.95	-	48.56	22.1	1073

TABLE 6. LENSES AND FIELDS

	Focal length (mm)	Projected field angle	
		Azimuth (degrees)	Elevation (degrees)
Telephoto	75	7.5	5.5
Normal	25	22	16.5
Wide	10	51.5	40
Extra-wide	6	79	63

zontal by 750 vertical resolution elements. Of course, this inherent capability would only be realized if the lens used to produce the image were of sufficient quality.

CAMERA - A 16mm cine-camera was available in-house. A constant speed electric camera drive and a 120 meter magazine with motorized take-up was purchased to give the capability of shooting long, uninterrupted sequences without rewinding or reloading. One-hundred twenty meters of film at 24 frames/sec corresponds to approximately 11 minutes running time. Additional camera accessories needed included a battery pack to drive the camera and take-up motors, a changing bag to reload the magazine, and a shoulder-harness mount to stabilize the camera.

CAMERA MOUNT - The problem of stabilizing the camera against the vibration of the flying helicopter was apparent as soon as an actual helicopter ride was experienced. Just how much stabilization was required became the next question. When considering the effect of camera vibration on image blur it is immediately apparent that when long focal length, telephoto lenses are used the vibration effect is severe, while with short focal length, wide angle lenses the effect of vibration is small. To quantify this effect with respect to the vibration of the helicopter, the experimental footage was shot from the helicopter with lenses of varying focal length. This footage was then subjectively evaluated from the standpoint of acceptable or unacceptable image vibration. As expected the short focal length lenses produced acceptable image quality. The lenses evaluated in this way had focal lengths and field angles as listed in table 6.

The relation between camera motion and its effect on the image can be understood by considering a small angular excursion of the camera induced by the vibration of the helicopter. For example, consider a 0.55° excursion in the vertical direction; with the 75mm lens the image would shift an amount equal to 10% of the total frame height; with the 6mm lens the shift would only be 0.88% of the frame height. Other factors to consider are the additional problems introduced when multiple cameras and projectors are used. These include synchronization, edge matching, alignment, etc. For these reasons, a single, wide-angle lens was chosen and complex vibration stabilization was not used for this feasibility demonstration. However, for comfort in supporting the camera during shooting a shoulder harness mount was obtained.

LENS - The requirement called for a 83° x 49° display. By utilizing the projected format of the 6mm, wide-angle lens and a slightly shorter focal length projection lens this requirement could be met. The perspective distortion generated by viewing a 79° x 63° piece of the real world spread out over a slightly larger display field is minimal especially when compared to the perspective distortions introduced in the projected display. The resolution capabilities of the wide-angle lens are discussed in section VI.

MOTION PICTURE - Approximately 840 meters (7 magazine loads) of film were shot from the side window of a moving helicopter using the camera, accessory equipment, film, and lens discussed previously. The pilot was instructed to fly at speeds of 40-50 meters/second and at an altitude of approximately 100 meters. He was also told to take evasive action on command of the cinematographer. The flight area spanned the North Carolina coast including such terrain features as shorelines, rivers, roads, coastal plains with islands, wooded sections, farms, houses and open water with boats. The camera was sighted with the center of the field approximately 20° down from horizontal and normal to the flight direction. This was accomplished by placing a horizon reference line on the reticle in the camera reflex viewing system. The camera was then kept as stationary as possible with respect to the helicopter body. The cinematographer filmed continuously and observed the passing terrain for potential target areas. When he saw a good potential target he waited until it was past the center of the field and then instructed the pilot to take evasive action.

FILM EDITING - The processed film was edited to approximately 160 meters. This was done by sujectively analyzing the processed film for best exposure and content. Unfortunately, the weather during the two days of shooting varied from heavy overcast to rain showers. This caused most of the film to be dull and colorless. However, enough acceptable film was available for the movie.

TARGET INSERTION - The original concept ideally envisioned groups of "actors" in the terrain to play the "enemy." As the helicopter flew over a planned course, the actors would fire blanks at the aircraft. This approach was abandoned when the extensive time, cost and logistics involved were computed. At a minimum the length of the course had to be 20 kilometers with men stationed one or two kilometers apart. The availability of the men, weapons, and transportation would be difficult to coordinate. Also, the visibility of the muzzle flashes, when synchronization with the camera was considered, as well as light level, was an unknown.

Since targets were primarily muzzle flashes, a technique of simulating muzzle flashes was developed. This technique involved punching small holes in the film. When projected, the small holes appeared to be bright spots which flashed on the display screen. The holes were punched manually using a film editor to locate target sites and then punching the hole while observing with a low power microscope. Although this technique provided a very crude simulation of enemy muzzle flashes, it had the advantage of not requiring a major film production effort. The evaluation of the muzzle flashes is included in section VI.

DISPLAY CONFIGURATION. The recorded film contains an image approximately 80° horizontal by 60° vertical, as seen from the pivot point of the weapon. The observer should always be watching the display along a line parallel to the barrel and slightly above it. The allowable motion of the weapon in the vertical plane is approximately 85° to 135° for a total of 50°. By choosing the film image to cover 80° to 140° a slight overlap is produced such that the trainee has some image available above and below his extreme aiming angles. The optimum display configuration is one in which the eyepoint of the observer is located right at the projection lens of the display. In this case the eye sees what the camera saw if the display screen is a sphere centered on the projector-eye position. This type of display configuration is possible in certain display system configuration is possible in certain display system configurations where head motion is restricted and there is no requirement for simulating weapons effects or wide angles. Any deviation from this optimum situation leads to perspective distortion.

Perspective distortion can be minimized by proper choice of projector-screen-observer configuration. The gunner's eye position and his angular field has already been fixed by previous assumptions. These parameters are illustrated in figure 7. The vertical field should fill the angular range and have the horizon line appearing at the eyepoint level on the screen.

The horizontal field of fire available to the trainee in the actual aircraft is 83°. Since the film image only contains 79° there will be no overlap if the displayed angular coverage is the same as the recorded angular coverage is the same as the recorded angular coverage. Since the actual case could not be simulated exactly, it was decided to have the simulator deviate in the field of fire capability from 53° forward to 30° aft in the actual aircraft to 40° forward and 40° aft in the simulator. This decision allowed the display system to be symmetrical in the horizontal plane if the projector and eyepoint are located along the same vertical line. This symmetry minimizes perspective distortion in the horizontal direction, which is the more critical since horizontal perspective distortions affect the apparent height, range, and speed of objects in the display as they move across the screen. For these reasons the projector was located on a vertical line with the eyepoint.

The mechanical dimensions of the weapon station and gun barrel add other constraints to the projector location. In addition, the maximum floor-to-ceiling height available was approximately 5 meters which imposed another restriction.

Projector Above Eyepoint - Location of the projector above the eyepoint was analyzed at the possible positions limited by the physical constraints of the projector, weapon station, and floor-to-ceiling height. When the projector is located as close as possible to the eyepoint, there was a

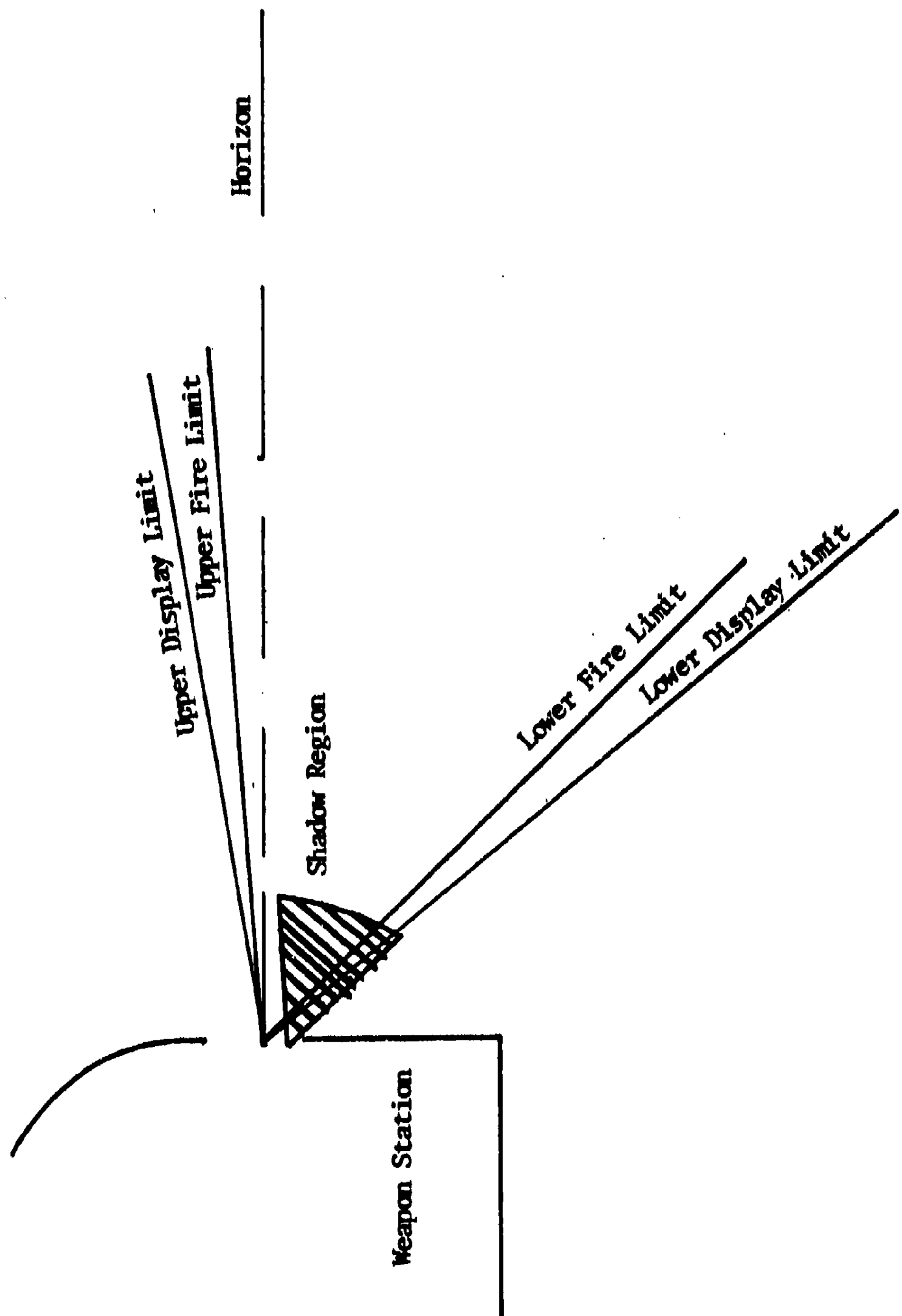

Figure 7. Gunner's field of fire: Elevation

tradeoff to be made between the amount of shadowing allowed and the distance to the screen. When the shadowing is restrocted to the lower 5° of the display, the distance to the screen exceeds 10 meters and the room height required is greater than 5 meters. If the shadowing is restricted to the lower 15° (one-third of the displayed terrain) the distance to the screen at the horizon from the eyepoint is approximately 4.5 meters, and the distance to the screen at the lower limit of display is approximately 1.5 meters. Therefore a fairly large display screen is required in any case. However, the second situation requires the trainee to look at the screen from almost edge on, which generates a significant amount of perspective distortion as well as the shadowing. These analyses as well as consideration of convenience of access to the projector led to the location of the projector below the eyepoint.

Projector Below Eyepoint - Analysis of various screen shapes and positions for the projector located as close as possible to the eyepoint on a vertical line through it led to the conclusion that minimum perspective distortion and maximum angle fidelity (angle fidelity is defined as maximum when the observer looks down at an angle and sees a point on the simulated terrain which was at that same angle when the movie was made) occur when the display screen is as large and as far away as possible. The screen should be spherical with the screen center of curvature at a point midway between the eyepoint and the projector. The floor-to-ceiling height limitation places a 5 meter radius limitation on the screen curvature. A minimum screen radius of 2.2 meters is imposed by a condition of barrel shadowing and severe perspective distortion at a smaller screen radius. A spherical screen having 3.8 meter radius was available in-house and was utilized for the final system. Although this screen is not optimum, it has the advantage of less display screen area which leads to a brighter display. This will be discussed below in the discussion of projector selection. Figure 8 shows the display configuration in a vertical plane utilizing the 3.8 meter radius spherical screen. This configuration has an angular fidelity within 1° deviation over most of the display range. The keystoning effect due to the projector and observer being located off center gives the observer a trapezoidal field having a width of approximately 110° at the top of the screen, 80° at the center, and 70° at the lower end of the display. The effect of this on the visual presentation is to make it appear as if objects in the foreground rise up slightly as the simulated terrain passes.

