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SMAWT SIGNATURE TEST

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This was not a detection study, but rather a field test conducted to obtain descriptions and comparisons, and evaluate tactical usefulness of antitank systems firing signatures. Two standard issue systems (the M72 LAW rocket and the M67 recoilless rifle), a proposed 81mm recoilless rifle system with two types of propellants, and a proposed 79mm rocket system with two types of propellants were fired in pairs. Five enlisted men served as downrange observers and judged the firing signatures and returned simulated counterfire. The reported tactical usefulness of signature components depended on the contrast ratio such that high contrast ratio for a component resulted in greater

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usefulness. Although all the candidate systems produced larger signatures than the LAW, the larger signatures did not prove to be tactically dramatically detrimental in terms of decreased post-firing survivability of the systems.

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CONTENTS

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INTRODUCTION

Consideration is being given to replacing the M72 LAW with a new lightweight, disposable antitank system for high-density issue to riflemen. A system with several times the hit and kill probability of the M72 at 250 meters is desired. One approach to the desired capabilities is by increasing the launch velocity.

The U. S. Army Materiel Command (AMC), in anticipation of this requirement, established an antitank technology program called SMAWT. The acronym stands for Short-Range Man-Portable Antitank Weapon Technology Program. The objective of this program was to have each agency improve on their technology base so that AMC could provide a trade-off matrix to the infantry community showing the effects of weapon design parameters on performance.

The developing agencies within AMC — U. S. Army Missile Command (MICOM) and the U. S. Army Armament Command (ARMCOM) — were required to demonstrate hardware. The U. S. Army Human Engineering Laboratory (HEL) was to answer the following questions: (1) How much noise can it have? (2) If fiberglas is used for the launcher, will it be rugged enough to withstand infantry use? (3) How much recoil can it have? (4) How much can it weigh and how long can it be? (5) What type of sight should it have? and, (6) If new propellants are used and produce more signature, how will the increased signature affect tactical effectiveness? The first five questions were answered in various separate reports (4, 5, 10).

Because of the requirement for increased range over the current M72 LAW, it was anticipated that there would be an increase in the firing signature resulting from the larger propellant charge required to provide the longer range capability. In addition, both developing agencies — MICOM and ARMCOM — were considering different propellant types. MICOM considered two new types of propellant for the rocket motor. Both propellant types would use a carborane main charge. One type would use a boron (NHC) burn rate catalyst whereas the other would use a sulfide burn rate catalyst. Carborane propellant was chosen in part because of its temperature insensitivity and high-burning rate. The other developer, ARMCOM, used a recoilless system and considered standard M8 as the main charge with two types of substrates to hold the charge, aluminum and stainless steel.

The objective was to compare the signature produced by the new propellants with the standard issue systems such as the M72 LAW and the 90mm M67 recoilless rifle.

A review of the literature (1, 2, 6, 8, 9, 12) indicated that the Army does not have a standard test to measure and compare the signature of weapon systems. Techniques vary from photography to spectroscopy. Since no standard test was available, we took the approach of planning a field study which would, on a one-time basis, compare the six different propellant systems. There was one serious constraint in the design of the study. There were only ten each of the four propellant types available for testing.

The rationale developed and used to design the field study assumed that the only time signature becomes important is when the enemy can use it to return fire in an accurate and timely fashion. Therefore, it was important to define the relationships between firing signature and its tactical usefulness in aiding a downrange observer to aim a weapon uprange in an attempt to destroy the position from which one of the six systems had been fired. In addition, subjective comparisons of tactical usefulness of firing signatures produced by the candidate and standard-issue systems was important.

Data gathering was limited to recording aiming error as observers returned (simulated) counterfire from a downrange position; gathering jury-type judgments of signature visibility, size, and usefulness; and recording physical characteristics of the firing signatures.

METHOD

The antitank weapon systems fired during testing were:

a. 90mm, M67, recoilless rifle (designated 90).

b. 66mm, M72, HEAT rocket (designated LAW).

c. 81mm recoilless rifle system with aluminum substrate for the M8 propellant (designated WI).

d. 81mm recoilless rifle system with stainless steel substrate for the M8 propellant (designated WII).

e. 79mm HEAT rocket system with a boron (NHC) burn rate catalyst for the carborane main charge (designated MI).

f. 79mm HEAT rocket system with a sulfide burn rate catalyst for the carborane main charge (designated MII).

