AN INDIRECT-FIRE TERMINAL EFFECTS SIMULATOR

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ABSTRACT

This paper describes the concept development and feasibility demonstration of a man-safe cueing system for the impact of indirect fire in a simulated battlefield environment. This system provides a safe, cost-effective method for including mortar and artillery into the battlefield training/evaluation scenario for both mounted and dismounted players. This cueing system is based on a lightweight projectile having a very low impact energy and carrying a flash/bang/smoke generator. This projectile is launched from a low pressure pneumatic device that is capable of projecting the cue to ranges of 200 to 300 meters using a simple constant-mass, constant-drag projectile. A manually controlled launcher was constructed to demonstrate the feasibility of the cueing concept. A remote controlled, multiple shot launching device (providing coverage of a one kilometer diameter circle) is well within current technology. The soft-nose projectile is designed to have a terminal energy similar to that experienced during the impact of a served tennis ball. The flash, acoustic and smoke cues are tailored for player safety.

INTRODUCTION

Overview

Increased military awareness of the importance of finding cost effective methods of simulating battlefield conditions for the purpose of testing concepts and training personnel has led the U.S. Army to investigate simulation techniques for indirect fire as well as small arms and direct fire weapons. Examples of the latter are the MILES (Multiple Integrated Laser Engagement System) and the IDFSS (Infantry Direct Fire Simulation System) programs. Current technology for the simulation of indirect fire uses ground-placed flash/bang/smoke (FBS) generators, smoke bombs, referee-designated impact areas, and other techniques which detract from the realism or imperil the participants.

The Engineering Experiment Station (EES) of the Georgia Institute of Technology entered into a one year-three month research program to show the feasibility of an air launched indirect fire cue (1). The overall objective of this research was to perform an exploratory analysis of various methods to accurately and remotely place a cue of an exploding shell in a predetermined area. This cue must automatically and simultaneously deliver a triple-signature display involving a brief but intense flash of light and audible impulse, as well as the deployment of a gaseous or particulate smoke. All facets of the system were investigated with regard to minimizing their potential for causing injury to the operator, players, or observers. Attention was also given to the environmental impact resulting from the presence and use of the system.

Background

The objective evaluation of military tactics and doctrine requires scientifically controlled experiments of free play war game exercises in a simulated battlefield environment. The support for such field experiments requires a sophisticated range instrumentation and data collection system. It also requires a realistic simulation of the weapon systems (in a manner that is player safe) to preserve realism for the player elements. The U.S. Army Combat Development Experimentation Command (USACDEC) at Ft. Hunter-Liggett, California, has established a facility of this type for use with dismounted players, vehicle mounted players, and player and weapon elements that are airborne on helicopters, and combat aircraft.

Direct fire weapons have been effectively simulated at the Ft. Hunter-Liggett test range through the use of co-boresighted laser devices that are attached to the weapon barrels. These laser units trigger electronic casualty assessment devices (photocells) located on other player elements at distances consistent with the effective range of the weapon being simulated. The laser simulation system is triggered for small arms fire by the firing of a blank cartridge in the weapon. With larger weapons such as a TOW launcher or a tank gun, the event of a firing may or may not be accompanied by a simulation of the firing signature (an FBS signature from a weapons effect simulator located at the launch site). These weapon simulation systems have provided many meaningful measurements in predefined tactical situations through the range instrumentation system and data collection facility at Ft. Hunter-Liggett. The simulated battlefield scenario addresses many of the weapon systems encountered in actual battlefield situations, but it does not include a simulation and casualty assessment for indirect fire weapons (howitzers, mortars, etc.). Indirect fire weapons may be used for inflicting casualties on opposing forces or for troop suppression. Inclusion of this important area of weapon technology is highly desirable to develop a realistic and accurate simulation of a battlefield environment. The relatively high trajectory and long firing range of the indirect fire weapon class does not allow the laser illuminator to be used as it is with a direct fire system. The simulation of the indirect fire weapon may be limited to the impact signature without affecting the realism to the players since the gun position would normally be several kilometers away. This impact simulation and casualty assessment is best accompanied by a suitable simulation of a FBS cue.

The impact simulation of indirect fire weapons is an extremely difficult problem to solve in a manner that is cost effective and relatively safe to the player elements in the field. As a result, the term "simulation" is not an accurate description due to the requirements for man safety. A true simulation (normally implying a reproduction or copy of the original) is not desired due to the possibility of human injury resulting from this level of explosion. In the simulated battlefield, a more appropriate term for creating the impact signature from an indirect fire weapon is a "cue" containing the three basic FBS characteristics. Each of these cues must be tailored to provide the required player safety for the battlefield scenario employed.

Evaluation Criteria

Evaluation criteria were applied to each feasibility model design task to optimize the final recommended cueing system. The evaluation criteria were (not necessarily in order of importance):

1. Performance
2. Cost
3. Reliability
4. Safety
5. Operational Life
6. Environmental Impact
7. Ease of Manufacture.

The performance of the deliverable system is of course a function of each integral component, however, the ultimate test of performance was judged on the basis of how accurately an FBS projectile could be projected to a desired location and to what degree the FBS projectile acted as an artillery or rocket fire cue to players engaged in a simulated battlefield situation. Accuracy was determined by a circular error probable (CEP) analysis of the projectile impact locations at the maximum contract-specified range (150 meters). The definition of CEP used in conducting this analysis is taken from (2). The effectiveness of the cue was based on the ability of the FBS unit to generate an attention-gaining audio/visual event. The performance of the deliverable system and that performance which is technically possible differ due to the constraints placed upon the system by the Surgeon General's safety standards as well as cost limitations. Compliance with established safety and health regulations placed ceilings on various parameters (e.g., sound level). Other items were economically regulated. For example, the projectile could employ sophisticated microelectronic circuitry to regulate flight characteristics, timing of FBS deployment, etc., however, the transferral of as much technology as possible from the projectile to the launching device is important because the launcher is a one-time fixed cost while expendable projectiles are a recurring cost and therefore should be as economical as possible. As is usually the case, economy implies simplicity, so constraints were placed on the projectile design complexity.

Operational life and reliability are related factors which also directed the course of the design. For example, the decision to have an expendable projectile (long shelf life but short operational life) was a step toward increased reliability. Reliability was also considered in terms of launcher design since future Army goals require the launcher to operate unassisted.

The predominant risks to environmental safety as a result of using this system stem from fire hazard and toxic materials pollution. The launcher design is completely free of these risks, however, the projectile design necessitates the use of nonbiodegradable materials and minute quantities of volitile substances. Care was taken to avoid toxic materials in the construction of the projectile. Ingestion by man or animal of any part of the projectile, though unsuitable for consumption because of the physical shapes involved, would not result in poisoning (especially in the quantities present). The chance of starting a fire is remote through careful gas containment design and is further diminished by the use of nonflammable and self extinguishing materials (e.g., polycarbonate sheet (Lexan), polystyrene (Styrofoam), teflon, etc.).

Ease of manufacture was essential to provide an affordable and usable cueing system. Economy, reliability, and serviceability all stem from uncomplicated design. Not only the composition and shape of each system component, but the underlying design philosophy had to be considered before recommending a design for mass production.

FLASH/BANG/SMOKE UNIT

The flash/bang/smoke (FBS) unit contained within the projectile has been engineered to deliver a triple-signature display consisting of an intense flash of light, an acoustic impulse, and a cold particulate smoke. The respective signatures have been limited to bounds established by the Surgeon General where applicable, and where no guidelines are available, safety limits have been justified and established through experimentation and consultation with medical specialists. Fire safety has been enhanced through the use of cold ejected particulate smoke, high efficiency light generation with triple light-transmitting/heat-blocking barriers to minimize heat leakage to the environment, and encapsulated, self-extinguishing, or fire-proof projectile and FBS unit components.

The purpose of the FBS unit is to deliver a detectable cue during war games so individual players will realize that they are under indirect fire. A secondary purpose for the FBS unit is that it will in a limited sense simulate the explosion of artillery round upon inpact. The most desirable situation from a cue standpoint and a simulation standpoint would be to have the FBS unit identically simulate an actual artillery impact and yet be man safe. This is a contradiction, however, and in a war game scenario, man-safety has priority over simulated realism.