PROJECTOR - The projected display area is approximately 20 square meters. This is a large display area for 16mm motion picture projection. A commonly used minimum screen brightness specification is 10 foot-lamberts in the direction of the observer. For a perfectly diffusing screen, the incident lumens required to produce this screen brightness over an area of 20 square meters is 2000 lumens. Typical lumens-output of 16mm projectors (measured with open gate and shutter running) varies from 200 to

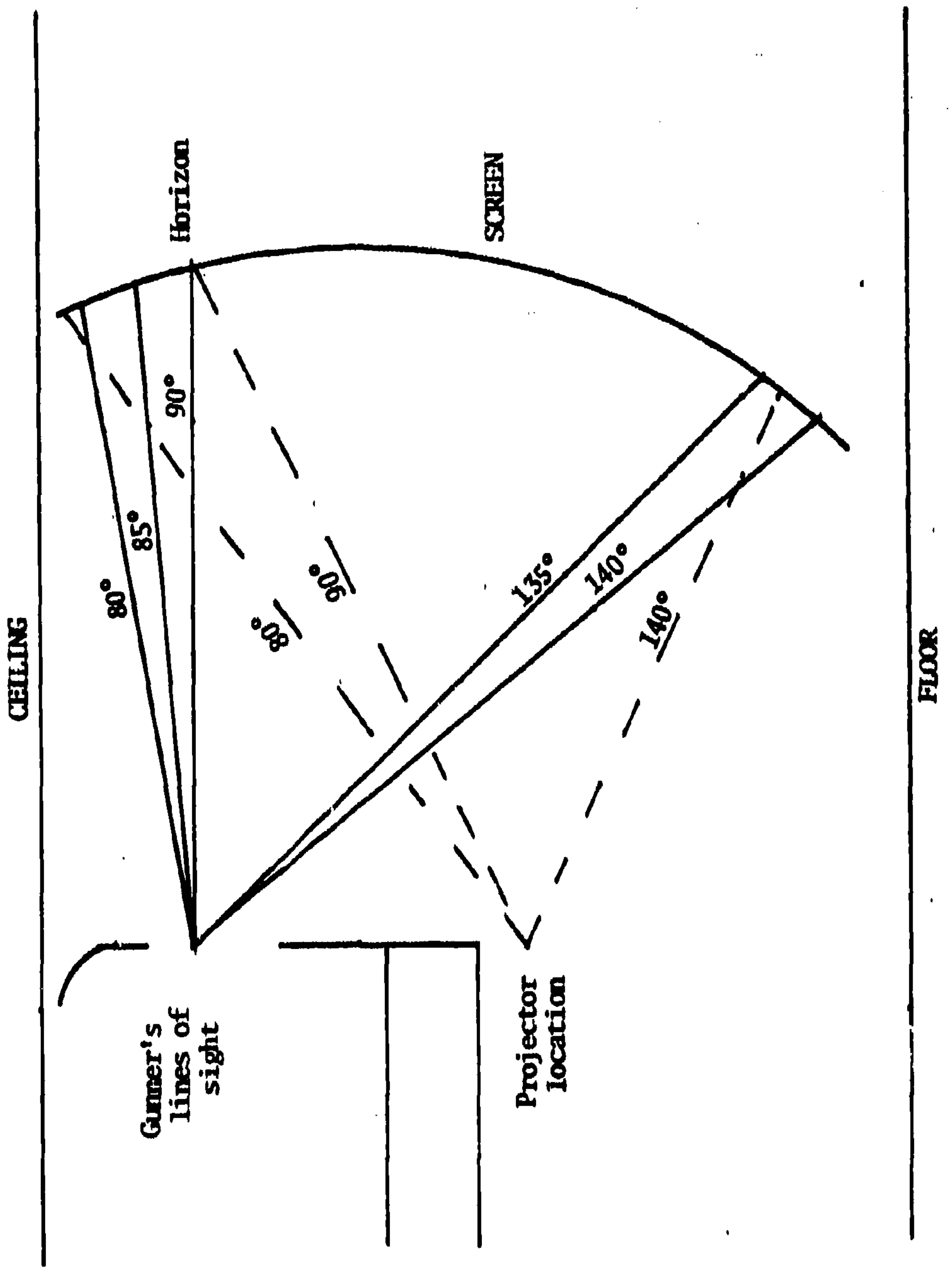

Figure 8. Display geometry

2500 lumens. Screen gain can improve the display brightness by as much as a factor of four over the brightness of a perfect diffuser with the same amount of projected light. Consideration as to the type of screen surface will be discussed in the screen paragraph below.

To remain as flexible as possible in obtaining sufficient brightness (a display can almost never be too bright) a 16mm projector having a specified lumen output of greater than 2000 lumens was purchased.

Another projector requirement was that it be capable of wide-angle projection. Available off-the-shelf 16mm projection lenses have a maximum horizontal projected field of 60° (corresponding to a focal length of approximately 9mm). An attempt was made to use the wide angle, 6mm, camera lens used for the filming as a projection lens. This lens was not mechanically compatible with any projector configuration. An attempt was made to rebuild a projector to accept the lens but the severe mechanical interference and shadowing problems led to another solution.

A commercially available f/1.4 lens having a focal length of 9.5mm was purchased. Experimentation with various available negative single element lenses led to the modification of the focal length to approximately 6mm.

The projector light level was specified using a f/1.2 aperture. Allowing for the difference in aperture and the use of uncoated supplemental optics, the expected light output was 1200-1500 lumens.

SCREEN - Since the shape, size, and position of the screen has been determined, only the surface quality of the screen remains to be investigated. As previously stated a perfectly diffusing screen is equally bright from all viewing directions. Assuming a projector output of 1200 to 1500 lumens and a screen area of 20 square meters the screen luminance would be 6.0 - 7.5 foot-lamberts. Therefore, some screen gain in the direction of the observer is required to meet the minimum screen luminance goal of 10 foot-lamberts.

The configuration of the projector, eyepoint, and screen is such that the light in a vertical plane should be specularly reflected, while the light in a horizontal plane should be retroreflected. An aluminized-lenticular screen with the lentils oriented in a vertical direction has these properties. Typical gain values for such screens are 3 in the specular direction and 2 in the retrodirective direction. A screen of this type should allow a display brightness 12-15 foot-lamberts with the projector and lens discussed above.

SCAN GEOMETRY. The purpose of the laser scanning systems is to put the laser spots on the display screen at the point where an actual round would have hit. In order to demonstrate feasibility, correction factors for gravity drop and windage were omitted although these factors are relatively easy to incorporate. Thus the laser spot ideally will appear at a spot on the screen directly along the gunner's line of aim (if he doesn't move the weapon during the time of flight). Unfortunately, the same type of perspective distortion problems arise for the laser scanning system as were discussed for the film projection system.

In the real world, the gunner sees the horizon as a flat line. Actually it is a circle with the gunner's eye at the center and in the same plane as the circle so it appears to be a straight line. If the gunner were to hold a fixed elevation and sweep the gun 360° in azimuth the rounds would impact the ground a fixed distance below the horizon. The locus of impact points is a circle of smaller radius than the horizon, but in this case the gunner's eyepoint is located directly above the center of the circle and he sees the impact points as falling on a curve. The impact points as the gunner sees them are plotted for various horizontal ranges in figure 9. The coordinate system is such that 90° elevation and 90° azimuth is straight out toward the horizon. Note that the greatest apparent curvature is at the shortest ranges. Also note that the field of fire in this coordinate system is approximately from 45° to 135° in azimuth and 80° to 140° in elevation. The point "o" in figure 9 is the observer's position. The observer is viewing in the direction indicated. This describes the situation in the real world.

In the simulation system the position of laser impact on the screen is determined by the deflection angles of the laser scanning system. If the deflection angles of the weapon are equal to the deflection angles of the laser scanner the simulated impact points can be computed from the display geometry.

Consider the scanner to be at the center of a four meter radius sphere. Let the azimuth scan vary from 45° to 135° as the weapon moves from 45° to 135° and let the scanner move from 66° to 126° elevation as the weapon moves from 80° to 140° elevation. The different scan range in elevation is to partially correct the parallax due to the observer's eyepoint being located above the scanner. Before describing the simulator scan lines as they appear from the observer's position the scan lines will be computed as they actually occur on the spherical surface.

The equations which determine the points of intersection of the laser beam and the screen for given deflection angles are:

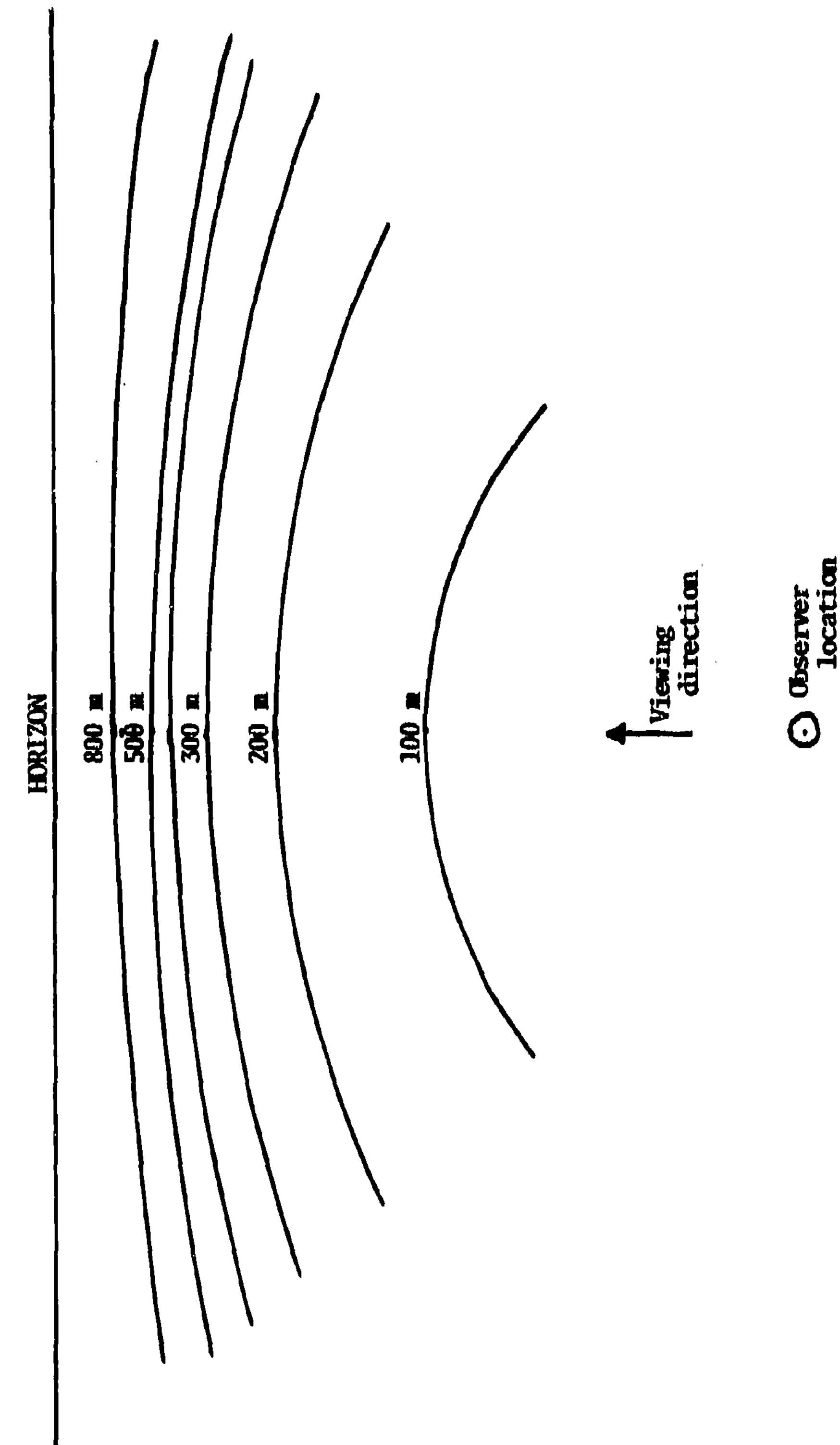

Figure 9. Impact curves

$$x = (\cos \alpha / \cos \gamma)\, z. \qquad (1)$$

$$y = (\cos \beta / \cos \gamma)\, z. \qquad (2)$$

$$z = (16 - x^2 + y^2)^{1/2}. \qquad (3)$$

In equations (1), (2), and (3) $\cos \alpha$, $\cos \beta$, and $\cos \gamma$ are the direction cosines of a line passing through the scanner and intersecting the spherical screen 4 meters away at the point (x, y, z). The coordinate system is pictured in figure 10. Note that the angle α is the azimuth deflection angle and β is the elevation deflection angle. The angle γ is determined by the identity relating direction cosines in equation (4).

$$\cos^2 \alpha + \cos^2 \beta + \cos^2 \gamma = 1 \quad (4)$$

Table 7 gives the (x, y, z) values for various sets of deflection angles. Note that for $\beta = 76^{\circ}$ the weapon elevation is approximately 90° or aimed at the horizon; for $\beta = 83^{\circ}$ the weapon is aimed at a point at a simulated range of approximately 800 meters ground range; for $\beta = 126^{\circ}$ the simulated range is approximately 100 meters.

The appearance of the scanned curves from the observer's position can now be computed from the position of the intercept points and the known position of the observer. Figure 11 shows the simulated impact points as compared to where actual impacts would have been with respect to an observer in the real world.

Note that the curvature of the fixed elevation scan lines in the simulation system approximate the fixed elevation scan lines in the real world for the ranges of interest. The fixed azimuth scan lines depart from the real world situation in that the simulated scan lines appear to bow toward the 90° azimuth line.

Since most of the simulated firing on any particular target would occur as the target moved laterally across the field most of the scanning would be in azimuth with the elevation relatively constant. This situation led to the linear scan arrangement rather than trying to correct the scan discrepancy electronically.