The ammunition and firing fixtures for the proposed recoilless system were provided by ARMCOM and the ammunition and firing fixtures for the proposed rocket system were provided by MICOM. Both of the proposed systems were fired from steel launcher test fixtures because the final launch tubes were not available. All systems were mounted on tripods for remote firing (Fig. 1) and fired weighted slugs rather than live warheads. No provisions were made to capture the fired projectiles; however, at the request of MICOM, most of the rocket motors were recovered by searching the impact areas.

General

The experiment was designed with the following considerations:

a. The downrange observers should not be able to see the location of the system about to be fired, yet there should be a direct line of sight to each position from the observers.

b. Contrast ratio between the signature and background, possibly the most important variable, should be varied with regard to different, yet realistic tactical situations.

c. Paired comparisons should be made quickly, one with the other, so that there would be no change in meteorological conditions.

d. Since aiming error as a function of time would be the primary dependent variable, the location of each firing should not only be physically separate, but also, in order to make legitimate comparisons, must occur from a location where similar contrast ratio is available.

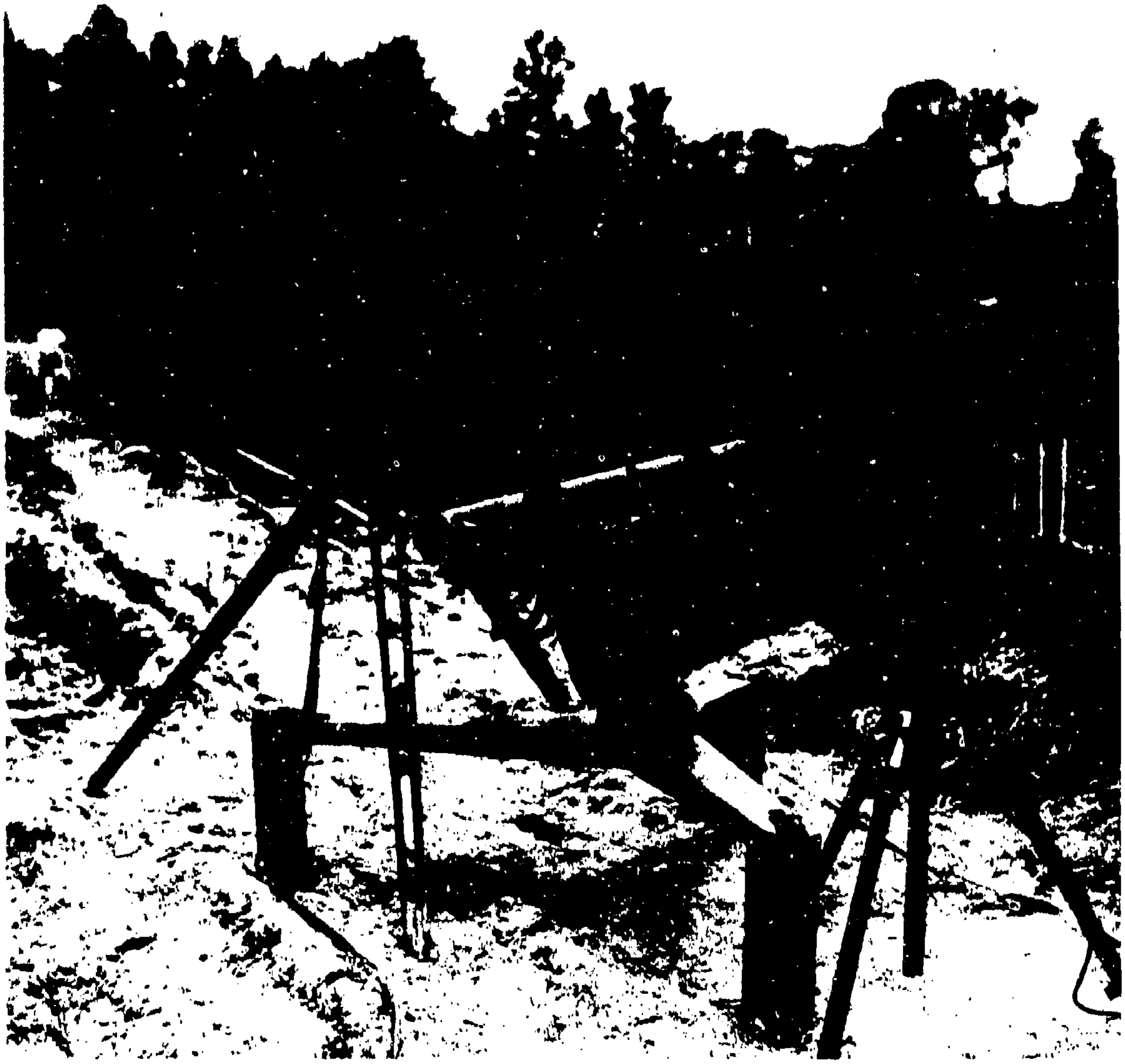

Fig. 1 Rocket system set up for remote firing.