Numerous restrictions have been placed on the FBS unit in an effort to assure man safety. First, the flash should not exceed that experienced during a normal photographic flash. The exposure to acoustic impulse noise is designated by the Surgeon General of the U.S. Army (TB MED 251) not to exceed 140 dB peak impulse at the ear without the use of ear protection to be ear-safe. A distance of six inches from the ear has been interpreted to specify the sound level "at the ear." This interpretation is justified (in the absence of any other guidelines) as being a reasonable estimation of what might be experienced by a player in the prone position having a cue impact on the ground beside his head. Thus, a peak level of 109 dB at 18 feet, for instance, would be nominally 140 dB at six inches. The consultants issuing TB MED 251 have designated the 140 dB peak value as being unlikely to provide hearing problems on successive applications.

The smoke associated with the FBS unit, particularly when used to cue a forward observer, must be visible at a range of one or two kilometers. A relatively dense cloud approximately two feet in diameter by four foot in height has been shown to be a minimum for two kilometer visibility (3). This nominal cloud size was the goal for this development program.

Basic Configurations

Combinations of flash, bang and smoke considered for the FBS unit included an integral flash, bang and smoke; separate flash from bang and smoke; as well as various means for producing each (e.g., electrical flash, pyrotechnic bang and chemical smoke). The success of any given technique as it relates to an FBS cue is somewhat subjective.

A commercially available Magicube camera flashbulb was adopted as an igniter and flash generator. It can be actuated by a slight impact of a small wire on the stem of the flashbulb and eliminates the need for an electrical ignition system or an impact primer system. The Magicube bulb puts out significant light with a 5500° Kelvin color temperature. The heat associated with the flash is such that it can be used to ignite pyrotechnics, thereby acting as a primer for the bang and smoke charges of the FBS unit.

The bang of the FBS indirect fire cue must be sharp enough to be heard, but not exceed on an impulse basis 140 dB peak at the ear of the player. The magnitude of this sound impulse is directly related to the rate of release of the pyrotechnic gases as well as the quantity of the gases. The release rate is a function, therefore, of the rate of escape of a sabot or the rate of rupture of a container.

Smoke is defined as a cloud of particulate material having particles between .01 microns and 100 microns of such number and concentration that the contrast between the population of these particles to nearby particulate affects visibility, light reflection and scattering. As defined, smoke may be composed of soot particles, dust particles or almost any small particulate matter suspended in the airmass. Consequently, in this program the two methods of providing smoke were to let a pyrotechnic develop the smoke during the combustion process, such as a phosphorus-oxygen type smoke, or to provide a dust material contained in a sabot which is dispensed into the air, by burning a small amount of pyrotechnic powder behind the sabot.

Tests show that pyrotechnic smoke performs better than ejected-dust smokes, however, the general fire hazard involved in a pyrotechnic smoke and the usually detrimental by-products of the burning substance which forms the smoke made pyrotechnic smokes a less desirable choice than the ejected dust for the FBS unit. In addition, ejected-dust smokes of the type of sodium bicarbonate, potassium bicarbonate and calcium carbonate are water soluable and what little dust of these types that actually gets into lung areas will be dissolved by lung fluids and subsequently be ejected with other waste material.

Bang and Smoke Ignition

Analysis indicated that the best solution to ignition of the bang and smoke section of the FBS unit was to utilize the caloric output of the Magicube (TM, Sylvania) flash generator. The zirconium oxide which is the product of combustion within the Magicube bulb boils at 5000° Kelvin. The boiling process tends to stabilize temperature and hence limits the peak temperature that is achieved. The radiating temperature is therefore 5000°, and the bulb can transfer only about one to two calories of energy into its surroudings. Ignition with this system is achieved by coating the inner faces of the Magicube bulbs (four per flash cube) with a rubber-based cement which holds an ignition compound in close proximity to the surface of the bulb for most realiable ignition. The "powdered-bulb" method of bang and smoke ignition has several advantages over others tried. In particular, realiability is increased because any one of the four flashbulbs in the Magicube can ignite the ignition compound and thereby result in detonation of the bang and smoke portion of the FBS unit. Testing of Magicubes has yielded a small number of bulbs which were defective for one reason or another, therefore, this redundant reliability factor is warranted. A further advantage is that the ignition compound burns within the plastic housing of the Magicube; this tends to minimize the chance of hot gases escaping into the atmosphere and causing a fire.

The bang and smoke section of the FBS unit is housed in a 16 gauge shotgun shell as shown in Figure 1. This portion of the FBS unit is herme-

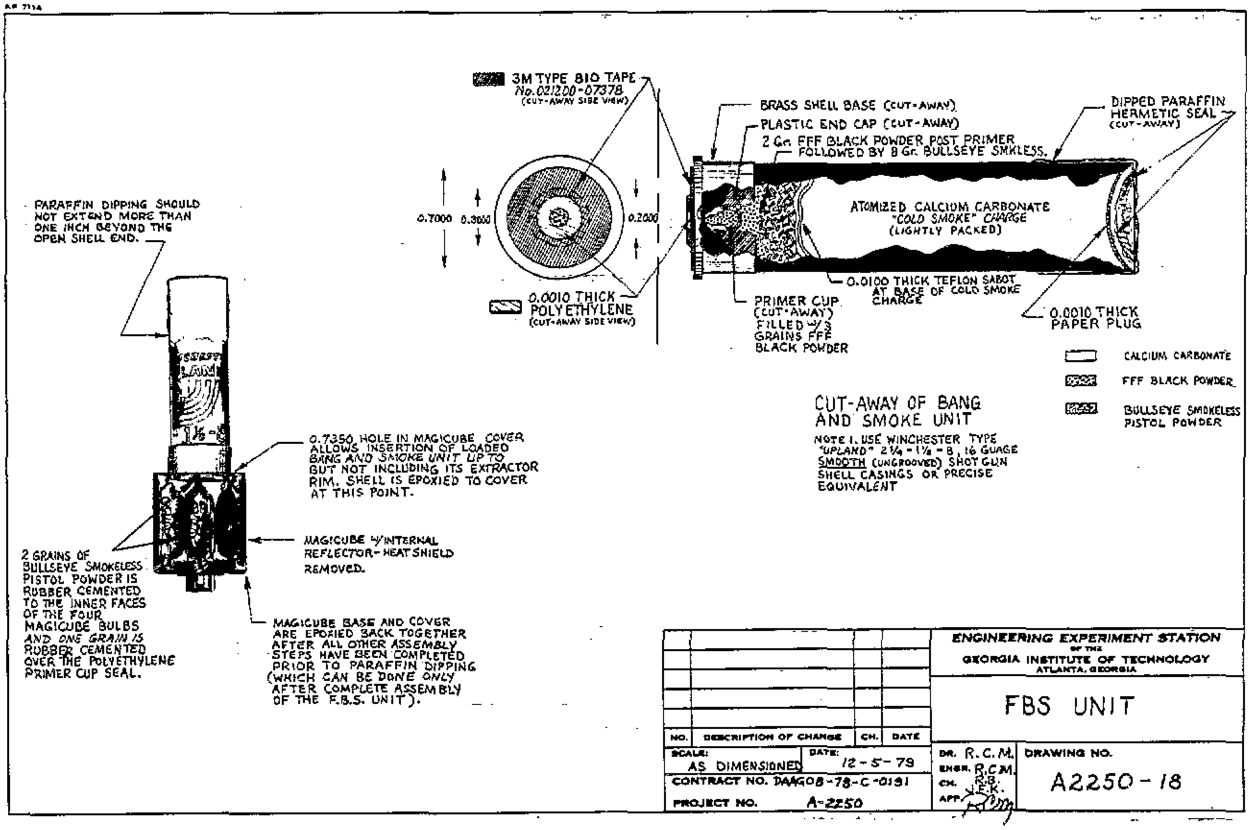

Figure 1. Flash/Bang/Smoke Unit

tically sealed since the bang and smoke charge primer is hygroscopic and the atomized calcium carbonate "cold smoke" must be moisture free for correct dispersion when deployed. As shown in the figure, the bang and smoke charge is placed through an opening in the top of the Magicube housing. Upon projectile impact, the Magicube bulbs are actuated, and this in turn ignites the ignition compound painted on the bulbs. The flash of the Magicube bulbs and the ignition compound constitutes the flash signature. The hot gasses produced by the burning of the ignition compound penetrate the hermetic seal over the primer charge on the bang and smoke unit.