PLATFORM

Implementation of the concept for the trainee's firing platform required the solution of several mechanical problems including the design of the weapon station mock up, design of a variable rate, variable amplitude platform vibration system, design of a weapon position readout system, obtaining a deactivated (for security reasons) M-2, .50 caliber machinegun, the design of a weapon noise simulator, and the design of a supporting

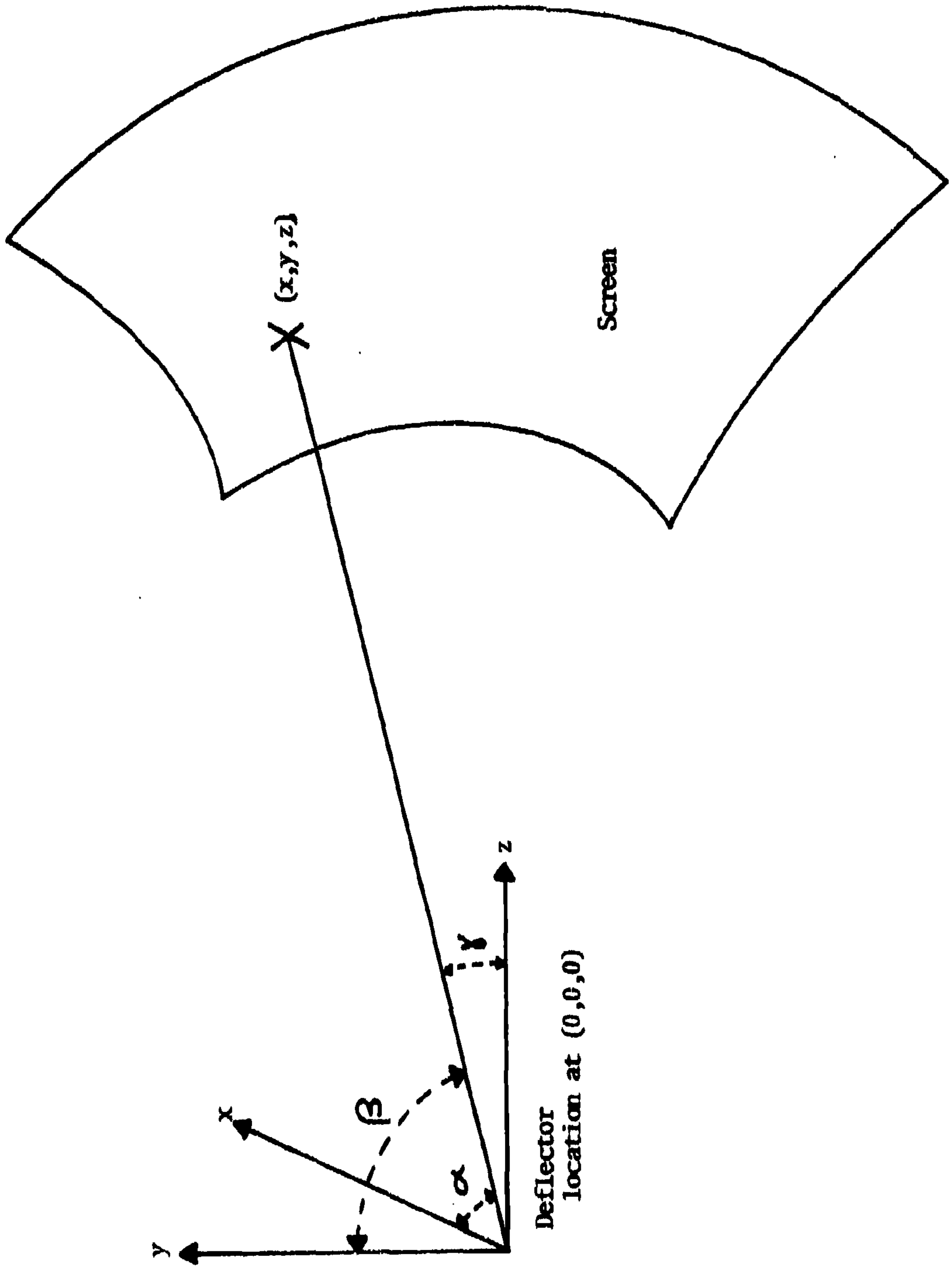

Figure 10. Coordinate system

TABLE 7. BEAM INTERCEPTS ON 4meter SPHERE

Deflection angles (degrees)			Intercept coordinates (meters)		
α	β	γ	x	y	z
45	66	55	2.83	1.63	2.32
45	76	48	2.83	0.97	2.66
45	83	46	2.83	0.49	2.78
45	126	67	2.83	-2.35	1.57
60	66	40	2.0	1.63	3.06
60	76	34	2.0	0.97	3.33
60	83	31	2.0	0.49	3.43
60	126	50	2.0	-2.35	2.54
75	66	29	1.04	1.63	3.51
75	76	21	1.04	0.97	3.74
75	83	17	1.04	0.49	3.83
75	126	40	1.04	-2.35	3.07
90	66	23	0	1.63	3.65
90	76	14	0	0.97	3.88
90	83	7	0	0.49	3.97
90	126	36	0	-2.35	3.24

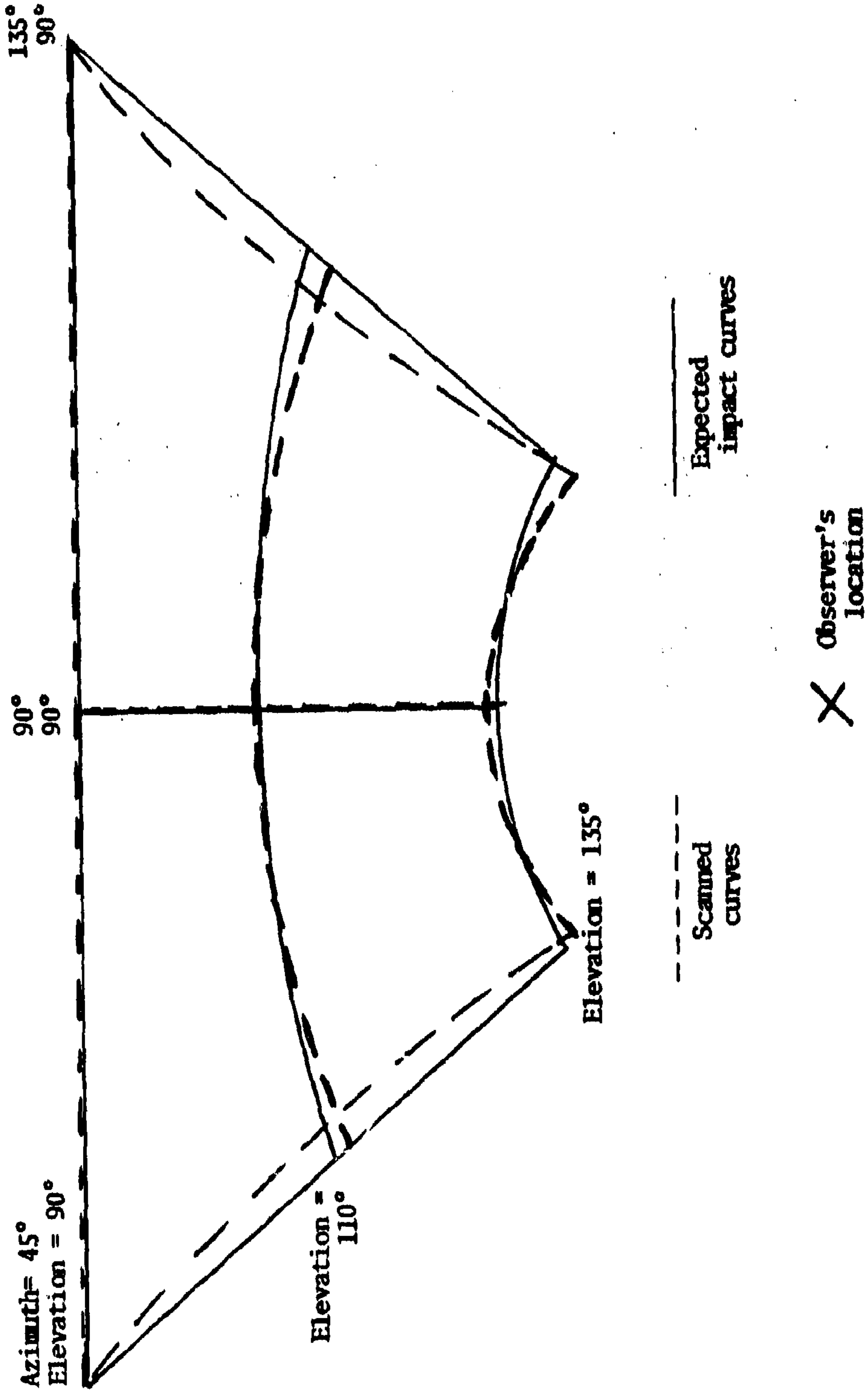

Figure 11. Comparison of expected impact curves and scanned curves

structure to meet the requirements of the display geometry outlined in the preceding paragraphs. Except for the vibration system the designs were relatively straightforward and required little experimentation. The designs are discussed in the following section. The platform vibration design involved some experiment and is discussed below.

PLATFORM VIBRATION - The vibration experienced by a door gunner is caused primarily by the helicopter rotors. It has a frequency of approximately 3 hertz and an amplitude which varies with the attitude of the aircraft. A vibration system was designed using a variable speed motor and an eccentric drive to oscillate the spring mounted weapon station. The amount of eccentricity and the frequency of vibration was then varied until the subjective feel of the vibration was considered right by laboratory personnel who had experienced actual flights. Unfortunately the consensus usually satisfied no one. The final system parameters are given in the next section.

LASER WEAPON EFFECT SIMULATION

LASERS. Helium-Neon Lasers have the capability of producing small, red spots of light on the display screen. This capability has been successfully utilized in other direct fire weapon simulation systems. The laser parameters of interest in this simulation will be discussed below.

<u>Spot Size</u>. Typical off-the-shelf, low power, He-Ne lasers have a beam diameter at the laser of approximately 10^{-3} meters and a beam divergence of approximately 10^{-3} radians. If the mirror deflectors do not change the beam divergence significantly, the predicted spot diameter on a screen, located 4 meters from the laser, would be $5x10^{-3}$ meters. This spot would subtend about 1 mil from the observer's position. A 1 mil spot is within the system resolution criteria already established by the display resolution. Therefore, no additional laser focusing optics are necessary and the laser beam can be used just as it comes from the laser.

<u>Spot Color</u>. The color of a He-Ne laser is a deep red, pure spectral line at a wavelength of 633 namometers. In actuality the color of tracers appear to be a more washedout red while incendiary hits are more yellow-orange.

<u>Spot Brightness</u>. The apparent brightness or luminance of the laser spot to the observer is a function of the laser power, luminous efficacy of the laser light, spot size, angle of incidence on the screen, screen gain in the direction of the observer, and time duration of the laser pulse. For a laser power of 0.4mw (see paragraph below on laser safety and Appendix A), the total luminous output of the laser is 6.4×10^{-2} lumens. The illuminance at the screen in a 5×10^{-3} meter diameter spot at normal incidence is then 3.3×10^{3} lumens/meter ^{2}. Since the laser deflection system

is near the center of the spherical screen, the angle of incidence is normal. For a screen having a gain of 2 in the direction of the observer the apparent spot luminance would be 6.6×10^2 foot lamberts for laser pulse durations in excess of the eye integration time of approximately 0.1 seconds. For laser pulses of shorter duration than 0.1 seconds the apparent luminance of the spot would be given by equation 5.

$$B_p = B_c t_p / 0.1 \qquad \text{for} \qquad t_p < 0.1 \text{ sec} \qquad (5)$$

In equation (5) the apparent luminance of the pulsed spot is B_p; the pulse duration is t_p and B_c is the continuous luminance for long pulse durations. This equation assumes that the laser power is constant for any pulse duration. Using equation 5, a pulse duration of 0.04 seconds, and a continuous brightness of 6.6×10^2 foot-lamberts the apparent spot brightness is found to be 2.6×10^2 foot-lamberts. The short pulse length corresponds to the duration of a single incendiary round as will be discussed below. Note that the tracer duration of 0.2 to 1.0 seconds always exceeds 0.1 seconds. Therefore, the predicted spot luminance of the tracer is 6.6×10^2 foot-lamberts and of the incendiary hits is 2.6×10^2 foot-lamberts. Both are well in excess of the desired display luminance of 10 foot-lamberts.

Laser Safety. The most common He-Ne lasers have a nominal 1.0 milliwatt output. Due to the laser safety considerations these can be easily filtered to the 0.4 milliwatt maximum described in Appendix A for direct intra-beam viewing for up to 10 seconds exposure.

Conclusions. Several 1 milliwatt lasers were purchased off-the-shelf, filtered to 0.4 milliwatts output and used as is, with no beam shaping optics.

DEFLECTION SYSTEMS. The wide field angle and relatively low rate required of the laser beam positioning mirrors led to the investigation of several alternative scanning techniques. All off-the-shelf laser scanner's are primarily directed toward small angles and fast rates. Most deflectors are designed for raster type scanning at fixed rates. The design goals and various types of scanning systems investigated are discussed below.

Scan Angle. The angular scan requirement for experimental purposes was set at 90° in azimuth and 60° in elevation.

Scan Rate. A subjective analysis of the maximum speed a gunner could maneuver his pivoted weapon led to a bandwidth requirement of 10 Hz.

Laser Scanner. The low scan rate requirement immediately suggests mechanical scanning as opposed to acousto-optical or electro-optical scanning system. Since the scan is not a raster scan, a fixed frequency mechanical scanner such as a torsional scanner or rotating mirror scanner is also unsuitable. The choice of scanning system was then narrowed to off-the-shelf galvanometer scanners and modifications of same; or any other electro-mechanical system which could rotate a small mirror to an angle linearly related to an input voltage signal.

Commercial Motor Laser Scanner. Off-the-shelf motor laser scanners have a maximum peak-to-peak mechanical rotation specified at 30°. Since a rotating mirror has an optical scan angle of double the mechanical scan angle, this gives a maximum optical scan of 60°. A 90° optical scan could be accomplished by mounting two scanners piggyback, i.e.; a scanner having 15° mechanical scan capability mounted on the shaft of a scanner having a 30° mechanical scan capability. The 60° elevation scan angle could then be accomplished by a single scanner. This was attempted with some degree of success. Commercial scanners and associated drivers were purchased. A two-axis mount having two scanners mounted piggyback for azimuth and one scanner for elevation was designed and fabricated in-house. The system was then tested with rather poor results. The primary problem appeared to be in the drivers. The laser spot could not hold position for more than a few seconds without blowing a fuse. Also the azimuth scan developed nonlinearities probably due to the piggyback mounting method. Rather than attempt to trace down the problems, alternative scanning schemes were investigated.

Servo Scanner. The slow rate requirement suggested a servo motor approach which had been implemented for scanning holograms in an unrelated effort. However, previous experience indicated this would be an expensive and time-consuming alternative even though proven reliable. This alternative was shelved in favor of the penmotor approach described below.

Penmotor Scanner. The penmotors used to convert voltage signals to pen positions in strip chart recorders have all the characteristics necessary for this laser scanning system. Several penmotors were purchased. Mirrors were mounted on the shafts. Two-axis deflection mounts were designed and fabricated. The deflectors were tested to give in excess of 60° mechanical or 120° optical scan angle capability. The spot position could be maintained for long periods without drift. Consequently the feasibility model utilized penmotors for deflecting the laser beam.

CONTROL SYSTEMS - The control systems interface the inputs of the trainee weapon motions with the deflection systems.

Incendiary Hit Control System. The function of the incendiary hit control system is to delay an analog voltage signal. The amount of the delay is variable from 0.2 seconds to 1.0 seconds. Several approaches to this problem were considered with the results indicated below.