Subjects

Five military men were used as downrange observers. All were of the rank of E-7 and MOS 11E40 (vehicle commander). Their ages ranged from 30 to 43 years and length of military service ranged from 10 to 20 years. All but one man had served one year combat duty. The subjects were selected on the basis of possessing MOS of MICV-type vehicle commanders, their familiarity with larger antitank-type weapon firings, and the experience gained in combat zones.

Test Range

The field experiment was conducted at Jefferson Proving Ground, Indiana. The layout of the test range is shown in Figures 2 and 3. A dense, homogeneous wood line consisting of a stand of pines was chosen, with the firing line then set up approximately 35 feet inside the wood line. Each position along the firing line was established such that when it viewed from the downrange observation point through a three-power aiming telescope, neither the system nor the instrumentation could be seen. Yet, a direct line of sight was established from each firing position by shining an intense light from the muzzle of each weapon that could be plainly seen from the downrange observation point. Numbered marker stakes were erected at the edge of the wood line to aid reduction of observers' aiming data.

In front of the wood line was an open grass field which was chosen as the second defensive position. Again, the firing points were camouflaged but line of sight ensured from the observation point. Numbered marker stakes were erected 40 feet in front of the firing line.

The test was divided into two phases. The first phase consisted of all firings from the wood line; the second phase included all firings from the grass line. The length of the firing lines subtended a fan of approximately 260 mils when viewed from the downrange observation point.

Observation Point

The observation point was located 45 degrees off the line of fire of the systems and located approximately 300 meters from the firing lines. Booths were provided for the observers. Each firing booth was approximately 1 meter wide, with a bench seat, a shelf table, and hooks for securing an aiming device. The table provided elbow support for a seated observer returning simulated counterfire with his aiming device. Furthermore, the booths eliminated cross-referencing between observers during counterfiring. For the wood line test phase, the booths were placed on the bed of a truck to provide an unobscured view of the firing lines and approximate mounted infantry. However, for the grass line phase, the booths were at the same location but placed in a 20-inch trench. This was done to approximate mounted and dismounted infantry having to view firings through tall grass and other low vegetation. At that time of year (early spring), the vegetation was low; therefore, the sight line of the observers was lowered to enable them to skim the tops of available vegetation.

The aiming devices generally resembled a shoulder-fired antitank system (Fig. 4). The main body of the device was an aluminum tube, 36 inches long and 3 inches in diameter. At one end (the rear) of the tube, a 16mm spring-powered motion picture camera was mounted to record aiming performance. The camera was equipped with a 150mm telephoto lens and set to run at 24 frames per second. An on-off button switch served as a trigger and provided power to a solenoid