These hot gases continue into the black powder shotgun shell primer causing it to flash through the flash hole in the primer cup of the shotgun shell and ignite the smokeless bang charge contained on the other side. When the smokeless bang charge detonates, it creates rapidly expanding gases which serve 1) to cause a bang and 2) to blow the calcium carbonate "cold smoke" charge out the back of the shell (and through the weak polystyrene tail section of the projectile), thereby deploying the smoke signature. Since the smoke is a cold smoke, the fire hazard is diminished. The rapidly expanding gases which drive the smoke charge out cool quickly and are dissipated upon reaching the atmosphere. The calcium carbonate also serves to lessen the chances of fire by acting as a chemical fire extinguisher. The FBS unit is doubly shielded against fire hazard by confining the hot gases evolved during ignition to the inner Magicube plastic housing and the outer flash housing of the feasibility model projectile fuselage (to be discussed).

Empirical Findings About the FBS Unit

Many firings of the feasibility model FBS unit were made both in the projectile and on a test stand. Each time an FBS unit was ignited, it was rated as to its effectiveness as a cue. The flash intensity is sufficient to be seen at a 200 meter range in bright sunlight. The flash of the FBS unit is striking in low light level conditions such as night, early evening or an extremely overcast day; in very bright sunlight conditions, a projectile landing some distance from an individual would not necessarily catch his attention via the flash unless it happened to fall within his direct field of vision.

The deployed smoke cloud produced by the ejected calcium carbonate is quite noticeable at a 200 meter range immediately after it is deployed (while the cloud has a cross sectional dimension of 1 square meter). Under calm wind conditions, the cloud is still entirely visible and stands out against its background when it has bloomed to a two square meter cross sectional area. This cross section is about maximum for the "cold smoke" cloud. Beyond this cross sectional area, the cloud begins to fade. In addition, wind will tend to disperse the cloud, particularly if the wind is turbulent. The cloud produced by the feasibility model FBS unit should be entirely useable by forward observers with a clear field of view up to 300 meters. Larger and more visible smoke clouds can be produced by combustion techniques within the same projectile delivery system, but are less player safe and present a greater fire hazard.

The sound level of the FBS unit is on the order of 108 dB (measured 3 meters from the point of impact). At a range of 200 meters, the FBS unit is clearly audible, though at this range the presence of any ambient noise in close proximity to the player (e.g., truck motor, gunfire, close talking) may totally obscure the sound signature of the FBS unit.

The deployment of an FBS unit at a range of 200 meters is adequate to cue a player engaged in a war game to the presence of incoming indirect fire. The effect is greatly enhanced if the cues are dropping within 100 meters of the players. Certain features in the FBS unit could be improved if the man safety requirements were to be less restrictive. A smoke cloud visible at 2 kilometers is well within reason if a pyrotechnic rather than cold ejected smoke could be used. A bang in excess of 108 dB is easily achieveable, and would result in a more noticeable cue for projectiles dropped at maximum range from a war game player. The flash intensity is the one item that is difficult to increase safely. The safety concern is not one of man safety but of fire safety. Since the eye has a logarithmic response merely doubling the flash intensity does not have a profound effect. The flash intensity would have to be increased by a factor of eight or sixteen to make a significant difference. A pyrotechnic flash would have to be used to achieve this level of intensity with the current feasibility model projectile. Some question exists as to whether the hot gases associated with such a flash could be easily contained within the flash housing of the projectile.

PROJECTILE

The basic design of the projectile for the indirect fire simulator/cue depended upon two performance factors; flight stability and man safety from the standpoint of impact blunt trauma to an individual. Tests were performed on a baseline projectile to determine its flight characteristics. This baseline projectile was a simple cylindrical object with an ogive nose section. Wind tunnel tests were used to determine the stability of the projectile in terms of roll, pitch, yaw, and effects of drag in the air mass.

Man safety of the projectile impact is directly related to impact momentum. Impact momentum (P) is a function of impact velocity (V) and projectile mass (M).

$$P = MV$$

One must reduce either the impact velocity, the projectile mass, or both to reduce the impact momentum.

A possible scheme to reduce the impact velocity is to use a variable drag technique, which employs air brakes that are deployed late into the flight of the projectile so as to achieve maximum range with a low drag profile and then, at a predetermined point in the flight, increase the drag to significantly reduce projectile velocity.

Another method to reach maximum range with minimum impact momentum is through the use of a variable mass projectile. A variable mass projectile can jettison mass during flight. A convenient source of discardable mass is fluid; however, powders and even gases can be allowed to escape. One possible mode of operation involves the use of a pressurized gas compartment and a fluid filled compartment within the projectile which are separated by a flexible balloon-like diaphram. The fluid compartment is vented to the outside through a narrow tube leading to the aft portion of the projectile. Upon launch, fluid is forced through the orifice at the end of the projectile by the expanding pressurized gas compartment acting through the flexible diaphram. Mass is therefore continually lost by the projectile throughout the flight. By careful timing of the fluid release, the projectile can be made to achieve the maximum desired range by the time the entire fluid charge has been expended. The projectile then falls to the ground with a mass that is significantly less than the launch mass, thereby imparting less momentum to any object that it strikes. Combinations of variable mass and variable drag are also possible. Both the variable mass and variable drag concepts are valid methods for reducing impact momentum, but the complexity and cost of the projectile is increased, while the timing of these final momentum-reducing schemes introduces an additional source of error into the launch system.

A constant mass projectile is one having a final impact mass that is the same as its launch mass, and a final velocity that is proportional to its launch velocity (where the constant of proportionality relates to the aerodynamic drag coefficient of the projectile shape). In any of the projectile configurations mentioned, terminal momentum must be low enough to allow impact upon an individual without causing bodily harm. (Note however that harm to an individual is possible by any practical projectile regardless of configuration if the impact is sustained upon certain areas of the body (e.g., eyes)). One major advantage of a constant mass projectile arises from its inherent reliability. Both variable mass and variable drag schemes could fail to deploy their final momentum-reducing mechanisms after launch, resulting in an unsafe impact momentum. Such a condition cannot occur with a man-safe constant mass projectile.

Constant Mass Final Velocity Tests and Man Safety

Early in the development of the pneumatic launcher, reuseable constant mass non-variable drag balsa wood test projectiles were used to test the launcher. These projectiles weighed anywhere from two to five ounces. When conducting tests at the 150 to 200 meter range, technicians standing nearby noted that the impact velocity of the projectile appeared sufficiently slow such that they were willing to try to catch them in midflight. Final velocity tests were then conducted to determine the man safety of the projectile if neither variable mass nor variable drag techniques were employed.

Three basic tests were performed to assess the final velocity of the projectiles. First, a projectile with a calibrated momentum sensor was used to measure the terminal momentum and hence velocity in situ. A second method involved high speed photography of the projectile upon impact, and the third, a standard police radar was used to measure the velocity just prior to impact.

All three methods yielded corresponding final velocity information. For the feasibility model projectile, the measured final velocity was on the order of 64 kph upon impact. Other objects were investigated that might also have a 64 kph impact velocity to obtain a feel for the damage that might be incurred by a human struck by such a projectile. In particular, a tennis serve was studied because the weight of a tennis ball was within grams of the feasibility model projectile, and therefore, would be a good indicator. Using the police radar, a tennis ball was served numerous times directly at the radar antenna. Spectrum analysis showed that the tennis serve also yielded a velocity of approximately 64 kph. This means that the danger of human damage due to a strike by the feasibility model projectile would correspond to that expected of a strike by a tennis ball being served. Various other sports activities were found to involve greater danger of damage due to strikes by the playing implements. For example, a fly baseball presents a greater danger to an outfielder than does the feasibility model projectile.

After reducing the impact momentum data and finding that the final velocity was 64 kph for the feasibility model projectile, the technicians were allowed to attempt to catch dummy projectiles in flight. The picture sequence in Figure 2 shows one such successful catch.