Tape Recorder. Utilizing a tape recorder to record an analog signal which may then be read out at a later time describes a time delay device. In such a system the input signal could be recorded at one point in the path which the tape follows and then read out at another point in the path. The length of time it takes for the tape to travel from the recording point to the reading point is equal to the delay time. The delay time could then be varied either by mechanically changing the distance between the two points or by changing the speed at which the tape moves. This technique has several disadvantages, however, which became apparent when manufacturer specifications of commercial tape units were reviewed. Most commercial units are designed for audio recording and reproduction. Correspondingly, the bandwidth of these units extends from 20 Hz to 15-20 KHz whereas the analog position signal varies from DC to 10 Hz at most. This incompatibility can be remedied by converting the analog voltage to a modulated audio frequency which can be recorded. This technique then has the voltage signal recorded as an AM or FM audio frequency. The recorded signal must then be reconverted to an analog signal after reading. The accuracy of recording a given amplitude for most recorders is approximately plus or minus 1%. This is too low a resolution for the system application. Frequency modulation has a higher inherent accuracy but changing delay times by moving the tape faster or changing the distance between the record and read positions causes frequency changes which must be considered. The utilization of such a system was considered as a viable solution but impractical when cost and complexity were considered.

Capacitor Store. Since the information to position a specific round on the display is digital in the sense that only a discreet position is required for the duration of a hit, the signal out to the scanner can consist of a series of discreet steps. The storage of a given voltage level for a time period varying from 0.2 seconds to 1.0 seconds can be accomplished with a capacitor circuit wherein closing a switch charges a capacitor to a voltage level corresponding to the peak signal voltage during the time the switch is closed. Opening the switch then leaves that voltage stored on the capacitor. By reading out the voltage a delay time later the signal has effectively been delayed. The number of capacitors necessary to provide a different position for each round at eight rounds/second for a maximum delay time of one second is eight. By connecting two reed switches to each of eight capacitors and sequentially operating the switches with a magnet the desired effect could be obtained. Such a system was breadboarded using a magnet mounted on the edge of a disc which was rotated by a variable speed motor. The reed switches were mounted on a stationary annular ring. As the magnet completed a circular path it would sequentially activate each of the sixteen switches. This system was tested and found to have several disadvantages. It was difficult to arrange the switches so that there was equal time of activation for all switches. Switching transients gave nonlinear response. Accuracies were far less than desired.

Digital Shift Register. The storing and subsequent recall of binary digital information is a common function of computers. Since this amounts to a delay, the same function could be used to act as a delay system. This was the concept which was employed. An analog-to-digital converter translated the analog voltage signal to binary digital information. The code for each voltage level was then stepped through a shift register. The step rate determined the delay time. The delayed information was then translated back into analog signal by a digital-to-analog converter. This system was breadboarded and tested to give the desired accuracy.

Tracer Simulation Control System. The function of the tracer control system is to store the position location of the weapon at the time the tracer round is fired and then hold this value for the duration of the tracer flight. A suitable circuit was breadboarded using relays and capacitors to perform the store and hold functions. The timing involved a suitable clock to update the position readings at a 1 Hz rate and was breadboarded. A variable delay circuit was also breadboarded to simulate the tracer duration. These circuits will be discussed further in the next section.

SHUTTER SYSTEMS. There are three shutters in the system whose function has been described previously. The rotating slotted disc interrupts the incendiary hit laser at an 8 Hz rate with the individual pulse duration being approximately 40 milliseconds. The 8 Hz shutter rate corresponds to a firing rate of 480 rounds/minute. This rate and also the pulse duration were arrived at by experimentally determining what subjectively appeared realistic. Faster rates led to a blending of one hit into the next and did not appear to be individual rounds. The shutters which determine the tracer duration time and the length of burst in the case of incendiary hits are off-the-shelf solenoid operated beam shutters.

SECTION V

FEASIBILITY MODEL

INTRODUCTION

The completed feasibility model is pictured in figure 12. The floor to ceiling height has already been mentioned as 5 meters. The width of the supporting structure is approximately 3 meters. The simulated weapon is visible mounted in the window. The projector is mounted on a separate table within the supporting structure. The control electronics are located on a platform within the lower left section of the main platform. The display screen is visible behind the platform structure. The system components, their functions, and interactions will be discussed in this section.

PLATFORM

The platform system simulates the internal environment of a flying helicopter. It is made up of a supporting structure, a vibration simulation system, a simulated weapon station, a weapon noise simulation system, and a simulated weapon system.

SUPPORTING STRUCTURE. The supporting structure was designed and fabricated to allow various experimental projection schemes to be evaluated. It is visible in figure 12. It consists of welded steel structural components making up the four separate sides which were then bolted together. The top is plywood reinforced with steel angle and then bolted to the four sides. The structure can be disassembled for modification or transportation in five separate pieces. The assembled structure resembles a table approximately 3 meters long and 2 meters wide with a height of $2\frac{1}{2}$ meters. The unobstructed front opening of the structure is approximately 3 meters wide by 2 meters high.

VIBRATION SYSTEM. The vibration system shakes the weapon station at approximately the 3Hz frequency experienced in a flying helicopter. It consists of steel A-frames separated by 2 coil springs and a balljoint, variable speed electric drive motor, and an eccentric cam linkage. The lower A-frame is bolted to the top of the supporting structure while the upper A-frame is bolted to the floor of the weapon station. Figure 11 shows the vibration system between the top of the platform and the floor of the weapon station. The eccentricities were found to vibrate the system most realistically when set at 2mm for the front spring and no eccentricity for the rear. In operation, the rotation of the motor shaft drives the forward spring mount in a small circle which is partially reinforced by the spring mounting system to vibrate the weapon station.

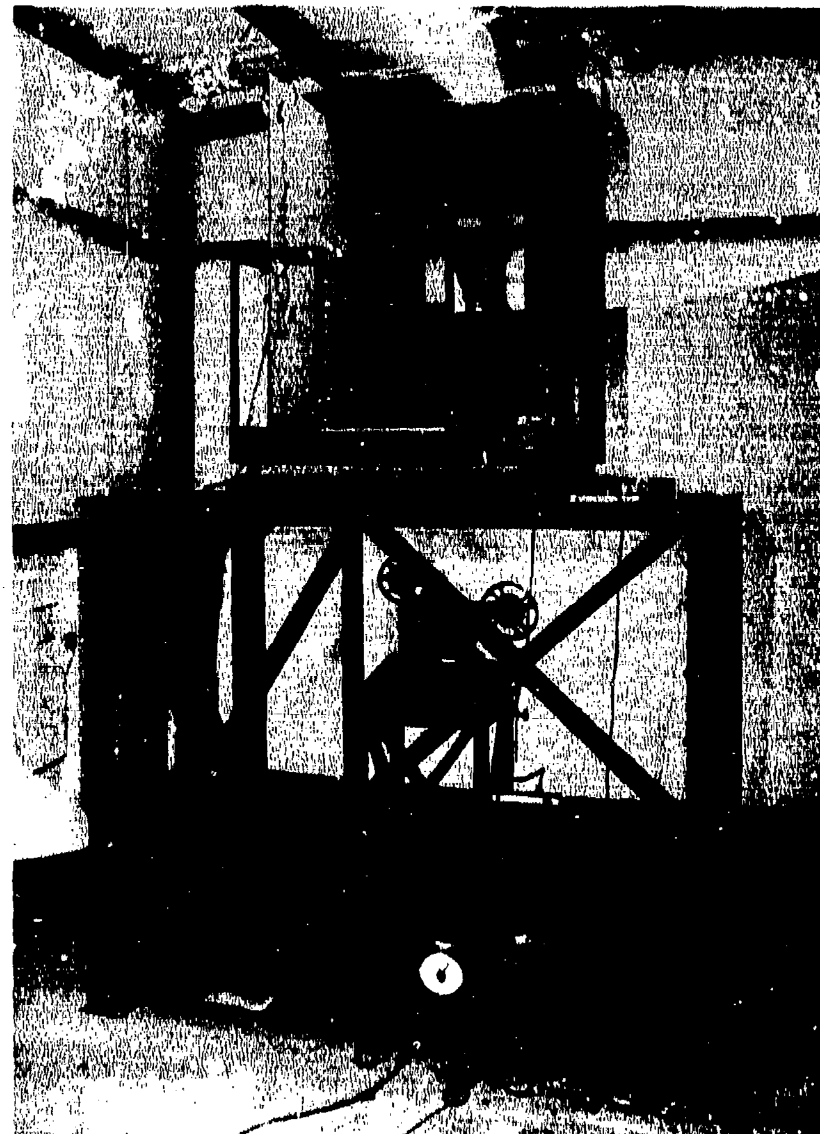

Figure 12. Feasibility model of Laser Helicopter Gunnery Trainer

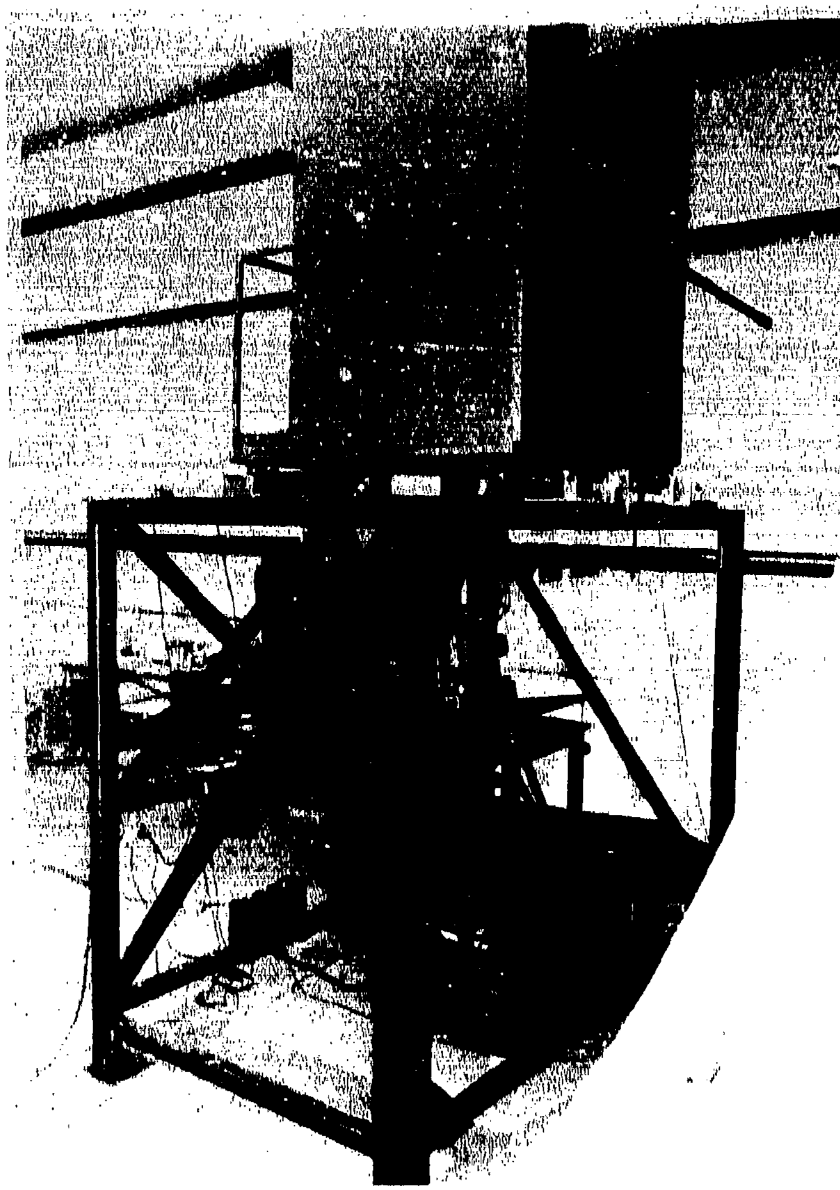

Figure 13. View of feasibility model from screen side

WEAPON STATION. The simulated weapon station is visible in figures 12 and 13. The floor is approximately 1.5 meters square and consists of plywood reinforced with steel channel. The side walls are plywood and the handrail is steel. The front section is plywood and sheet aluminum on the interior, mounted on a 2x4 reinforcing structure. The window is approximately 0.6 meters square located in the center of the front wall with its lower edge 0.7 meters above floor level.

WEAPON NOISE SIMULATION. The simulation of the weapon firing noise is accomplished by a pulse generator firing at the 8 Hz weapon fire rate feeding into a set of earphones worn by the trainee. The earphones and connecting cable are visible in figure 12 hanging on the left wall of the simulated gun station. The pulse generator is activated by the trigger switch. The audio level of the sound of the pulses was adjusted until it approximated the sound intensity of the actual weapon when heard through a flight helmet.

WEAPON SIMULATION. The weapon used in the feasibility model is a deactivated M-2 (.50 caliber) machinegun. It has deactivated by welding a plug in the breech and removing the bolt. The butterfly trigger is located at the butt end of the weapon. The trigger is activated by grasping the handles with the fingers of both hands and depressing the trigger with the thumbs. The handles and trigger are shown in figure 14. An electric switch was installed within the receiver below the trigger bar such that the trigger activated the switch.

WEAPON MOUNT. The machinegun is mounted in an actual door mount from a CH-46 aircraft. This mount allows the weapon to pivot in elevation and swivel in azimuth. Stops were installed such that the field of fire was limited to azimuth excursions from 45° to 135° and elevation excursions from 85° to 145°. A description of the mechanism used to sense the angular position of the weapon is contained in the paragraph describing the hit indication control system.

WEAPON FIRE SIMULATION SYSTEM

The Weapon Fire Simulation System lets the trainee know where he is shooting. It consists of two semi-independent laser projection systems; the hit simulation system and the tracer simulation system.

HIT SIMULATION SYSTEM

The Hit Simulation System consists of the Hit Deflection Control System, the Hit Deflection System, the Hit Shutter System, and the Hit Laser.