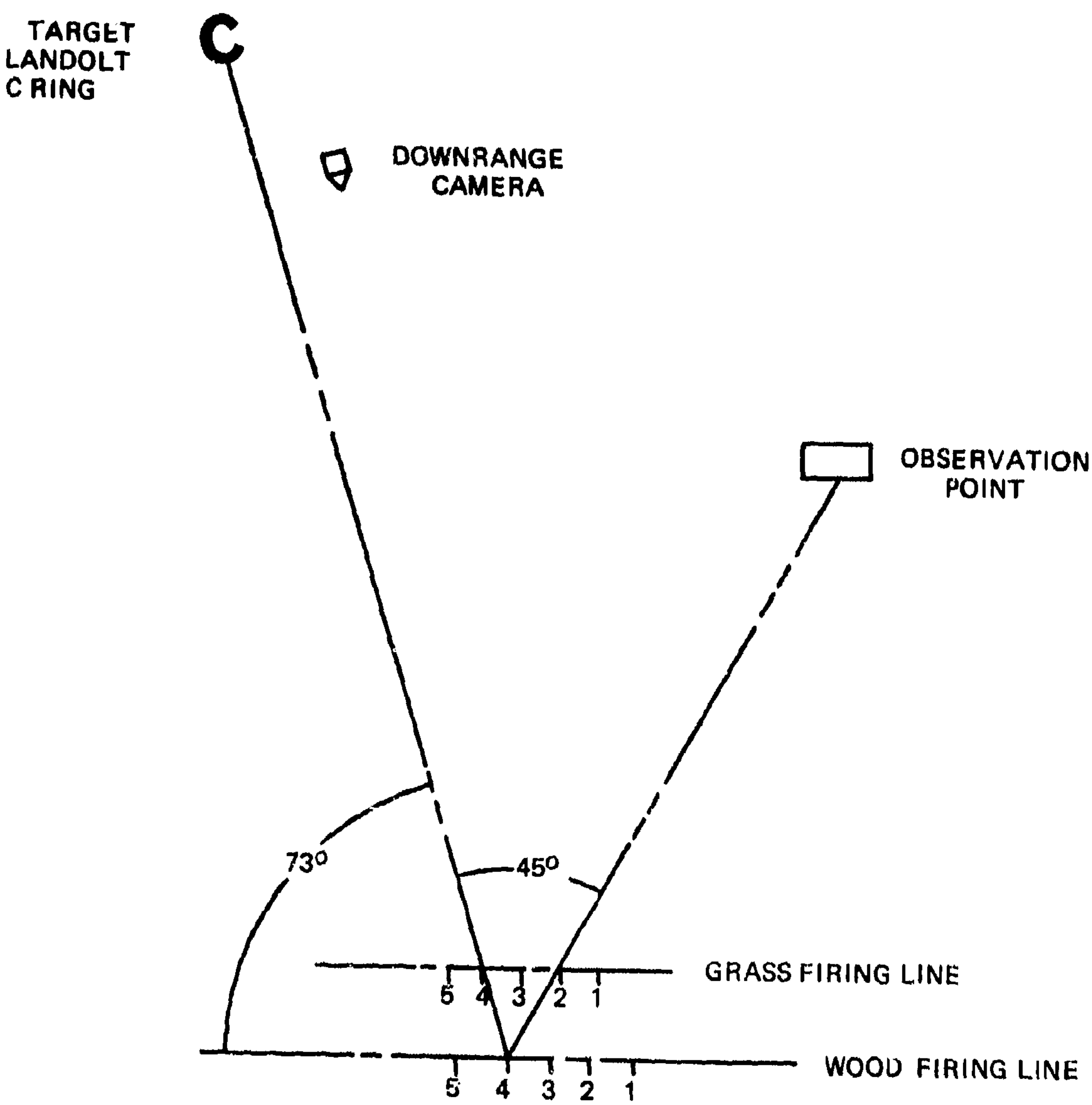

Fig. 2. General range layout.