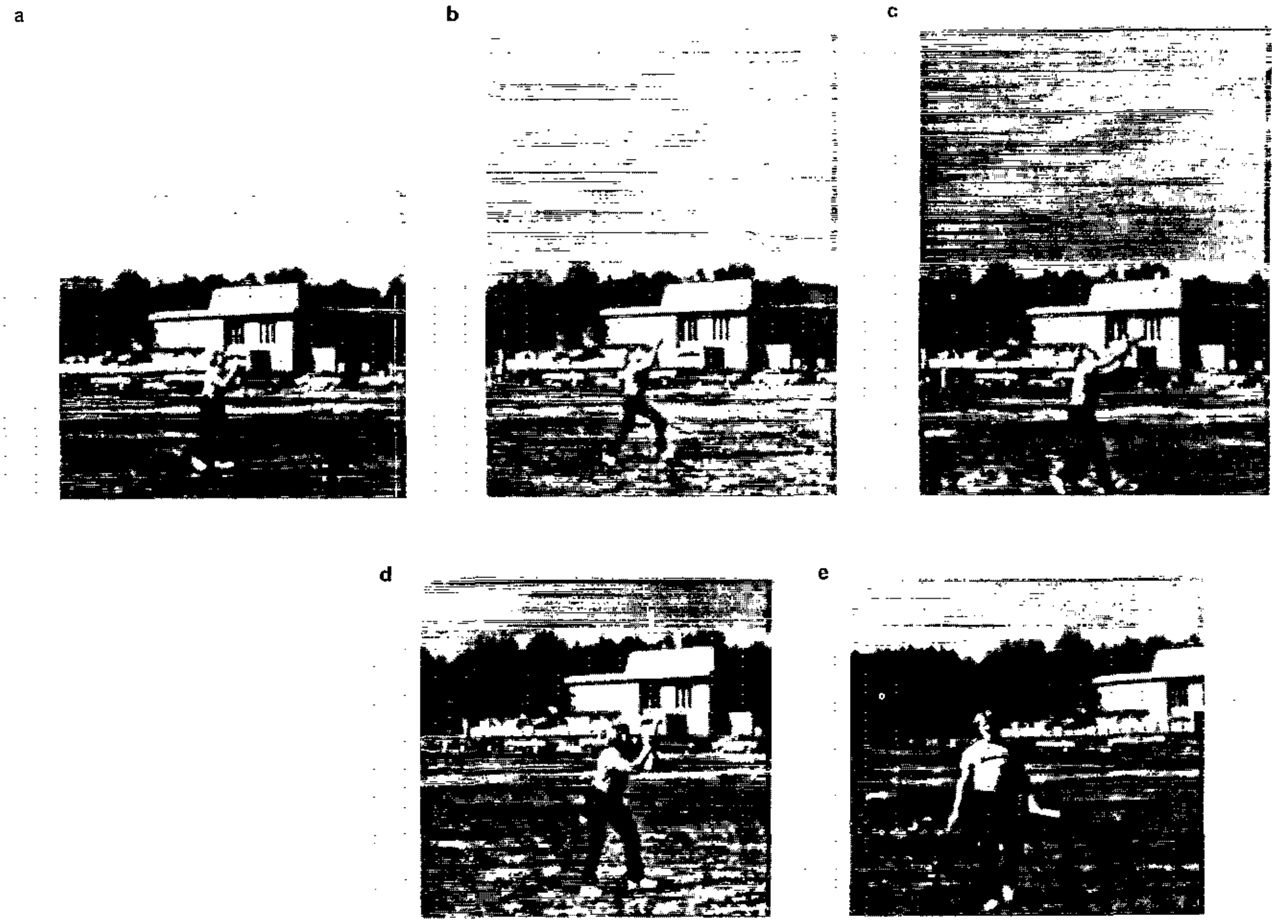

Figure 2. Impact Safety Demonstration

The Feasibility Model Constant Mass Projectile

Once it was demonstrated that projectiles were relatively impact safe to humans, a decision was made that variable drag and variable mass techniques would not be necessary to achieve the contract goals since constant mass projectiles could be launched to ranges in excess of 200 meters and still be man safe from an impact standpoint.

Figure 3 shows the components used to construct the feasibility model projectile. These components include a polystyrene tail section, rubber hemispherial nose section, two piece epoxy arming mechanism and guide mechanism, and Lexan flash housing. Each of these components was carefully designed as to size and weight to result in a feasibility model projectile of precise center of gravity and mass. The tail section is made from fused polystyrene beads. A smooth finish and a rough finish is possible depending on the size beads used in the manufacturing. Polystyrene beads that will result in a rough finish for the tail section are necessary because minor turbulance is formed over the surface of the tail section to break the laminar air flow in much the same way that the dimples on a golfball provide stability by breaking the laminar flow. The minor turbulance causes an increased drag in the tail section which results in projectile stability by assuring a greater side drag behind the center of gravity than in front. All portions of the projectile from the tail section forward must be kept as smooth as possible for the stabilizing effect of the rough tail section to be effective.

The Lexan flash housing is made of 10 mil Lexan tubing. Lexan was chosen as a flash housing material because it is self-extinguishing and does not shatter during impact. The use of Lexan assures that there will be no shrapnel upon impact and also prevents the high temperature gases evolved within the FBS unit from burning through to the outside.

The arming mechanism has four firing pins which are forced up through the base of the FBS unit upon impact, and result in FBS unit ignition. In the unarmed position, these pins are physically misaligned with the FBS unit ignition system. When placed in the armed position by manually rotating the arming mechanism relative to the projectile fuselage, the pins are aligned with holes in the base of the FBS unit, thereby allowing a forward impact to force the firing pins into the holes causing FBS unit detona-

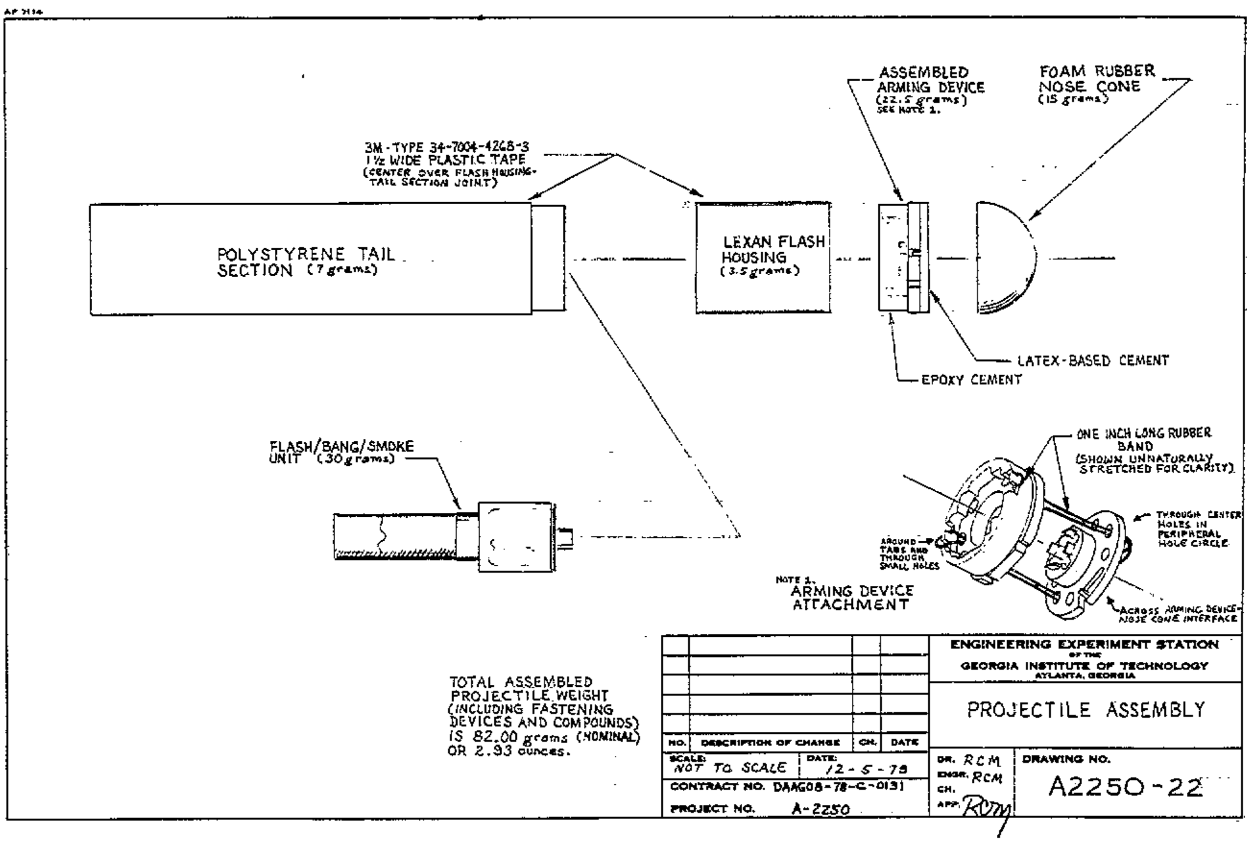

Figure 3. Projectile Assembly

tion. Tests have shown that an unarmed projectile can be handled rather roughly and even dropped without danger of igniting the FBS unit; however, when armed, dropping of the projectile on the nose from a height of as little as 1 foot can set off the FBS unit.