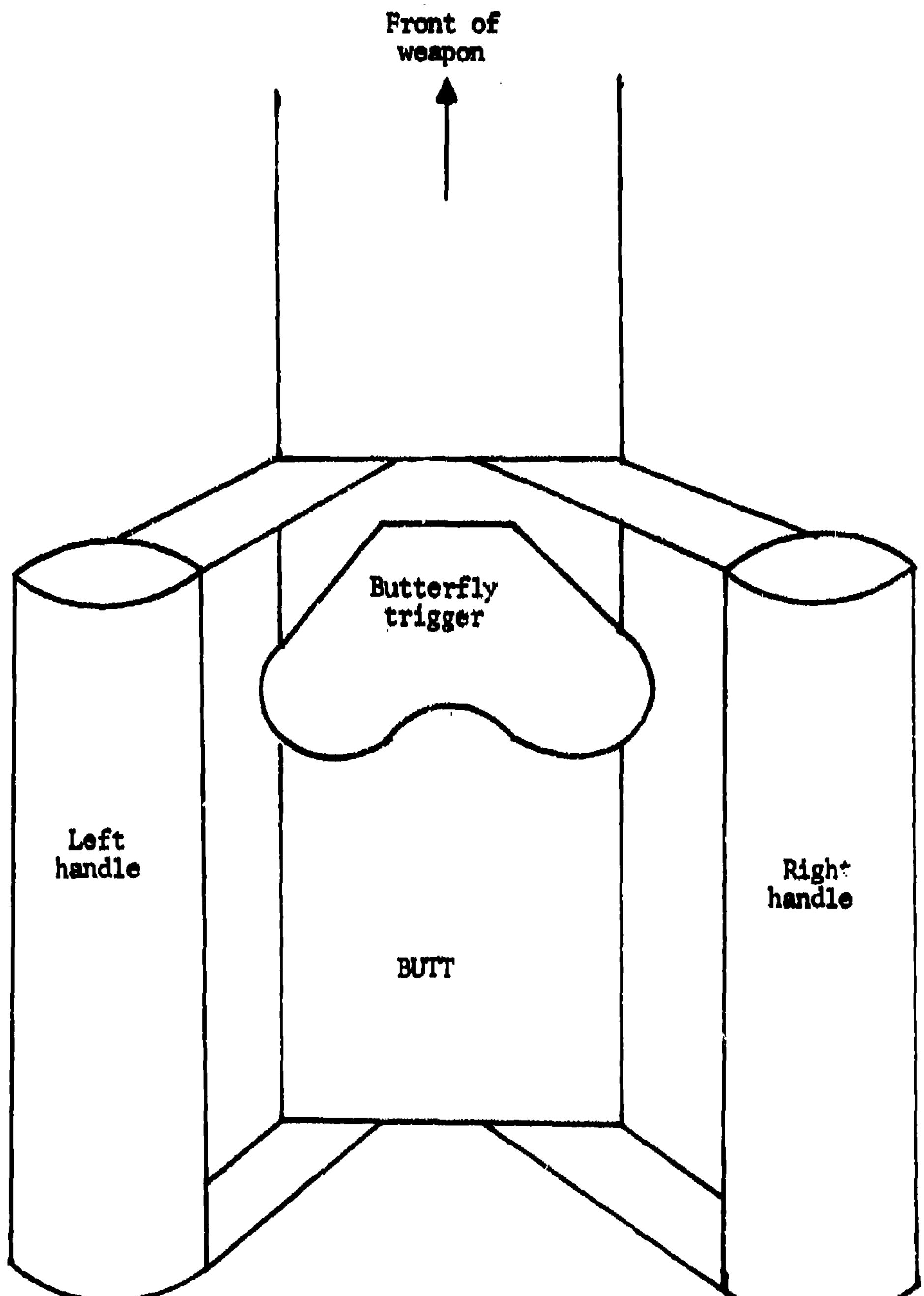

Figure 14. Trigger location

HIT DEFLECTION CONTROL. The Hit Deflection Control System is an analog signal delay device which reads the gun and trigger positions and stores them for a time delay and then uses the position information to control the deflection angles of the Hit Deflection System and Hit Shutter System. Most of the components of the system are contained in a single electronic console. The remainder of the system components consist of a remote position readout module located below the weapon mount in a housing the size of a shoe box and the interconnecting cabling. (A block diagram of the control system is given in figure 15). The three principal divisions are the remote read module, the delay module, and the driver module.

Remote Read Module. The Remote Read Module provides information about where the weapon is aimed and whether the trigger is pulled. It essentially consists of two potentiometers and a switch, both controlled by mechanical linkages to the weapon. The two potentiometers provide two analog voltage signals, one corresponding to the azimuth angle of the weapon and the other corresponding to the elevation angle. The switch provides the digital trigger signal.

The potentionmeters are mounted as depicted in figure 16. When the weapon is pivoted about the horizontal axis defined by the elevation pivot, the spring loaded elevation probe moves vertically. This causes the rack gear at the lower end of the elevation probe to rotate the pinion gear on the shaft of the elevation potentiometer. Rotating the weapon in azimuth about the vertical axis defined by the elevation probe causes the ring gear attached to the shaft housing to drive the gear mounted on the shaft of the azimuth pot. The elevation pot is attached to the elevation shaft housing so that it rides along with the system when the weapon is varied in azimuth. The azimuth gear is mounted directly on the fixed mount so that only its shaft is free to move.

When the shafts of the potentiometers are rotated, an analog voltage signal is generated from each of them. The magnitude of the signal is proportional to the angle of rotation.

The trigger switch is mounted in the breech of the weapon. It is activated by a mechanical lever arm extending from the trigger at the rear end of the weapon to the breech.

Delay Module. The Delay Module takes the analog signal inputs from the remote read system, delays them a variable time, and then feeds them to the driver system. Figure 15 shows the principal components of the delay system in block form. These consist of a master sync clock, an analog-to-digital converter, a serial shift register, and a digital-to-analog converter.

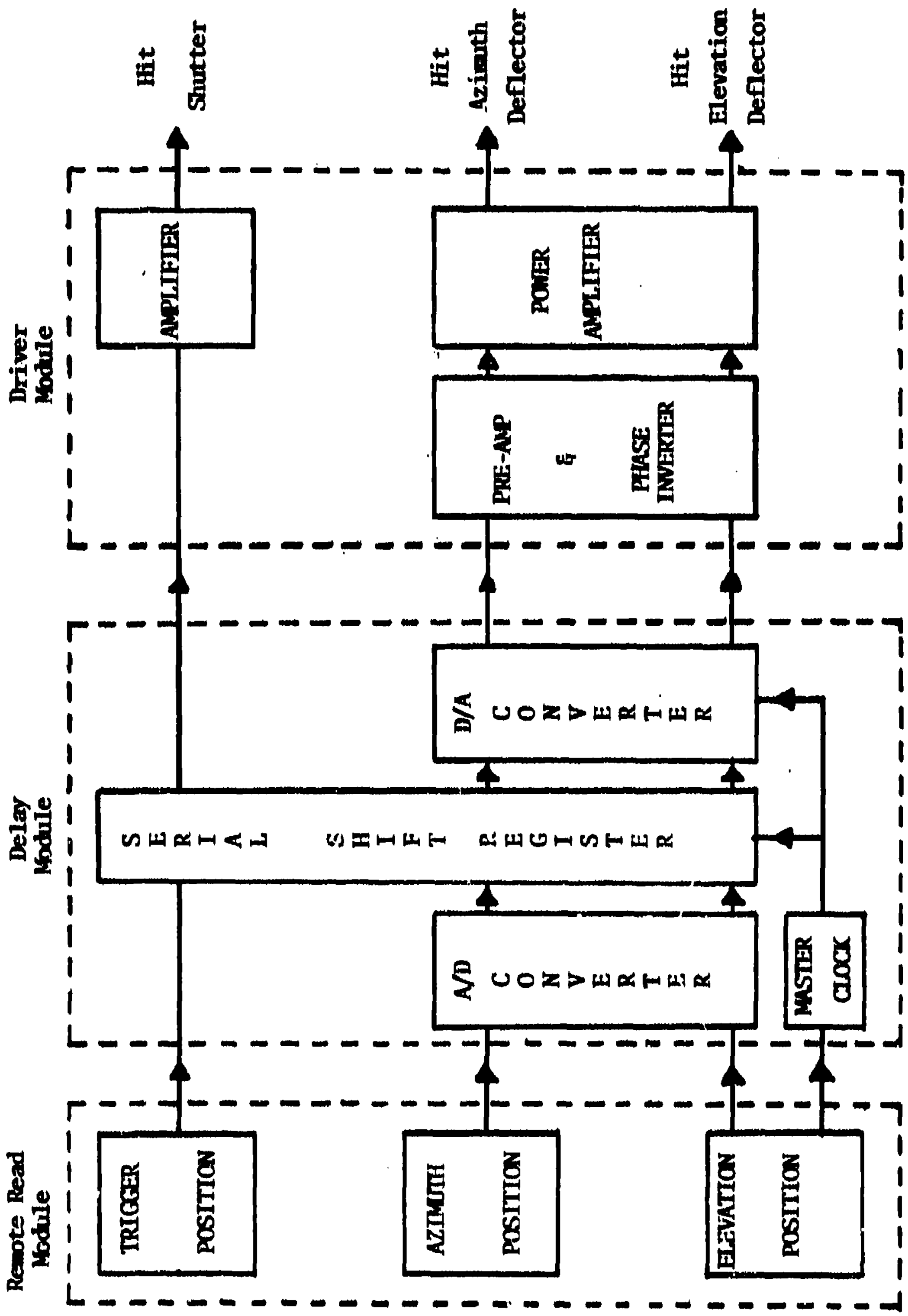

Figure 15. Block Diagram of Hit Deflector Control System

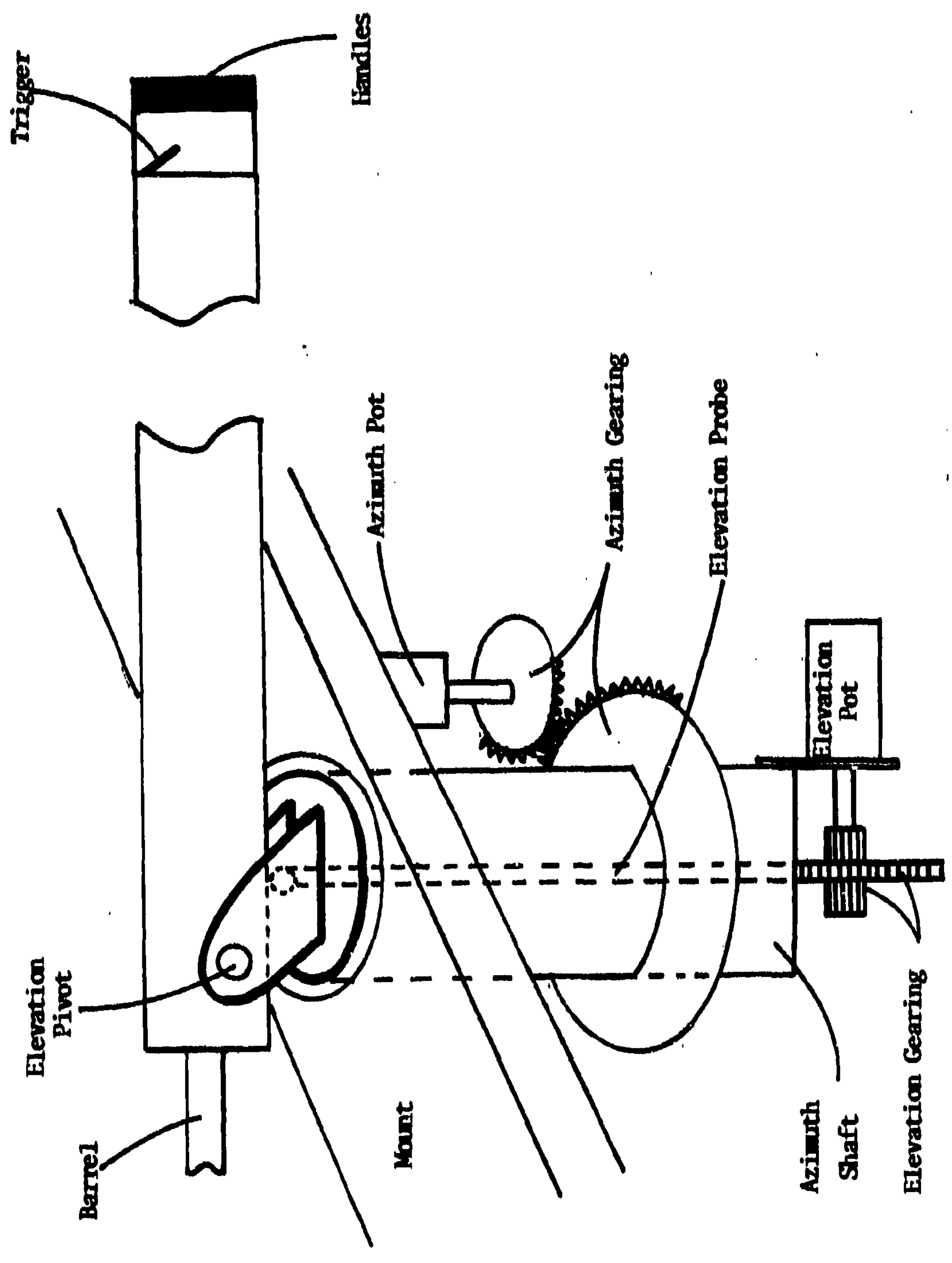

Figure 16. Configuration of Remote Read Module

The master sync clock provides the timing necessary to have the delay system perform its function. The clock generates two timing signals which tell the converters when to convert and the shift register when to shift. Since the time delay is simulating time of flight, it will be proportional to simulated range to the target and also a function of the elevation angle of the weapon. The clock uses the information about elevation it receives from the Remote Read Module to control the shifting rate of the serial shift register. When the weapon is aimed high the clock puts out a low frequency causing the shift register to shift less often and thereby increase the delay, or length of time it takes for the signal to get through the register.

The analog-to-digital converter changes the azimuth and elevation signals into binary digital signals. This is accomplished by coding which divides the two inputs of analog information into sixteen output channels of digital information. The master sync clock tells the analog-to-digital converter when and how often so sample the analog signal and convert it to digital. The number of digital-channels-out per analog-signal-in is a measure of the number of resolvable voltage increments whose values are capable of being encoded. In this case there are eight digital channels for each analog channel. This implies $2^8 = 256$ measurable voltage increments.