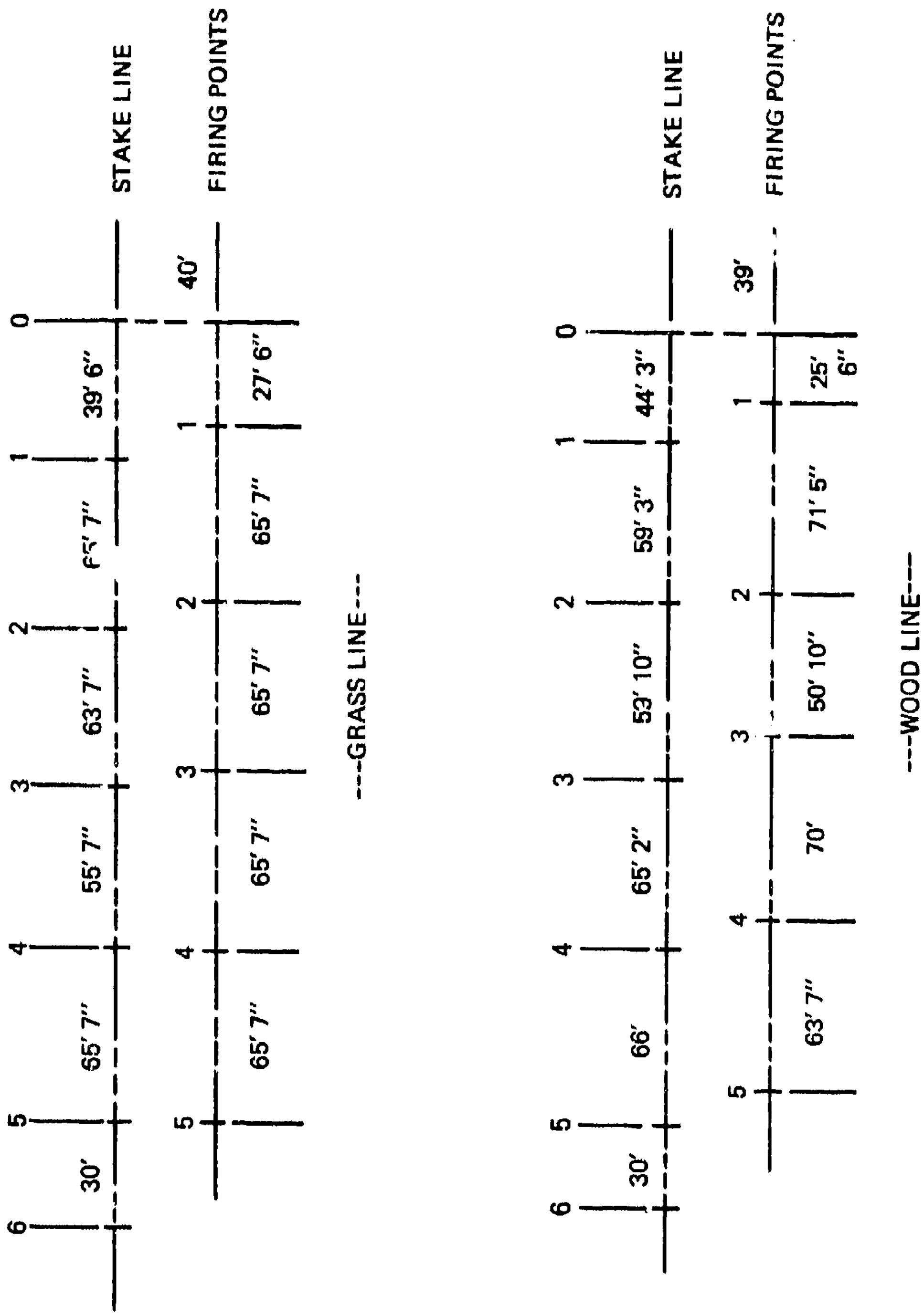

Fig. 3. Firing line layout.

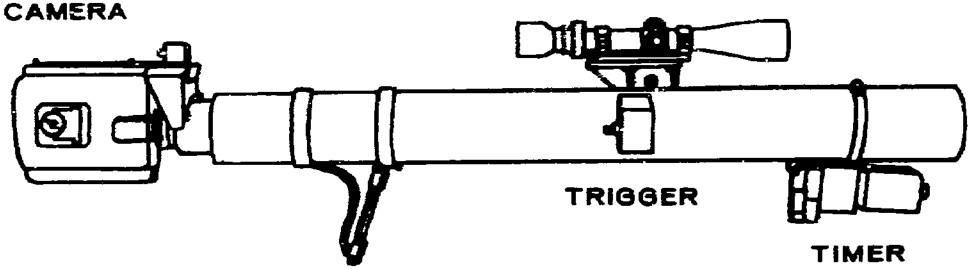

Fig. 4. Aiming device.

which controlled the running lever of the camera. When the switch was pressed, the solenoid energized, tripped the run lever, and started the camera. Conversely, when the solenoid was deenergized, the run lever was released and the camera stopped. A timing device, included in the trigger circuit, limited camera runs to approximately 5 seconds after the solenoid was energized. A three-power aiming telescope, with fixed, nonadjustable crosshairs, was mounted on the tube and aligned such that the error between telescope and camera sight lines did not exceed 1/4 mil. The telescope and camera offered a field of view of approximately 30 mils of the firing line. Total weight of the aiming device was approximately 6 pounds.

Using the aiming devices, the observers were to return simulated fire as if they were firing a 5-second burst, rather than firing a single round.

Instrumentation

Three 16mm motor-driven motion picture cameras were positioned around each firing system to record signature characteristics. All cameras ran at 24 frames per second and used Ektachrome MS film. Two cameras were positioned approximately 60 feet from the system and perpendicular to the line of fire. One camera was aimed at the front of the system, the other at the rear, and recorded the flash produced at the front and rear, respectively, by each system. The third camera was positioned to represent a firer's eyes and photograph downrange indicators to determine degree and duration of obscuration of the firer's view.