The nose cone of the feasibility model projectile is hemispherical, and is made of a foam rubber compound. This nose cone adds the weight necessary to bring the center of gravity to the very front of the flash housing. From an aerodynamic standpoint the hemispherical nose shape is a 73% drag improvement over a simple flat ended projectile nose. A fully assembled feasibility model projectile is shown in Figure 4.

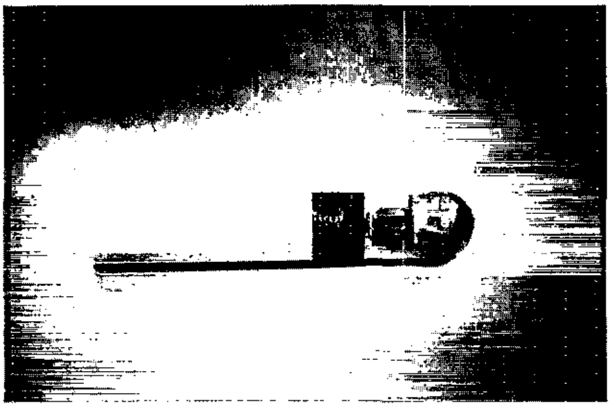

Figure 4. Final Feasibility Model Projectile With FBS Unit

PNEUMATIC LAUNCHER

Early attempts to test a pneumatic launcher employed a freon tank, a two inch brass ball valve, and a length of Polyvinal Chloride (PVC) plastic pipe, as shown in Figure 5a. Figures 5b through 5d show the pneumatic launcher that was ultimately developed. Figure 6 identifies the major components which comprise this feasibility model pneumatic launcher. It operates on the pneumatic principle of a blow gun using vaporized liquid CO_2 as a propellant. An explosive flapper valve is used to transfer pressurized CO_2 gas from an intermediate holding reservoir to the barrel of the launcher in which a projectile has been placed. *The expanding CO_2 gas is capable of* ejecting a two to three ounce projectile from the barrel and hurling it in excess of 200 meters using CO_2 reservoir pressures as low as 30 psig (see Figure 7).

Valve Considerations and Pressure Rise Time Within the Barrel

The early pneumatic launcher used a large diameter ball valve which was activated through a spring mechanism to achieve as fast an opening as possible. After extensive testing, data showed that at higher pressures increased range was not appreciable. Analysis indicated that the valve opening speed played an important role in achieving maximum range at these higher pressures due to the pressure rise time within the barrel. When the valve is initially opened, the pressure in the reservoir begins to drop, and the pressure within the barrel behind the projectile begins to rise. Immediately upon overcoming static friction, the projectile moves down the barrel in front of the increasing pressure wave front. Tests involving the ball valve and high pressures, demonstrated that the projectile could move down the barrel and, in fact, leave the barrel before the complete build-up of barrel pressure had taken place. As reservoir pressure was increased beyond this point, it had little effect because the pressure front could not fully transfer its energy to the projectile once the projectile had cleared the end of the barrel.

An improved valve design emerged wherein a flapper valve was used to explosively transfer pressure from the reservoir to the barrel. A significant increase in performance was immediately noticed. By using the pressure in the reservoir to blast the valve open, it was possible to obtain a reservoir-to-barrel pressure transfer in much less time than previously achievable with the ball valve/spring arrangement. The pressure in the barrel could reach a maximum before the projectile left the end of the barrel; therefore, up to 30 psig, most of the pressure stored in the reservoir could be applied to the projectile. If pressure were to be increased beyond 30 psig a limit would be reached where the reservoir pressure transfer time would exceed the projectile time-in-barrel. Other higher speed valve configurations, such as exploding diaphrams, are possible; however, these devices are not reusable and would not be suitable for automated operation of the launcher.

Muzzle Brake

A muzzle brake was designed for use with the pneumatic launcher. The purpose of this break was to minimize the effect of diffracting air currents passing from the barrel into the atmosphere. If allowed to go unchecked, these diffracting air currents can deflect the tail of the projectile as it clears the end of the barrel (high speed motion pictures of test projectiles leaving the barrel without the muzzle brake have visually confirmed this deflection). These initial tail deflections result in undesired trajectory perturbations. Placement of parallel plates at the end of the barrel which have holes that are slightly larger than the inner barrel diameter passing through the center of each plate, allows the projectile to move from the barrel, through the plates, and into the atmosphere under the direct force of the planar pressure front that drives the projectile up the barrel. Any pressure wave fronts which are off-axis impinge upon the parallel plates and are redirected perpendicular to the flow direction of the main wave front. Several plates were employed to increase the efficiency of the muzzle brake (see Figure 5e). Photographic, CEP, and range data analyses all confirmed the effectiveness of the muzzle brake.

The Creation of the Air Bearing

During launch, the pressure front formed behind the projectile forces it down the barrel. Initially, there is contact between the

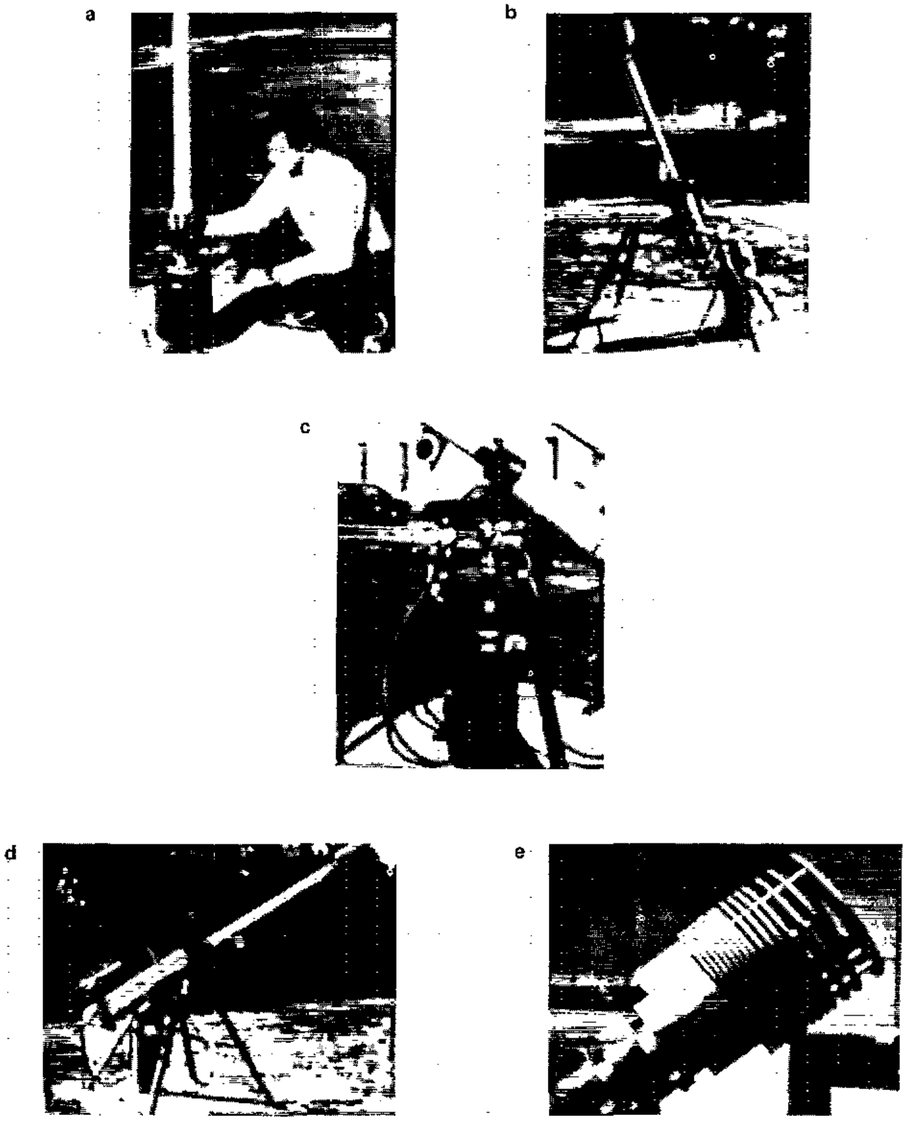

Figure 5. Pneumatic Launcher

projectile and the barrel. As the projectile begins to move down the barrel, however, it rides on a cushion of air as the pressure from behind escapes along the narrow projectile/barrel-wall interface. This air bearing is not formed at low launch pressures (e.g., five psig). Only when the launch pressure is of sufficient magnitude to force gas past the projectile, does the air bearing form. The movement of the projectile can also enhance the formation of the air bearing. There is a point at which the projectile will begin to move up the barrel at low pressures (after having overcome static friction) while maintaining significant barrel contact. After obtaining a certain barrel velocity at these low pressures, leakage occurs around the projectile which eventually forms an air bearing. The production of the air bearing is essential for efficient operation of the pneumatic launcher. Best results are achieved at pressures above 8 psig due to the formation of the air bearing. Short range launches are therefore best achieved through the increase of quadrant elevation, rather than the continual decrease in reservoir pressure.