The serial shift register takes the 16 channels of azimuth and elevation digital information as well as a channel of digital trigger signal information and shifts them through thirty-two steps. Each piece of digital information is passed down a channel in the shift register much like the water in a bucket brigade. When the command is received from the master sync clock the piece of digital information is dumped into the next bucket. The rate generated by the clock determines how long it will take for the piece of information to get from the first bucket to the last. The digital to analog converter transforms the digital information coming from the serial shift register in the sixteen azimuth and elevation channels back into two analog channels closely resembling the inputs which originated from the read system. The difference is that the output analog signals do not have as high a resolution as the input signals due to the loss of resolution caused by the digitizing which occurred in the analog to digital converter.

Hit Driver Module. The driver module interfaces the delayed azimuth, elevation, and trigger signals with the hit deflection system and hit shutter system. It consists of a pre-amplifier, phase inverter system, a differential power amplifier, and a trigger signal amplifier.

The preamplifier converts the single polarity signals required by the azimuth and elevation deflection motors.

The differential power amplifier provides the power necessary to drive the motors while maintaining the proper analog voltages such that the motors will deflect to angles corresponding to the gun aiming angles in azimuth and elevation.

The trigger amplifier boosts the digital trigger signal in order to drive the solenoid actuated hit shutter. The design is such that the shutter opens a delay time after the trigger is pressed and closed a delay time after the trigger is released.

HIT DEFLECTION. The Hit Deflection System is a two-axis laser beam deflection system. Figure 17 shows the configuration of the hit detector system. The laser beam enters from the left and is incident on the 1 cm square azimuth mirror (AM). The azimuth penmotor (A) is capable of rotating the azimuth mirror and reflecting the laser beam to any angle about the x-axis within the 90° fan AF in response to the azimuth signal from the hit deflection control system. The azimuth mirror is oriented such that any reflected beam from the laser will be incident on the hit elevation mirror, EM. The hit elevation mirror is 1 cm wide and 7 cm long. The elevation penmotor mirror (E) is capable of reflecting any beam from the azimuth mirror to any elevation angle about the x-axis within the 60° fan EF. The hit elevation mirror responds to the elevation signals from the hit deflection control system. The two penmotors are mounted on a supporting structure which is visible in figure 18.

HIT SHUTTER. The Hit Shutter System consists of two independent shutters. The first shutter is an off-the-shelf, solenoid operated, laser beam shutter. Its function is to open and shut in response to the shutter signal from the hit deflection control system. It determines the burst length or number of hits which will be visible on the screen. The second shutter is an 8-slotted disc driven continuously by a synchronous motor at a speed of 60 RPM or 1 revolution per second. This shutter operates continuously regardless of the trigger position. The circumference of the disc is 24 cm and the width of the slots is 1 cm leading to an individual pulse length of 40 milliseconds.

HIT LASER. The hit laser is an off-the-shelf helium-neon laser having a filtered output power of 0.4 milliwats, an output beam diameter of 1 millimeter and a beam divergence of 1 milliradian. It is mounted together with the hit shutter system and the hit deflection system just below the weapon as can be seen in figures 12 and 17.

TRACER SIMULATION SYSTEM

The tracer simulation system consists of the tracer deflection control system, the tracer deflection system, the tracer shutter system, and the tracer laser. The tracer deflection system and the tracer laser are duplicates of the hit deflection system and the hit laser as described previously. The only differences being that the laser beam enters the tracer deflection system from the opposite direction and responds to signals from the

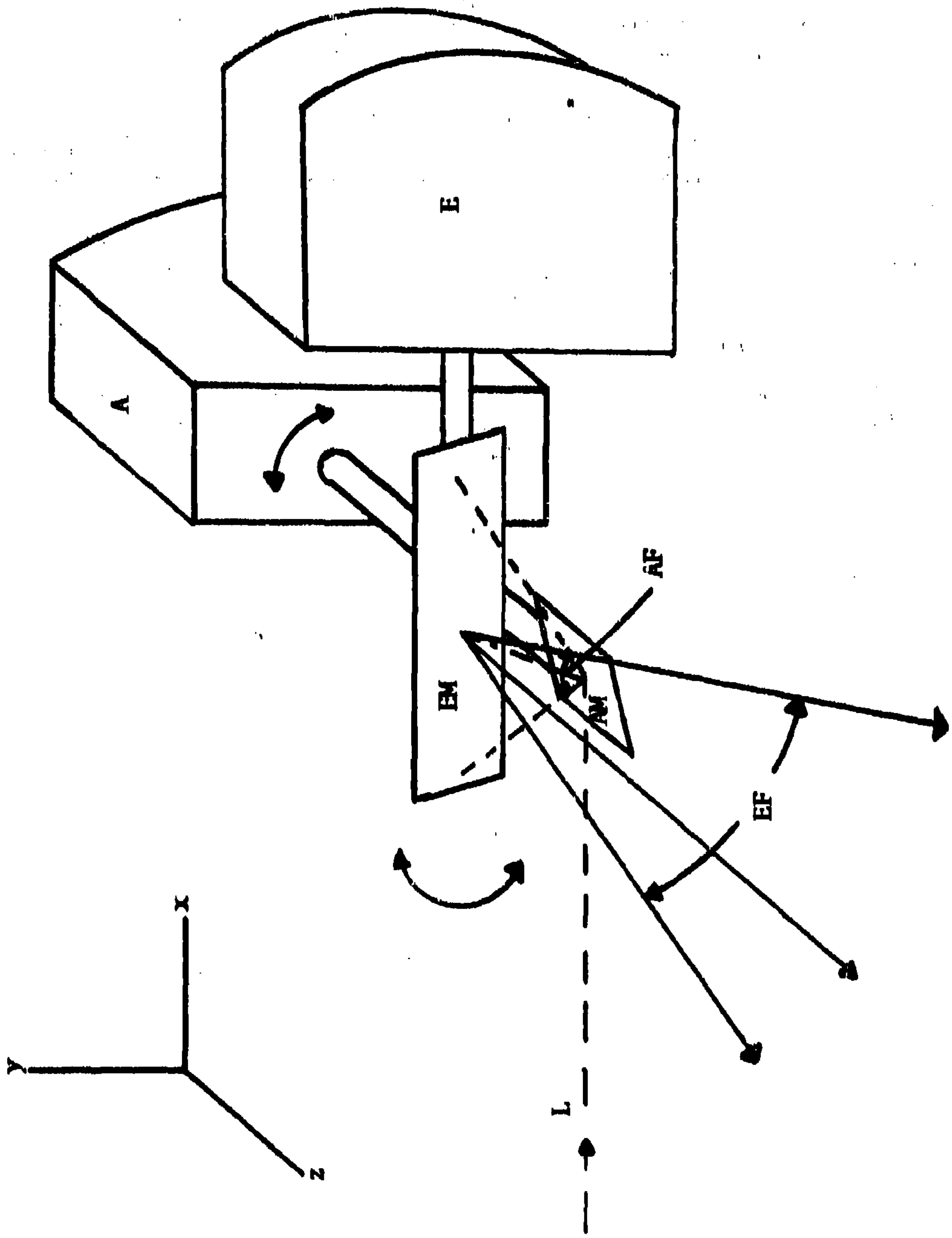

Figure 17. Configuration of Hit Deflection System

Figure 18. Hit Simulation System

tracer deflection control system rather than the hit deflection control system.

TRACER DEFLECTION CONTROL. The tracer deflection control system uses the same remote read unit as the hit indication control system. In the case of the tracers, however, there is no need to delay the control signals. The system is designed to continuously sample the elevation and azimuth position signals and then hold on fixed values when the trigger is activated. The tracer duration is equal to the simulated time of flight and the tracer repetition rate is fixed at 1 hertz to avoid the problem of simulating two tracers simultaneously. A block diagram of the tracer control is pictured in figure 19.

The remote read system provides four information channels to the tracer control system. The trigger channel tells whether the trigger is activated; the azimuth channel provides an analog voltage proportional to the azimuth position of the weapon; the elevation channels provide both an elevation position and an analog voltage proportional to the simulated time-of-flight. The sample and hold module, once activated, freezes the azimuth and elevation positions and decouples the trigger from the shutter control.

In operation the weapon is aimed at some point on the screen and the trigger is depressed. The sample and hold module then decouples from the remote-read module, having stored the fixed voltages of azimuth and elevation position. The shutter control unit immediately opens the shutter. The shutter remains open until the simulated time-of-flight has elapsed. The shutter then closes. The sample and hold module continues to be decoupled from the remote read module until one second has elapsed measured from the time of initial trigger activation. At this time the system resets and will recycle if the trigger is still depressed.

During the simulated time-of-the-flight constant voltages from the sample and hold module are fed to the tracer shutter, the azimuth amplifier, and the elevation amplifier. These amplifiers have high input impedance and are capable of holding the tracer deflection penmotors at a relatively fixed position for up to 1 second.

TRACER SHUTTER. The tracer shutter is a duplicate of the first hit shutter. It opens and shuts in response to the control signal from the tracer deflection control system. It is mounted immediately in front of the tracer deflection system.

DISPLAY SYSTEM

The display system consists of a motion picture film, a projector, and a display screen. Its function is to provide a motion picture display of targets and background as they would appear from the side door

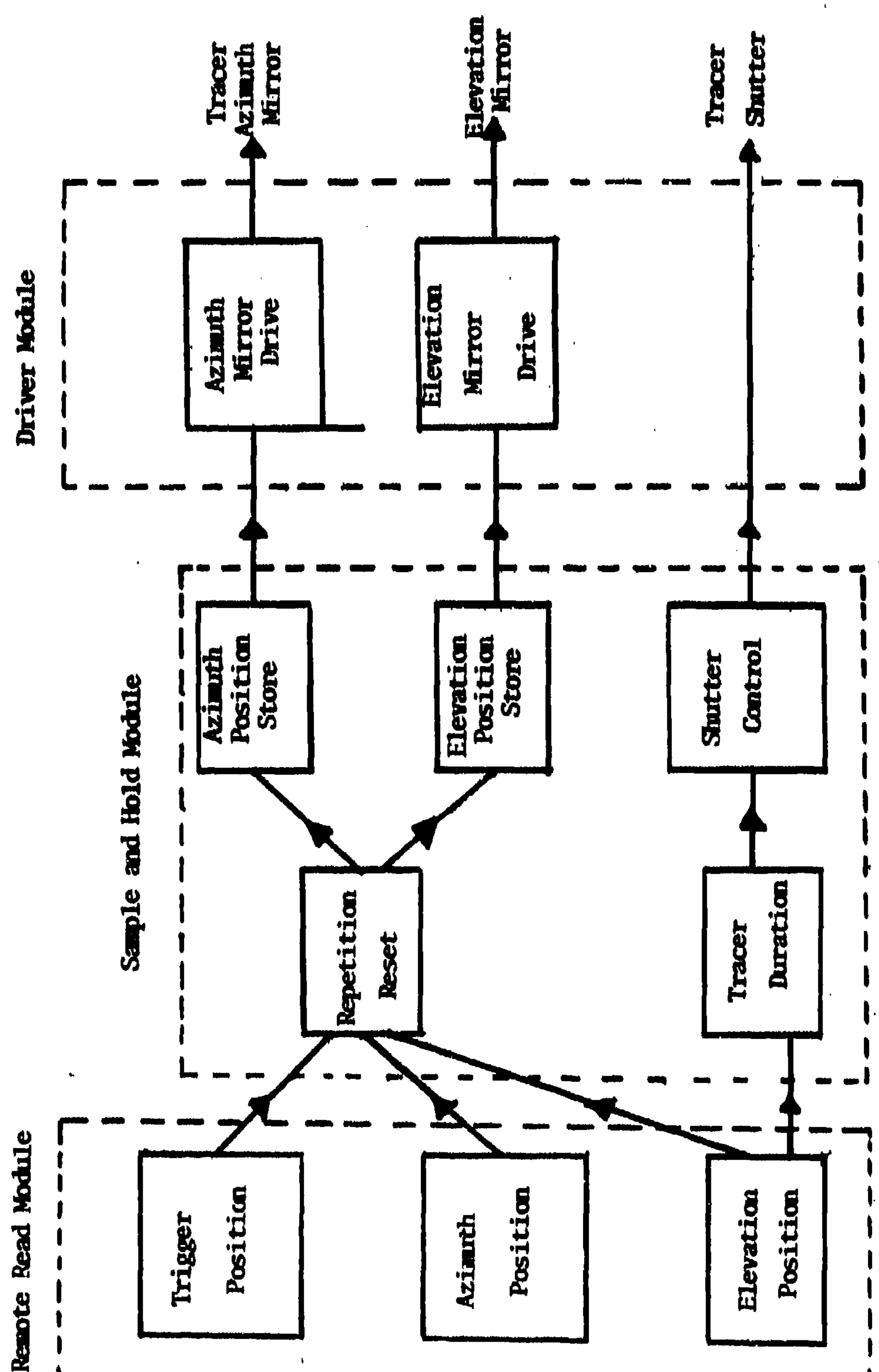

Figure 19. Block Diagram of Tracer Deflection Control System

or window of a flying helicopter.

MOTION PICTURE. The final edited film containing both targets and background has a film running time of 15 minutes corresponding to a film length of 165 meters.

Background. The film segments selected for inclusion in the final film consisted of several different types of terrain areas. These included islands, shorelines, treelines, planted fields, orchards, roads, canals, streams, buildings, and flat marsh areas. Each segment is presented for a time varying from 30 to 90 seconds.

Targets. Simulated muzzle flash targets were inserted in the manner previously described. The total number of target locations was 40. The total number of bursts from all target areas was 69. The total number of individual muzzle flashes was 550.

Muzzle flashes were inserted such that they appeared at azimuths varying from 60° to 70° and elevations from 100° to 120°. Some targets fired two bursts in which case the second burst was made to appear at azimuths varying from 80° to 110°. The total length of time that known targets were within the available field of fire was 170 seconds.

PROJECTOR. As previously stated the projector is an off-the-shelf 16mm projector with a modified projection lens. The projector is visible in figures 11 and 12 on its own mounting table. The height of the projection lens and the projection angle are 2.2 meters above the floor level and 17° up respectively.