Approximately at the impact area, two Landolt C rings were erected as indicators for the obscuration measurements. The black rings were painted on a white background. The overall target dimensions for the 5-minute C ring were 10 by 10 feet, and for the 2-minute C ring the dimensions were 8 by 8 feet (Fig. 5). The line width and the gap width of both rings were, respectively, 5 and 2 minutes of arc times the viewing range (3). However, the diameters of the rings were made less than five times the gap width to minimize overall target dimensions.

Slightly offset from the direct line of fire and out of the impact area but in the area of the Landolt C rings, a 16mm motor-driven camera with a 50mm lens was set up to record the smoke characteristics and drift for each system. Running speed was set at 24 frames per second.

System firing and sequencing control was kept at the observation point. Approximately 10 seconds before a system was fired, the three cameras at the system and the downrange camera were started. The system was fired and the four cameras were permitted to run for 15 seconds after firing. Each observer independently started his aiming device camera at his trigger pull. The sequence times of system firing and each observer's initial trigger pull were recorded on a strip-chart recorder running at 6 inches per minute. Timing marks were displayed on the paper at 0.1-second intervals.

Samples of the questionnaires used to obtain jury judgments of firing signatures are shown in Appendix A. Two questionnaires were used. The first required rating of tactical usefulness and visibility/magnitude of the signatures; the second required the observer to rate the paired signatures against each other to give explicit comparisons to augment comparisons which could be inferred from other measurements.

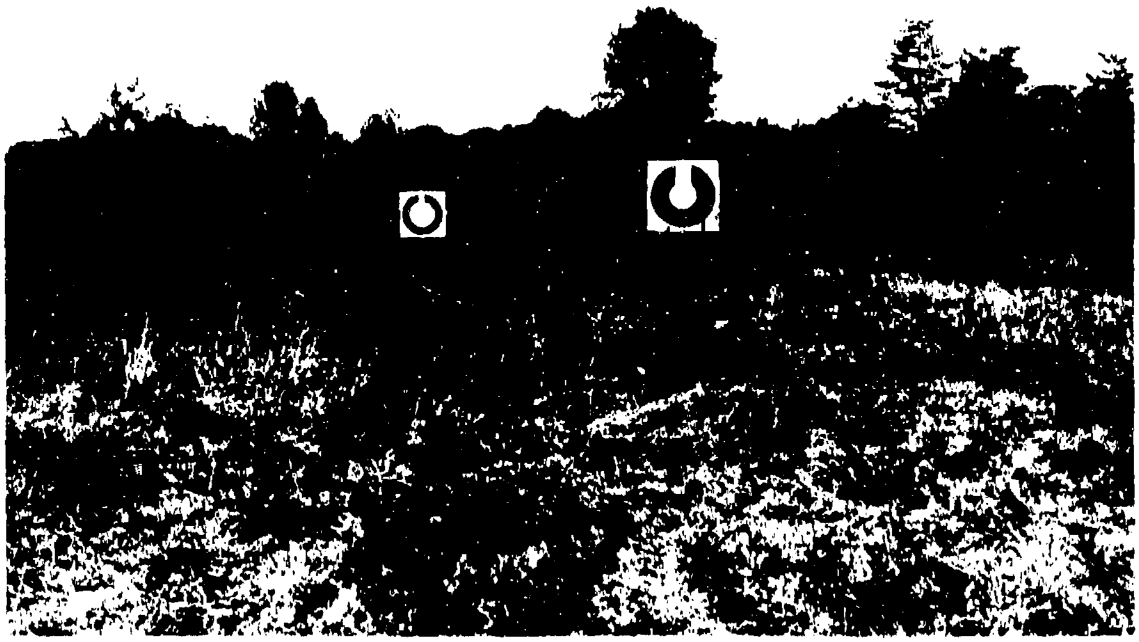

Fig. 5. Landolt C rings.

Procedure

The purpose of the test was explained and the observers were instructed as to what was expected of them. They were allowed to familiarize themselves with the observation booths, aiming devices, and the questionnaires; then each subject was assigned a booth for the entire test. Two checkout firings were done – one with the 90, the other with the LAW – to verify instrumentation and familiarize the observers with the test procedures.