Wide Area Coverage Considerations

Consideration was given to the question of maximum range attainable versus launcher cost. Either a single launcher must be capable of 360° operation at a range sufficient to cover an area, or a number of shorter range 360°-operable launchers must be employed in a matrix to achieve maximum coverage of a given area. Figure 8 shows the geometry used to determine the spacing of

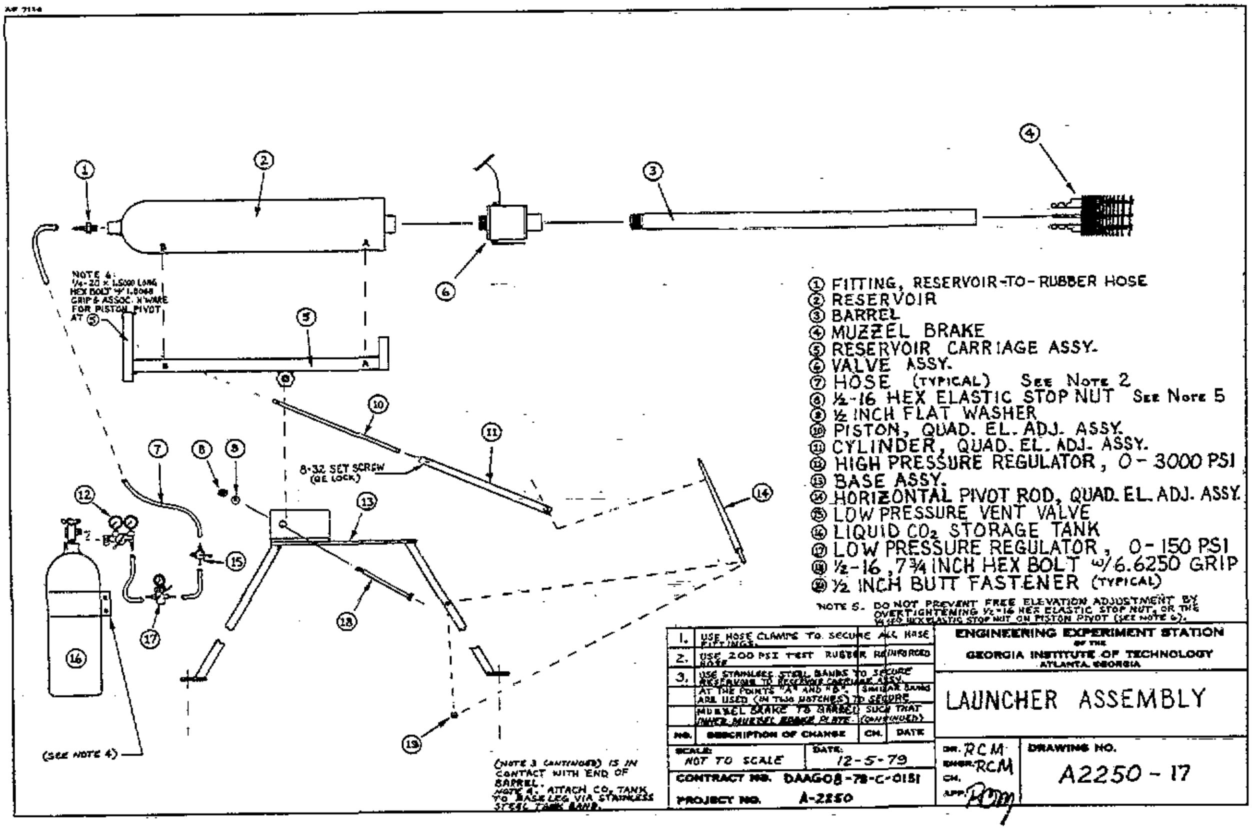

Figure 6. Launcher Assembly

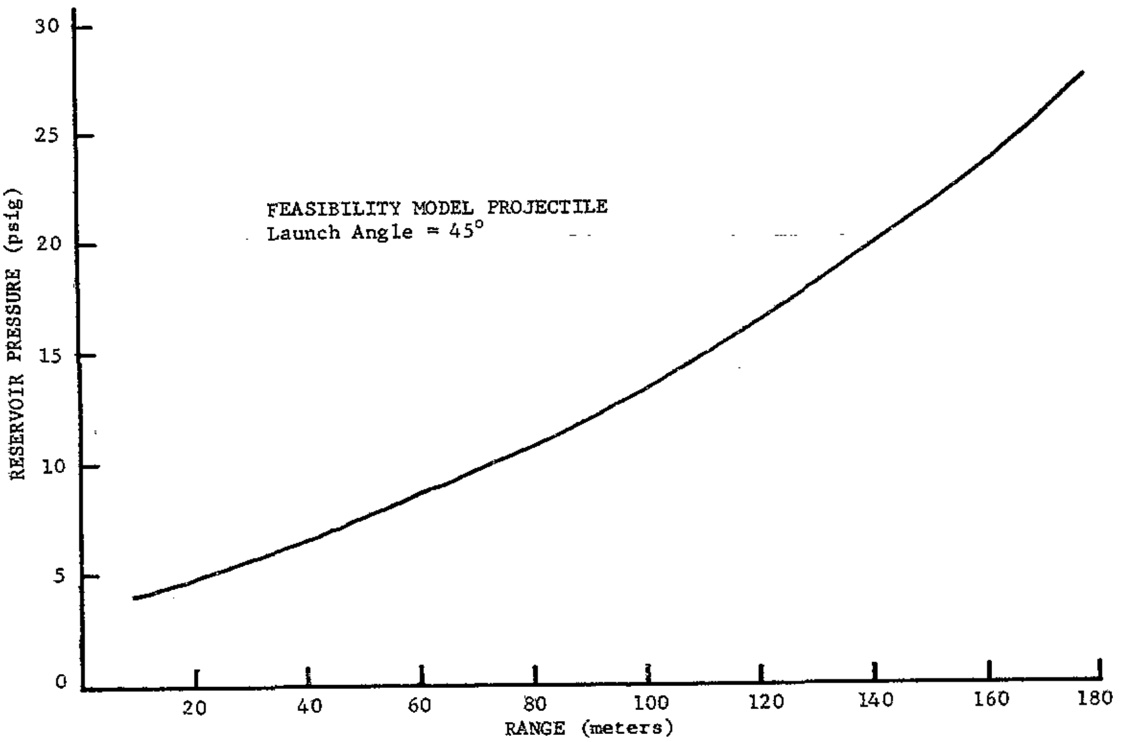

Figure 7. Range Performance vs. Reservoir Pressure

launchers of a maximum launch range (R) within the matrix. The separation (D) necessary for these launchers is related to the maximum range of the launcher by the curve shown in the graph of Figure 8. Note that this curve is exponential and that the average number of launchers decreases drastically as range capability is increased. Currently the feasibility model launcher can attain a maximum range of approximately 200 meters using reservoir pressures that do not exceed 30 psig. Additional research will be necessary to determine if significantly greater ranges can be achieved through either launcher modification (e.g., increased reservoir pressure or advanced valve design) or modification of the feasibility model projectile (computer simulations have recently shown that maximum launch ranges of 500 meters (1 km circular coverage) are possible using increased launch pressures coupled with a reduced diameter projectile that has a launch weight two and one half times greater than that of the feasibility model projectile. Verification of these computer simulated results is forthcoming). A performance constraint is placed on the maximum achievable range however. As the maximum range capability of the launcher is increased, so is the projectile time-of-flight. The projectile trajectory is subject to wind-induced perturbations as long as the projectile is in flight, and therefore the CEP of the indirect fire cueing system will degrade with increased range capability.