SCREEN. The display screen is a section of a 3.8 meter radius sphere. The screen was available in-house already aluminized. The fact that the screen was not lenticular led to a less than optimum screen brightness. The screen is partially visible in figures 12 and 13. The screen is located such that its center of curvature is approximately between the two laser deflection systems.

SECTION VI

TECHNICAL EVALUATION

Measurements of various system parameters of the feasibility model were made for comparison to design predictions. The results and interpretations of these measurements are given in this section.

MOTION PICTURE

The resolution capability of the wide angle camera lens as described in manufacturer's literature is given as 142 lines/mm on center and 71 lines/mm at edge of field (tangential lines) for an aperture of f/2.8 using a relatively high resolution, commercial, black and white, negative film.

Since the motion picture was filmed in color and at f/5.6, resolution measurements were made in our laboratory using the 16mm camera with an aperture of f/5.6 using the positive color transparency film. The resolutions measured were 90 l/mm on center and 66 l/mm at the edge of the field. These results lead to a recorded angular resolution of approximately 2×10^{-3} radians or 2 mils.

TARGETS

The simulated muzzle flash targets were manually punched through the film using a jewelers drill having a diameter of approximately 0.15mm mounted in a pin vise. With sufficient practice and the aid of a magnifier, holes could be punched within 0.2mm of desired location. The resultant target muzzle flashes appeared to emanate from an area of approximately 80mm diameter on the screen which corresponds to an angle of approximately 20 mils. The placement accuracy is such that the total target area is approximately double this or 40 mils.

DISPLAY

The display measurements included: Background scene resolution as measured using a test film of resolution targets; background brightness as measured with an open gate and the shutter running; target brightness; and laser spot brightness.

BACKGROUND RESOLUTION. The resolution of the background scene as measured using a film of a resolution target made in the laboratory using the same film, camera, lens and aperture as used to record the background scene was approximately 3 mils on center and 6 mils at the edge of the display (for simulated vertical lines). This corresponds to resolving 64 lines/mm on center and 28 lines/mm at the edge of the field at the film. Table 8 lists the various calculated and measured resolution values. For a perfect, diffraction limited lens of focal length equal to 5.9mm and apertured at

TABLE 8. RESOLUTION DATA

	Center of field		Halfway to edge		Edge of field	
	1/mm at film	mils equiv.	1/mm at film	mils equiv.	1/mm at film	mils equiv.
Perfect lens f/ = 5.6 FL = 5.9 mm	265	0.6	227	0.7	158	1.1
Specified performance f/ = 2.8	142	1.2	71	2.2	71	1.8
Measured performance f/ = 5.6	90	1.9	74	2.1	66	2.0
Projected performance (unmodified)	66	2.6	49	3.2	41	3.2
Projected performance (modified)	66	2.6	45	3.5	29	4.6

f-stop equal to f/5.6 the on-center resolution limit is 265 lines/mm. The camera lens is specified by the manufacturer to have on center resolution of 142 lines/mm for a high resolution black and white film at aperture f/2.8. The measured resolution using color transparency film at an aperture of f/5.6 on-center was 90 lines/mm. The projected resolution on center using the off-the-shelf projection lens as well as the modified lens was 66 lines/mm. Table 8 lists equivalent resolution in mils ($1^{\circ} = 17.5$ mils) for the situation specified. Note that the final projected display varies from 2.6 mils resolution on center to 4.6 mils at the edge. All of the resolution measurements were made along a horizontal line passing through the center of the display format. Also note that the resolution measurements were made using a film of a resolution target under stable controlled conditions in the laboratory. The actual film used in the simulation system was recorded using an essentially handheld camera in the vibrating enriornment of an airborne helicopter with a fairly low contrast scene.

BACKGROUND BRIGHTNESS. The manufacturer specified output light level of the projector using f/1.2 projection lens was 2400 lumens. The measured output light level using the manufacturer supplied f/1.2 projection lens was 1500 lumens. This difference in output light level could be due to a number of factors such as measuring technique and photometer used, different lamp, different lens, etc. For the off-the-shelf wide angle lens having an aperture of f/1.4 the measured output light level was 1200 lumens. The output light level for the modified projection lens was 1200 lumens. Using the 3.8 meter radius aluminized screen the screen brightness as measured from the observers position was 48 foot-lamberts peak. The variation of screen brightness over the screen as seen from the observer's position is given in figure 20. Note that the screen luminance was not symmetrical indicating some misalignment at the time of measurement.

MUZZLE FLASH BRIGHTNESS. The apparent brightness of the individual muzzle flashes was approximately 20% of the open gate brightness due to the brief duration of the flash. The brightness of the simulated muzzle flashes peaked at 10 foot-lamberts.

LASER SPOT BRIGHTNESS. The apparent brightness of the laser projected spot was 60 foot-lamberts for the tracer simulation and 50 foot-lamberts for the incendiary hit impact simulation.

WEAPON EFFECTS

The weapon effects simulation system as evaluated in terms of observable parameters, i.e., tracking accuracy and simulated time of flight. The error contribution of the various sub-systems is discussed briefly and comparison's are made to optimum system performance.

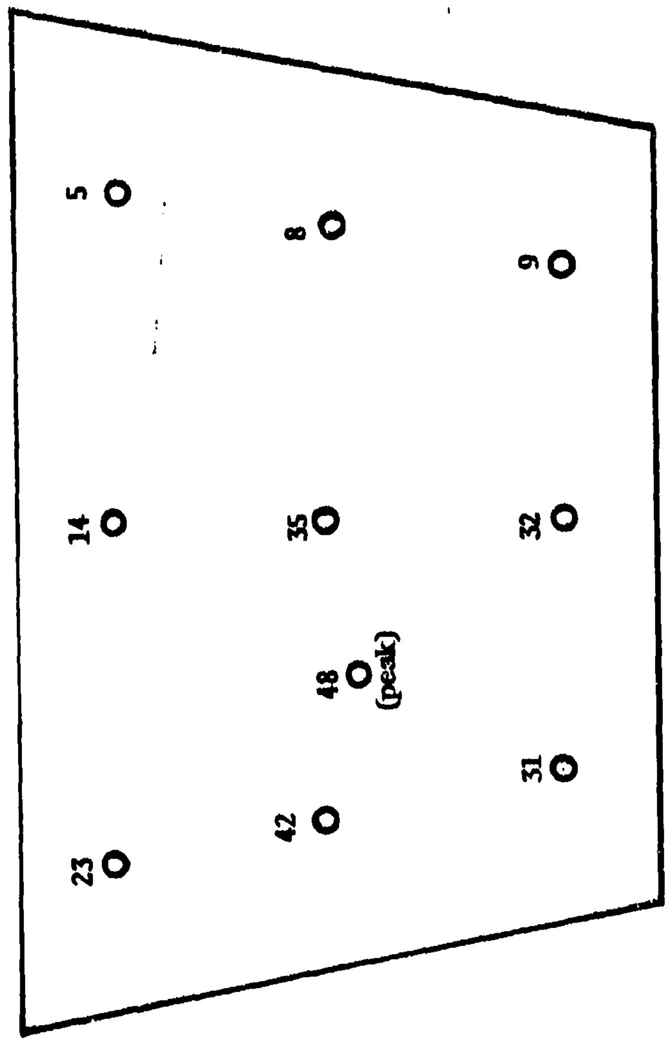

Figure 20. Measured screen luminance from gunner's position (ft-lamb)

TIME OF FLIGHT. The requirement on the time-of-flight simulation is that it vary from 0.2 seconds for a weapon elevation angle equal to or greater than 117° to 1.0 seconds for elevation angles equal to or less than 97°.

The accuracy of the time delay need only be approximate since the ability of an observer to judge small time differences is poor. The measured time delay as a function of elevation angle is plotted in figure 21, together with the actual time of flight for a round fired at the same elevation angles from an altitude of 100 meters. The simulated time-of-flight is within 0.1 seconds of actual flight time for the ranges of interest.

TRACKING ACCURACY. Due to the geometric distortion factors noted in the previous section the laser spots indicating impacts (or location at tracer burnout) were not expected to follow the aim line exactly. Other factors which influenced the tracking accuracy were: weapon position readout resolution, resolution of store and hold module, resolution of analog delay module, and the resolution of scanning systems. These are discussed below.

Position Readout. The potentiometers used to provide analog voltage signals as a function of the weapon azimuth and elevation positions were capable of resolving in excess of 2 mils in elevation and 3 mils in azimuth. This was inferred from repeatable voltage readings to within 0.01 volts over 5.0 volt range translating to 90° in azimuth and 60° in elevation.

Store and Hold. The store and hold subsystem was capable of storing voltages at approximately the same accuracy as the position readout system but due to bleed off of voltage during the time of flight the voltage drops during the time of flight and causes the tracer spot to drift toward the center of the screen. The amount of drift is greatest when the deflection is greatest from the center of the screen. Because of this drift, the impact or extinguishing position of the simulated tracer round was measured to be as much as 25 mils off at the corners of the display. Proportionately smaller errors or drifts were observed as the center of the screen is approached.

Analog Delay. The delay subsystem had a measured resolution of 4 mils in elevation and 6 mils in azimuth corresponding to the capability of the analog-to-digital converter of 256 resolvable voltage levels.

Deflection Systems. The penmotors used to deflect the laser beams were linear within the measurement tolerance with the applied voltages.

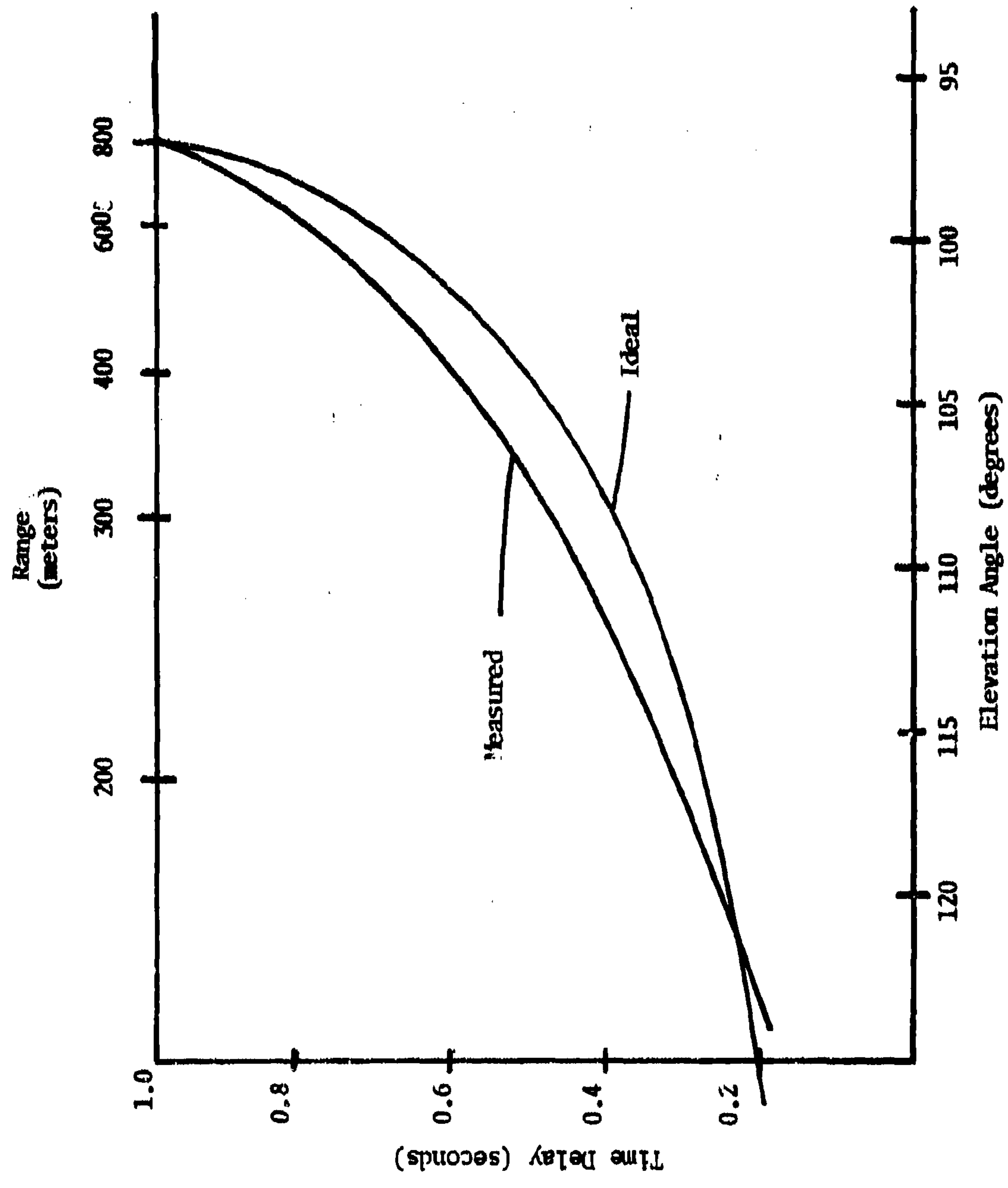

Figure 21. Measured time delay as function of range and elevation angle

SECTION VII

TRAINING POTENTIAL EVALUATION

INTRODUCTION

The purpose of this training potential evaluation was to obtain some feedback from Aerial Gunnery School personnel as to the utility and implementation of the Laser Helicopter Gunnery concept. The evaluators consisted of the current aerial gunnery training instructor, two experienced door gunners and two Marine pilots from the Marine Corps Air Station. The evaluators individually experienced two simulated flights each. The first flight was with ground effect (incendiary hits) only; and the second flight was with tracer simulation only. The first flight was monitored by lab personnel who recorded the time the trigger was activated and the time the rounds hit on target. These parameters gave a more objective determination of the evaluator performance than the subjective impression of the evaluator alone.

After the simulated missions, the evaluators were requested to complete the evaluation questionnaire (Appendix B). The day after the evaluation, a discussion was held with all evaluators simultaneously and consensus results were also listed on a questionnaire. The evaluators were encouraged to comment freely on all aspects of the concept. A summary of the various comments was included in this evaluation.