Table 1 shows the matrix used to select systems for paired firings. The limited supply of ammunition for the candidate systems did not permit counterbalancing order of presentation. For example, the 90-MI systems pair was fired – it could not be balanced with an MI-90 pair. Similarly, systems could not be fired against themselves in pairs. The systems were fired from adjacent firing points; however, the right-left or left-right firing sequence was randomly varied. The firing points were evenly spaced; however, during the wood line it was necessary to deviate from the even spacing (Fig. 3) to achieve clear line of sight and line of fire to the target area. Choice of firing points was random; but, shaded to favor the right (as seen from observation point) side of the firing line. This was done to minimize variations of range and viewing angle. The variations, caused by seating the observer abreast, were assumed very small and ignored.

TABLE 1

Matrix of System Pairing for Firing

First System Fired	Second System Fired for Pairing				
90	LAW	MI	MII	WI	WII
LAW	MI	MII	WI	WII	
MI	MII	WI	WII		
MII	WI	WII			
WI	WII				
WII					

The testing sequence started when a point was ready for firing and the observers were called from their holding area (so that they could not see the preparatory activity) and seated in their booths and had their aiming devices on the ready. After the 10-second warning – used to start recording equipment – the observers were to scan the firing sector with their unaided eyes and:

a. Return simulated counterfiring as soon as they identified a firing.

b. Maintain, or improve, their sight picture through their aiming telescope so that their counterfire would kill the enemy who had fired the system. (The observers were to assume a firer was in a kneeling position.)

c. When their camera stopped, secure the aiming device, turn their back to the firing line, and fill out the questionnaire.

d. Hand in questionnaire, return to the holding area, and not discuss the firing.

The only variation occurred after the second firing in each pair. Then the observers were required to complete two, rather than one, questionnaires. This testing sequence was followed for both the wood line and grass line test phase.

The round-by-round sequence and pairing are shown in Appendix B for the wood line and grass line phases. Approximately, depending on setup time, 15 minutes elapsed between firings of systems within a pair and approximately 30 minutes elapsed between paired firings.

At the completion of each test phase, a bright light was illuminated at each firing point and the observers were required to aim and fire at the light. This served to calibrate each observer's aiming data.

RESULTS

Table 2 shows the average temperature, humidity, and barometric pressure during the wood line and grass line firings. The wind was generally gusty and blowing from left to right of the firing lines when viewed from the observation point. However, firing was delayed if the winds gusted above 10 miles per hour.

TABLE 2

Average Meteorological Data During Test Firing

		Temperature Deg. F	Humidity Percent	Pressure[1]	Wind
Wood line	Avg.	60.4	45.6	29.16	A
	S.D.	4.6	7.7	0.1	
Grass line	Avg.	61.3	48.3	28.3	A
	S.D.	5.5	10.8	0.02	

A Winds were variable speed.
Prevailed from left to right of firing line when viewed from observation point.
No firing done when winds were gusting over 10 miles per hour.

[1] Expressed in inches of mercury.

The films, taken by the downrange camera, were analyzed to obtain smoke envelope data. The film was rear-screen projected and digitized at quarter-second intervals; then averaged to define the smoke envelope as a function of time at second intervals. All measurements were converted to mils.

During the wood line firing phase, the smoke was not consistently visible on the films to give usable data. This was because of lack of contrast and the tendency of the smoke to disperse more between the trees. However, for the grass line firings, the average height, width, and drift of each system's smoke cloud are given in Table 3. The height and width measurements were taken by reading the vertical and horizontal limits of the smoke cloud. Drift was defined by taking the center of the horizontal measurements and locating that point relative to the location of the system. The smoke data were averaged for five firings of each system.

The flash envelopes, at the front and rear of each system, were obtained by digitizing, frame by frame, the films taken by the cameras at the front and rear of each system. The horizontal limits were obtained by reading the length of the flash extending from the launcher. Similarly, the vertical limits were measured above and below the boreline. Included in these readings were tightly-grouped clusters of sparks expelled by some of the systems as part of the flash measurements. All measurements were converted to foot-seconds by summing the length and height dimensions and multiplying each by the time (obtained by counting film frames) that the flash was visible. This was done separately for both dimensions at the front and rear of the weapon; then, the two converted measurements were totaled to identify amount of flash at the front and rear of the system. Finally, the front and rear totals were summed to obtain one number characterizing the flash of each system. All measurements were based on averaging results from five firings of each system, and are shown in Tables 4 and 5 for the wood line and grass line.