Man-Safety Aspects of the Launcher

Since the launcher normally achieves muzzle velocities on the order of 145 to 160 kph (see Figure 9), care should be taken to avoid direct impact by the projectile at point blank range since the projectile is moving at its highest velocity immediately after leaving the barrel of the launcher. Use of the feasibility model requires only that operators and onlookers remain out of the field directly in front of the muzzle. All other aspects of the launcher are man-safe. The propellant used is carbon dioxide, and the amount expelled per shot is not significant when expulsion is into the open atmosphere. The sound level of a launch is about 98 dB as measured three meters in front of the launcher and is well within the Surgeon General's guidelines.

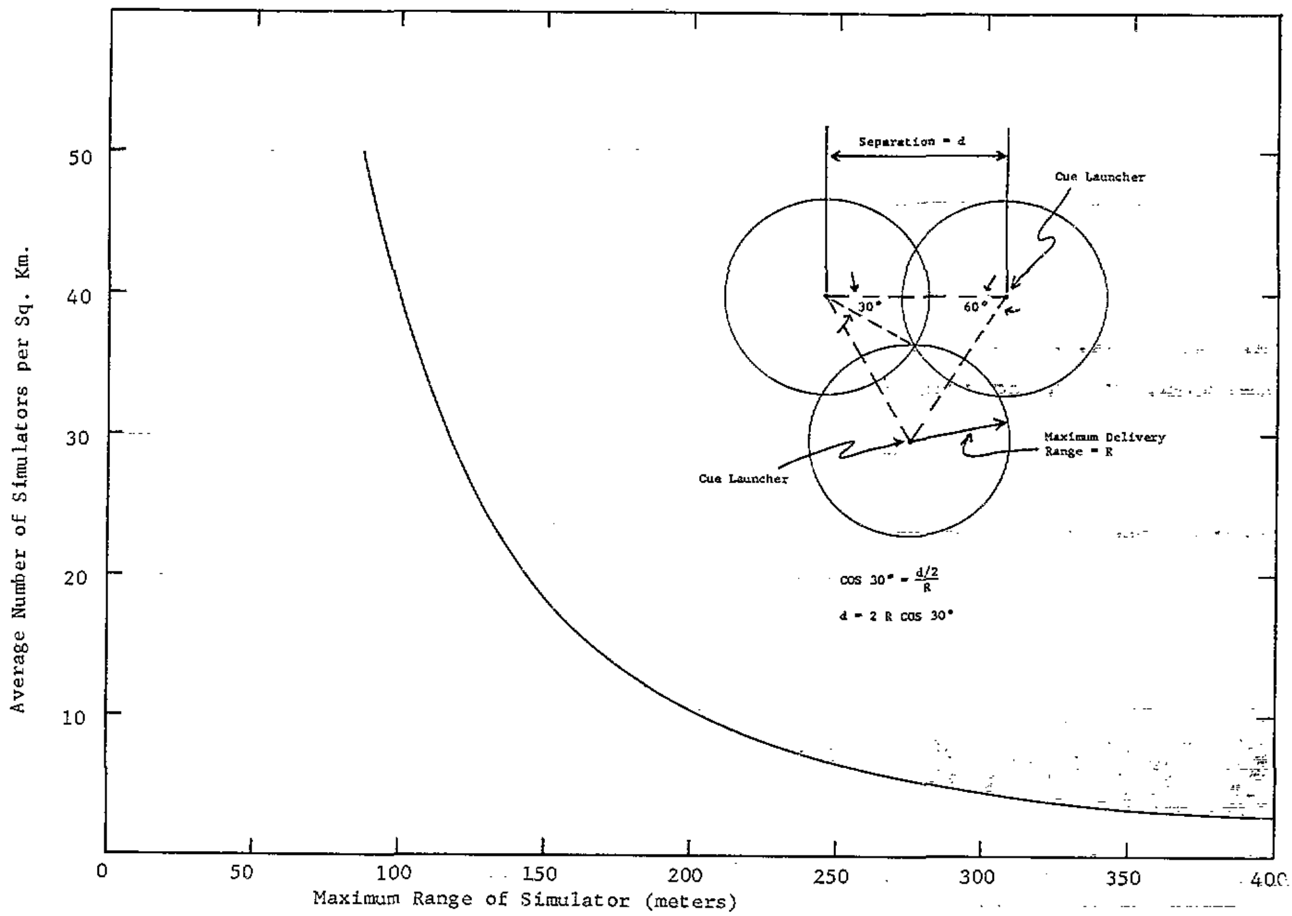

Figure 8. Number of Simulators vs. Maximum Simulator Range

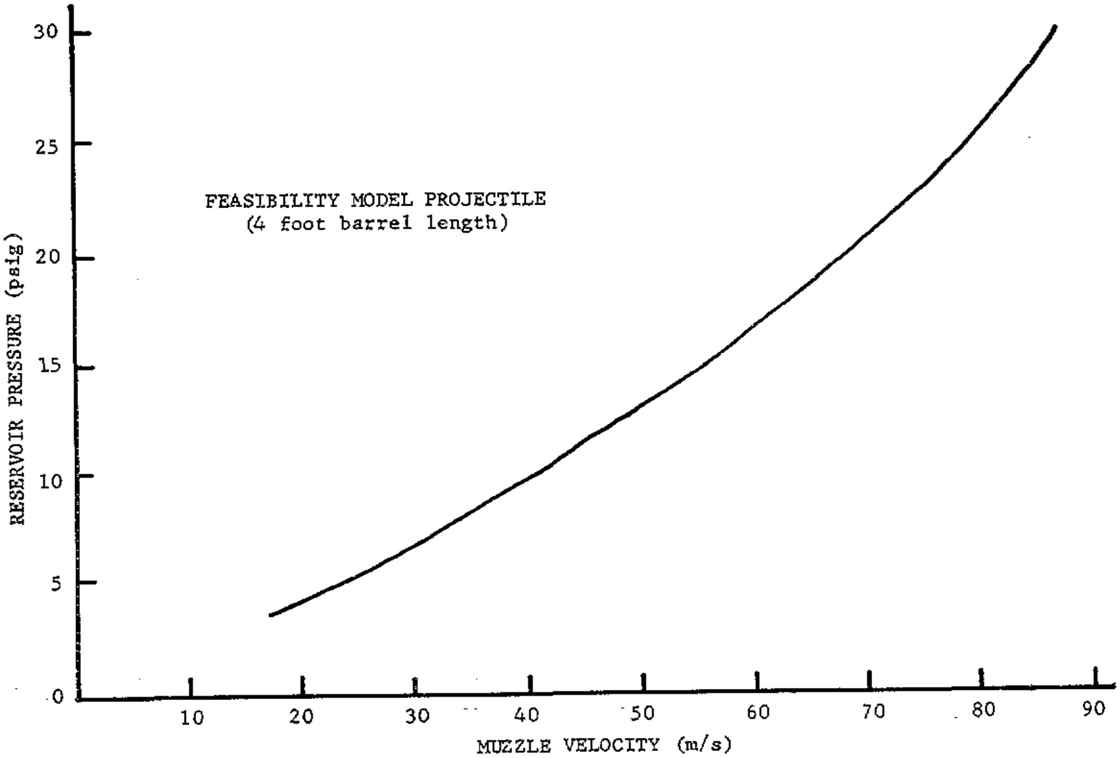

Figure 9. Muzzle Velocity vs. Reservoir Pressure

OVERALL SYSTEM PERFORMANCE

The performance of the system was ultimately determined through a number of experiments in the field which were geared toward measuring the accuracy with which a cue could be successfully delivered to a predetermined location and detonated upon impact. The accuracy of ballistic objects is usually described by the elliptical probable error (EPE) of their impact points about their corporate controid. For convenience, the major and minor axes of the typically elliptical impact pattern are normalized to yield a circle of the same area as the original ellipse which is called the circular error probable (CEP).

Circular error probable is defined as the radial distance from the center of impact which is as likely to be exceeded as not. This means that it is a circle whose center is at the impact area centroid and includes 50% of all the points of impact. The radius of this circle equals 1 CEP (1).

Circular error probable tests were conducted on the feasibility model system by firing a sequence of shots without changing QE or reservoir pressure from shot to shot. A theodolite mounted downrange from the launcher was used to accurately plot the relative angle of each impact. In addition, a measurement of the impact distance from the theodolite was made. Wind direction and velocity were simultaneously measured (at a height of 10 meters) to assure that the shots were occuring under minimal wind conditions.

The measurement of each impact point yielded polar information which was transferred to set of cartesian coordinates as shown in the graph of Figure 10. The CEP of 17.35 meters derived for these tests indicates performance far exceeding that required by the Army (25 m requirement). In fact 100% of the impacts fell within the 25 meter required CEP.