VISUAL DISPLAY

The individual responses and consensus are listed in table 9. It is interesting to note that, although each evaluator individually judged the display size to be adequate, the size of the display was judged to be too narrow in width by the consensus. The judgment of resolution to be excellent at the low values measured was surprising. Image jitter although noticeable was not considered to be too severe. Other comments indicated that the motion picture should include some takeoffs and landings since this is a critical training area. The amount of jitter was considered excessive even for a CH-46 aircraft. A CH-53 aircraft has much less jitter than the CH-46.

TARGET SIMULATION

The responses to the questions on muzzle flash simulated targets are listed in table 10. The overall consensus differed from individual responses only in the area of target size. For this question the answers ranged from too small to too large.

TABLE 9. VISUAL DISPLAY EVALUATION

	Evaluator					
	1	2	3	4	5	C
Resolution:						
Excellent		X		X	X	X
Sufficient	X		X			
Insufficient						
Brightness:						
Too bright						
Sufficient	X	X	X	X	X	X
Too dim						
Color:						
Sufficient		X	X	X	X	X
Insufficient	X					
No color required						
Size:						
Sufficient	X	X	X	X	X	
Too narrow height						
Too narrow width						X
Too narrow h & w						
Jitter:						
Not noticeable				X		
Not severe		X			X	X
Too severe	X		X			
Overall:						
Sufficient		X	X	X	X	X
Insufficient	X					

TABLE 10. TARGET EVALUATION

	Evaluator 1	2	3	4	5	C
Visibility:						
Obvious						
Sufficient	X	X	X	X	X	X
Too difficult						
Brightness:						
Sufficient	X	X	X		X	X
Insufficient				X		
Size:						
Too large		X			X	
Sufficient	X		X			X
Too small				X		
Duration:						
Too long						
Sufficient		X	X	X	X	X
Too short	X					

TABLE 11. GROUND EFFECT SIMULATION

	Evaluator 1	2	3	4	5	C
Brightness:						
Too bright						
Sufficient	X	X	X	X	X	X
Too dim						
Size:						
Too large						
Sufficient	X	X	X	X	X	X
Too small						
Frequency:						
OK	X	X	X	X	X	X
Tracking:						
Yes; training	X		X	X	X	X
Some training		X				
No training						

Individual comments on this question indicated: that there should be more targets; it would improve simulation to have color in the flash; and there should be moving targets.

GROUND EFFECT

The results of the ground effect simulation are listed in table 11.

TRACER SIMULATION

Table 12 contains the results of the tracer simulation evaluation. It must be noted that at the time of the test the tracer simulation was not optimum due to electronic problems. The effects of the malfunction were to cause insufficient scan angle in the horizontal plane and electronic noise in the motor drive circuits which caused the tracer spot to oscillate intermittently during tracer flight. This caused the poorer evaluation of the tracer simulation as compared to the ground effect simulation.

The comments on the tracer simulation indicate: more tracers are necessary; no comparison to actual tracers; tracer effect is a prime requirement for training.

FIRING PLATFORM

The dimensions of the firing platform and window were rated sufficient in all respects by individuals and consensus. The vibration of the platform was rated sufficient by consensus and either sufficient or excessive individually. Comments indicated platform and vibration scheme was very suitable for training purposes and that the vibrating platform is preferable to an actual aircraft used as a platform without vibration.

WEAPON

The results of the weapon handling evaluation are in table 13. The evaluators were consistent in their individual responses to requirements for recoil and noise. However, the group discussion led to a consensus that noise was not required. The scattered opinions as to the degree of simulating the weapon handling characteristics are probably due to the simulated weapon not having the weight of a bolt, ammo can, or brass catcher.

OVERALL SYSTEM

The consensus was that the system, as it stands, can supplement live fire training and substitute for some live fire training. The evaluators noted that there is a tendency to ride the trigger which would have detrimental effects on an actual weapon. Scoring capability was not considered

TABLE 12. TRACER SIMULATION EVALUATION

	Evaluator 1	2	3	4	5	C
Brightness:						
Too bright						
Sufficient	X	X	X		X	X
Too dim						
Color:						
Accurate	X					
Sufficient		X			X	X
Unacceptable			X			
Tracking:						
Yes; training	X				X	
Some training			X			X
No training		X				
Frequency:						
Too often						
Sufficient					X	X
More required	X	X	X			

TABLE 13. WEAPON HANDLING EVALUATION

	Evaluator 1	2	3	4	5	C
Maneuvering:						
Too difficult	X	X				
Same as actual				X	X	X
Too easy			X			
Recoil:						
Not required	X					
Required		X	X	X	X	X
Noise:						
Not required						X
Required	X	X	X	X	X	

to be of importance for training purposes.

SCORING

During the first firing run (ground effect only) laboratory personnel timed the time on target and utilized a clock switched by the trigger to time the total firing time. When rounds hit within approximately 5 meters of the simulated target position, the evaluator was considered to be on target. The results of these measurements are given in table 14. In table 14 the evaluator's numbers are in a different sequence since evaluation questionnaires were anonymous.

The meanings of the rows are: total fire (seconds) - The length of time the trigger was activated during the 15-minute exercise; total fire (equivalent rounds) - number of simulated rounds fired at eight rounds/second; on target (seconds) - the length of time that hits occurred within 5 meters of the target location; on target (equivalent rounds) - the number of hits occurring at the target location at eight rounds/second; hit percentage/fire - the percentage of hits compared to the number of rounds fired; hit percentage/target - the total time that targets were available to fire at was 170 seconds. This indicates the ratio of times on target to time target was available times 100%; fire percentage/target - the ratio of firing time to time target available times 100%.

The number of rounds fired varied from 320 for evaluator 4 to 1232 rounds for evaluator 3. Evaluator 4 was the most accurate in that 55% of the rounds he fired were hits. Evaluator 3 had a hit percentage/fire of only 23% but since he fired 91% of the time a target was available, he obtained a greater number of hits than evaluator 4. Evaluator 5 had the greatest number of hits while firing 84% of the time targets were available. More extensive testing and comparison to live fire testing would be required to determine which door gunner is the best.

TABLE 14. SCORING EVALUATORS

	Evaluator				
	1	2	3	4	5
Total fire					
seconds	118	75	154	40	143
rounds	944	600	1232	320	1144
On target					
seconds	62	40	35	22	69
rounds	488	320	280	176	552
Hit % /fire	52	53	23	55	48
Hit % /target	36	24	21	16	41
Fire % /target	69	44	91	24	84

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

The feasibility of training direct fire techniques from a moving platform has been demonstrated by the Laser Helicopter Gunner Trainer. The favorable training potential evaluation by the potential user indicates that the system concept is viable and would provide effective training to supplement or enhance live fire training.

Improvements in design or concept which are to be considered in the next level of devlopment, i.e., prototype, include:

a. Expand display field of view in azimuth if requirement for wider field is valid.

b. Design and fabricate a more optimum projection lens.

c. Optimize projector-observer display geometry.

d. Optimize screen surface and radius.

e. Add some recoil effect.

f. Optimize content of motion picture including landings and takeoffs and moving targets.

g. Optimize scanners and control electronics for improved tracking accuracy and higher resolution.

REFERENCES

1. NAVAIR 01-250 HDB-1 NATOPS Flight Manual; CH-46 D/F Helicopters.

2. Department of the Army Field Manual, FM 23-65, Browning Machinegun Caliber .50.

3. Department of the Army Field Manual, FM 23-67, Machinegun 7.62-MM, M-60.

4. Klaiber, R. J., Physical and Optical Properties of Projection Screens, Technical Report Naval Training Device Center, IH-63, Dec 1966.

5. American National Standard for the Safe Use of Lasers ANSI Z136.1-1973 American National Standards Institute, 1430 Broadway, NY 10018.

APPENDIX A

LASER SAFETY

The worst case condition for laser eye hazard is when all of the laser beam enters the eye pupil and is focused down to the minimum spot, on the retina, possible. This condition could occur in this system if the observer were to look directly into the laser beam as it left the laser.

The "American National Standard for the Safe Use of Lasers, (ANSI Z136.1 - 1973), specifies the maximum permissible exposure (MPE) for direct ocular intrabeam viewing of visible laser light as listed in table A-1 as a function of exposure time.

The standard also specifies that measurements of visible laser power or energy be averaged over a circular aperture having a diameter of 7mm and an area of approximately 0.4 cm^2. This implies that in order to be completely eye safe, for exposures up to 10 seconds, a visible, cw laser must have less than 0.4 milliwatts output. A 0.4 milliwatt laser is then eye safe unless an observer stares directly into the beam for a period exceeding 10 seconds.

Table A-2 lists various exposure times, MPE's, and calculated exposures for a 0.4 mw laser.

TABLE A1. MPE FOR DIRECT OCULAR INTRABEAM EXPOSURE

Exposure time (seconds)	MPE (joules / cm^2)
10^{-9} - 2×10^{-5}	5×10^{-7}
2×10^{-5} - 10	$1.8 \times 10^{-3}\ t^{3/4}$
10 - 10^{4}	10^{-2}

TABLE A2. COMPARISON OF MPE AND LASER EXPOSURE

Exposure time (seconds)	MPE (joules/cm^2)	Laser exposure (joules/cm^2)
10^{-6}	5×10^{-7}	10^{-9}
10^{-5}	5×10^{-7}	10^{-8}
10^{-4}	1.6×10^{-6}	10^{-7}
10^{-3}	10^{-5}	10^{-6}
10^{-2}	5.7×10^{-5}	10^{-5}
10^{-1}	3.2×10^{-4}	10^{-4}
1	1.8×10^{-3}	10^{-3}
10	10^{-2}	10^{-2}
10^{2}	10^{-2}	10^{-1}

APPENDIX B

EVALUATION COMMENT SHEET

I. Visual Display

1. How do you rate the quality of the background display in terms of ability to train aerial gunners?

a. Ability to see detail Required for gunner to do his job
- ☐ Excellent
- ☐ Sufficient
- ☐ Insufficient

b. Display Brightness
- ☐ Too bright
- ☐ Sufficient
- ☐ Too dim

c. Color
- ☐ Sufficient
- ☐ Color required but this display insufficient
- ☐ Color not required

d. Display Size
- ☐ Sufficient
- ☐ Too narrow both Width and Height
- ☐ Too narrow width sufficient height
- ☐ Too narrow height sufficient width

e. Image Jitter
- ☐ Not noticeable
- ☐ Noticeable but not too severe for training
- ☐ Too severe

f. Overall Display Quality
- ☐ Sufficient
- ☐ Insufficient

g. General Comments and Criticism
Comments on overall quality, choice of subject matter, what can be done to improve, etc.

2. How do you rate the target muzzle flash simulation?

a. Visibility
- ☐ Too obvious
- ☐ Sufficient
- ☐ Too Difficult to Notice

b. Brightness
- ☐ Sufficient
- ☐ Insufficient

c. Size
- ☐ Too Large
- ☐ Sufficient
- ☐ Too Small

d. Duration (Length of time on screen)
- ☐ Too Long
- ☐ Sufficient
- ☐ Too Short

Comment on method of simulation.
Should moving ground targets be included? Should there be more targets?
Recommendations and suggestions.

3. How do you rate the hit indication simulation?

a. Brightness
- ☐ Too Bright
- ☐ Sufficient
- ☐ Too Dim

b. Size
- ☐ Too Large
- ☐ Sufficient
- ☐ Too Small

c. Frequency - In this system every round produces a visual effect. Should this be changed?
- ☐ Yes
- ☐ No

If yes, should it be changed to:
- ☐ 1 round in 2
- ☐ 1 round in 4
- ☐ 1 round in 8
- ☐ 1 round in more than 8

d. Tracking - Considering that the skill being trained is to correct fire by watching hit impacts do the laser spots provide training in correction of fire?

- ☐ Yes
- ☐ Insufficient but some training
- ☐ No - Training unrelated to actual skills required

e. General comments and criticism

Comment on color, visibility, tracking accuracy, realism as compared to incendiary hits, effect of seeing hits in sky, etc.

4. How do you rate Tracer Simulation?

a. Color
- ☐ Accurate
- ☐ Inaccurate but OK for training
- ☐ Unacceptable

b. Brightness
- ☐ Too Bright
- ☐ Sufficient
- ☐ Too Dim

c. Tracking (same comment as 3d)
- ☐ Yes
- ☐ Insufficient but some training
- ☐ No training

d. Frequency (one tracer/second)
- ☐ Too Often
- ☐ Sufficient
- ☐ More traces required

e. General comments and criticisms.

Comment on realism, duration of tracer, compare with actual tracers, etc. Would ballistic drop add anything? Wind effect?

II. PLATFORM

1. How do you rate the firing platform?

   a. Size and shape (check as many as apply)

   - ☐ Platform area sufficient
     - ☐ Too Large
     - ☐ Too Small
   - ☐ Window sufficient
     - ☐ Too Large
     - ☐ Too Small
     - ☐ Too High
     - ☐ Too Long
   - ☐ Walls sufficient
     - ☐ Too Close

   b. Vibration (prime purpose of vibration is to throw off aim simulating effect of recoil)

   - ☐ Sufficient
   - ☐ Too much
   - ☐ Not enough

   c. General comments and recommendations, comment on general appearance, feeling, suitability for training.

   Would use of actual helicopter in a hangar as firing platform (without vibration) be better for training?

2. How do you rate the weapon and handling characteristics?

   a. Degree of difficulty in maneuvering aim

   - ☐ Too difficult
   - ☐ About the same as actual
   - ☐ Too easy

   b. Recoil - What effect does lack of recoil have on training

   - ☐ No effect
   - ☐ Some recoil is required

   c. Noise - What effect does lack of noise have on training

   - ☐ No effect
   - ☐ Some noise is required

d. General Comments and Recommendations.

What should be added, in way of weapon simulation? What about weapon malfunctions? What about M-60 simulation?

III OVERALL SYSTEM

1. How do you rate the overall training capability of the system; 1. as is and
2. as modidied by your recommendations?

	1	2
Can serve no useful Training Function	☐	☐
Can supplement live fire training	☐	☐
Can substitute for some live fire training	☐	☐
Can replace all live fire training	☐	☐

2. Additional comments not covered above. For example; need for scoring capability, need for motion system, etc.

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