The effects of upper level winds on the trajectory can be severe. An upper level wind shear would, on numerous occasions, cause the projectile to move significantly off course. These upper level winds are difficult to predict over the entire test range. The CEP impact graph of Figure 10 was constructed from data taken during the final acceptance tests. On other occassions, similar tests yielded CEP's as low as 6.1 meters which is likely due to differences in upper level wind turbulance.

A projectile fire hazard assessment was also conducted during the final acceptance tests wherein a standard projectile was ignited in the presence of gasoline saturated paper. The projectile was ignited successfully, deploying its FBS unit without igniting the surrounding gasoline saturated papers or the gasoline vapor in the air. Recognition must be given to the fact that this test is not conclusive proof that the feasibility model projectile would not cause grass fires under normal use. However, the fact that the gasoline saturated paper (considered to

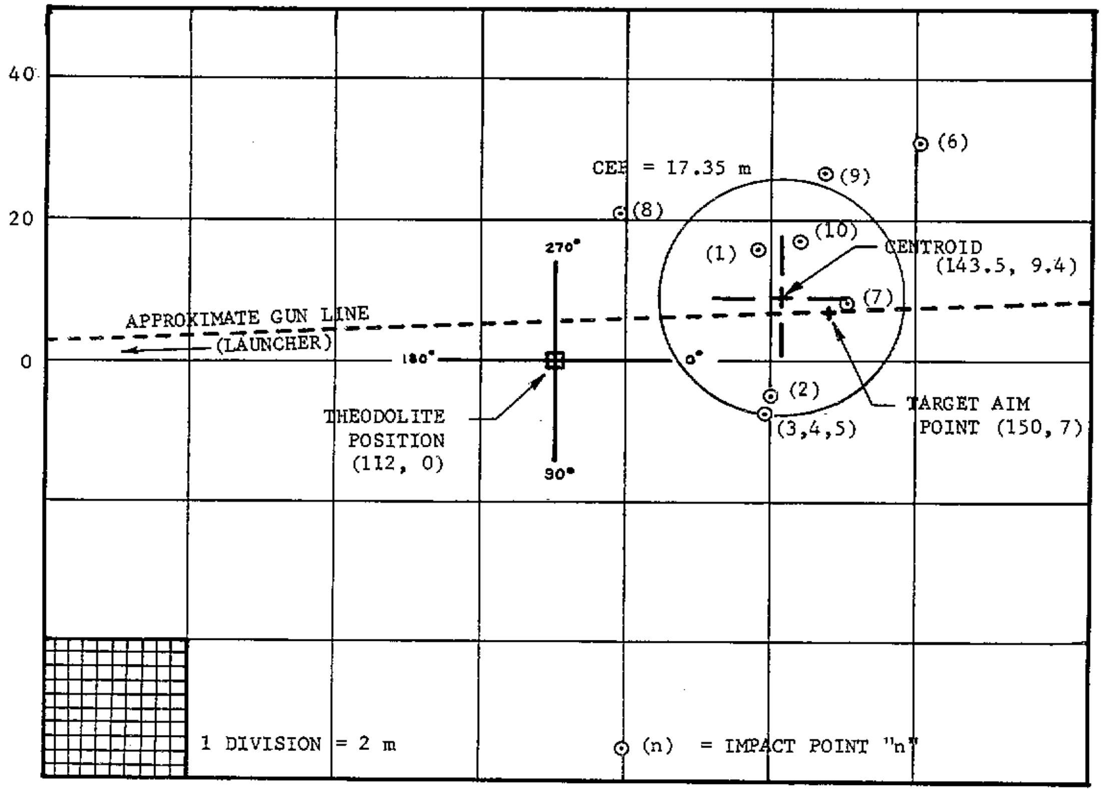

Figure 10. CEP Acceptance Test Results

be more flammable than dry grass) did not ignite indicates that the projectile can be deployed in the presence of highly flammable material without necessarily igniting that material.

Another set of measurements conducted during the final acceptance test consisted of maximum range tests. These tests were designed to evaluate the maximum achievable range of the feasibility model system. Projectiles launched with pressures of 25 psig and launcher QEs of 45 degrees had impact points in excess of 200 meters from the launch site. These projectiles ignited correctly upon impact deploying a visible smoke cloud and audible bang at the 200+ meter ranges.

CONCLUSIONS

FBS Unit Determinations

Many ignition techniques, sound generators, smoke generators, and light sources were investigated for use in the FBS unit. The FBS unit was developed around a Magicube primer and a shotgun shell loaded with a cold particulate smoke generator. Pyrotechnic generators were found to be more effective cues than cold particulate smokes; however, they were less man-safe and a greater fire hazard. The sound level of the shotgun shell approach is easily adjustable and lies within the acceptable ranges as set forth by the Surgeon General of the United States. The light output from the Magicube is very intense but brief. The use of the Magicube as a primer for the shotgun shell yields a small lightweight package that is highly stable and man-safe.

Projectile Determinations

Variable mass, variable drag, constant mass, and hybrid configurations of projectiles were investigated. A baseline projectile was hypothesized and modified numerous times to obtain the feasibility model projectile. These modifications were based on simulations by both computer and direct wind tunnel experiments, in addition to empirical data derived from actual field tests.

Flight stability is a function of two major factors. First, a hemispherical nose cone is used which decreases the forward drag. Second, a rough finish is used on the tail section to create minor turbulence which causes increased drag in the tail section resulting in projectile stability by assuring a greater side drag behind the center of gravity than in front. All portions of the projectile, from the tail section forward, must therefore be kept as smooth as possible for the stabilizing effects of the rough tail section to be effective.

Launcher Determinations

Several launcher schemes were investigated during the indirect fire simulation/cueing program. Of those investigated three were implemented; of these three, the pneumatic launcher was chosen for development.

A fast acting valve was found to be essential to efficient operation of the pneumatic launcher. The valve design chosen was an explosive flapper valve.

Barrel length also affects launcher efficiency. Of those tested, the four foot barrel length was chosen because of its tractability. As pressures are increased in later prototype models, the barrel should be increased in length.

During the course of pneumatic launcher evaluation, an air bearing was found to be created between the projectile and the barrel wall for pressures above 8 psig. The creation of the air bearing is essential to efficient operation and maximum range.

Projectile fish-tailing immediately upon launch lead to the development of a muzzle brake which channeled off-axis gas flow away from the tail section of the newly airborne projectile. The addition of the muzzle brake improved impact groupings.

Extensive testing indicates that upper level winds are a dominant factor in biasing impact centroids. QEs of less than 60 degrees were found to be desirable in order to avoid these upper level winds. Observance of the 60 degree limit becomes more important in future prototype launchers where maximum ranges will be increased.

Production Conclusions

All expendable components of the feasibility model system are designed to be conducive to mass production techniques. Whenever possible, components are cast or molded from specific types of plastics. The choice of plastic for use in a given component is dictated by its weight, tinsel strength, or elasticity. The tail sections are made from expanded polystyrene because of its extremely low density. The arming device is made from two types of plastic; one being very rigid and the other being elastic. Rigidity was important in the Magicube receiver section of the arming device since this section provided the major structural strength for the front half of the flash housing. The upper section of the arming device contains machined plastic leaf springs which must be able to flex without breaking, so a different, more elastic kind of plastic was necessary to implement this component. Other parts of the system must be fire proof or self-extinguishing. The flash housing is one example, being made out of Lexan, a self-extinguishing polycarbonate material. The nose section must be able to maintain its hemispherical shape under the acceleration of launch, but also must be able to deform upon impact with a human to increase the level of man-safeness of the projectile. For this application, a cast foam rubber compound was employed.

Man-Safety Inferences

The feasibility model projectile was demonstrated to be impact safe for individuals in visual contact with the incoming round. Fully outfitted soldiers engaged in war games should be as safe from a direct impact given that the impact does not occur on the eye or in general, the facial region. Adequate eye protection would effectively render a facial impact harmless. The sound and light level outputs from the FBS unit are within acceptable medical standards. The cold particulate smoke is soluble in the lungs and is non-toxic in the quantities to be encountered during an actual war game engagement.

General Conclusion

Extensive experimentation has shown that the feasibility model system performs in accordance with theory and meets or exceeds all contract requirements. The feasibility model system, as delivered, proves the indirect fire cueing system concept to be valid. Further research is necessary to improve upon this system, however.

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