Figures 6 and 7 show the average obscuration times of the firer's view caused by signature smoke for the wood line and grass line. Times were obtained by counting those frames on which either the 5- or 2-minute Landolt C rings were obscured by smoke such that the gap of the ring could not be seen or distinguished. The "smokey-haze" was used to indicate some obscuration, but the gap was at least distinguishable in a threshold sense. Times were averaged for five firings of each system.

Jury judgments of the firing signatures were averaged over 25 data points; that is, five observers grading five firings of each system. The averaged assessments of signature characteristics relative to their tactical usefulness for attracting attention and defining target points for counterfiring are shown in Tables 6 and 7 for the wood line and grass line firings, respectively. Similarly, the averaged jury assessments of the magnitudes of the signature characteristics are shown in Table 8. Table 9 shows the jury judgments of intensities and duration of the visible signatures.

The results of a single factor, repeated measures, analysis of variance (11) of tactical usefulness of signature components are shown in Table 10. It should be noted that movement was not a discriminator between systems; therefore, it was decided to exclude that signature characteristic in further analysis. Similarly, an analysis of variance was performed on the jury judgments of intensities of the signature flash and smoke characteristics. The results are shown in Table 11.

The Tukey-a test (11) was applied to the data to evaluate significant differences in the rankings of the signature evaluations. For the data from the wood line and grass line firing phase, it was found that the systems did not differ with respect to the reported usefulness of firing noise

TABLE 3

Mean Height, Width, and Drift of Firing Smoke Cloud

System	Mean*	Time - Seconds 0**	1	2	3	4	5	6	7
90	Height	2.35	6.51	11.04	13.31	13.26	15.89	15.44	17.18
	Width	7.65	17.69	22.12	25.14	28.48	22.74	27.19	31.20
	Drift	4.36	6.25	11.71	18.56	31.91	35.40	46.52	58.75
LAW	Height	1.98	4.93	8.86	10.59	11.31			
	Width	5.35	9.14	11.37	10.01	5.83			
	Drift	-0.51	-0.22	-1.19	-10.03	-11.16			
MI	Height	3.80	11.23	18.80	25.36	31.19	36.67	43.50	
	Width	11.15	17.63	21.55	26.59	34.31	38.49	43.02	
	Drift	-0.01	0.48	2.70	5.04	7.63	9.81	7.17	
MII	Height	4.35	10.53	15.84	20.42	24.33	26.52		
	Width	10.76	17.19	21.34	25.39	29.61	33.75		
	Drift	1.84	2.87	5.01	8.62	12.20	14.38		
WI	Height	3.25	8.67	16.09	20.88	24.95	23.15		
	Width	9.41	17.13	23.37	29.64	31.74	30.67		
	Drift	-0.60	-0.34	2.49	4.21	6.97	9.09		
WII	Height	2.69	8.89	17.27	20.67	39.49			
	Width	7.81	14.15	17.27	20.67	39.49			
	Drift	-0.08	-1.52	-2.49	-1.75	-1.75			

*All measurements in mils. Height and drift measured relative to muzzle of weapon.

**Approximately 0.04 after trigger pull.

TABLE 4

Average Foot-Time*of Firing Flash for Wood Line Firings

System	Flash - (foot-seconds)						
	Front		Rear		Total		Grand
	Length	Height	Length	Height	Length	Height	Total
90	0.0	0.0	2.42	1.70	2.42	1.70	4.12
LAW	0.0	0.0	0.23	0.10	0.23	0.10	0.33
MI	1.50	0.17	1.18	0.78	2.68	0.95	3.63
MII	0.35	0.07	0.38	0.28	0.73	0.35	1.08
WI	0.24	0.17	0.0	0.0	0.24	0.17	0.41
WII	0.86	0.84	1.52	1.44	2.38	2.28	4.66

*Product of flash dimensions and flash duration.

TABLE 5

Average Foot-Time* of Firing Flash for Grass Line Firings

System	Flash - (foot-seconds) Front Length	Front Height	Rear Length	Rear Height	Total Length	Total Height	Grand Total
90	0.0	0.0	0.07	0.48	0.07	0.48	0.55
LAW	0.0	0.0	0.22	0.06	0.22	0.06	0.28
MI	0.30	0.26	0.38	0.25	0.68	0.51	1.19
MII	0.0	0.0	0.40	0.29	0.40	0.29	0.69
WI	0.0	0.0	0.59	0.35	0.59	0.35	0.94
WII	0.50	0.44	1.42	1.44	1.92	1.88	3.80

*Product of flash dimensions and duration of flash.

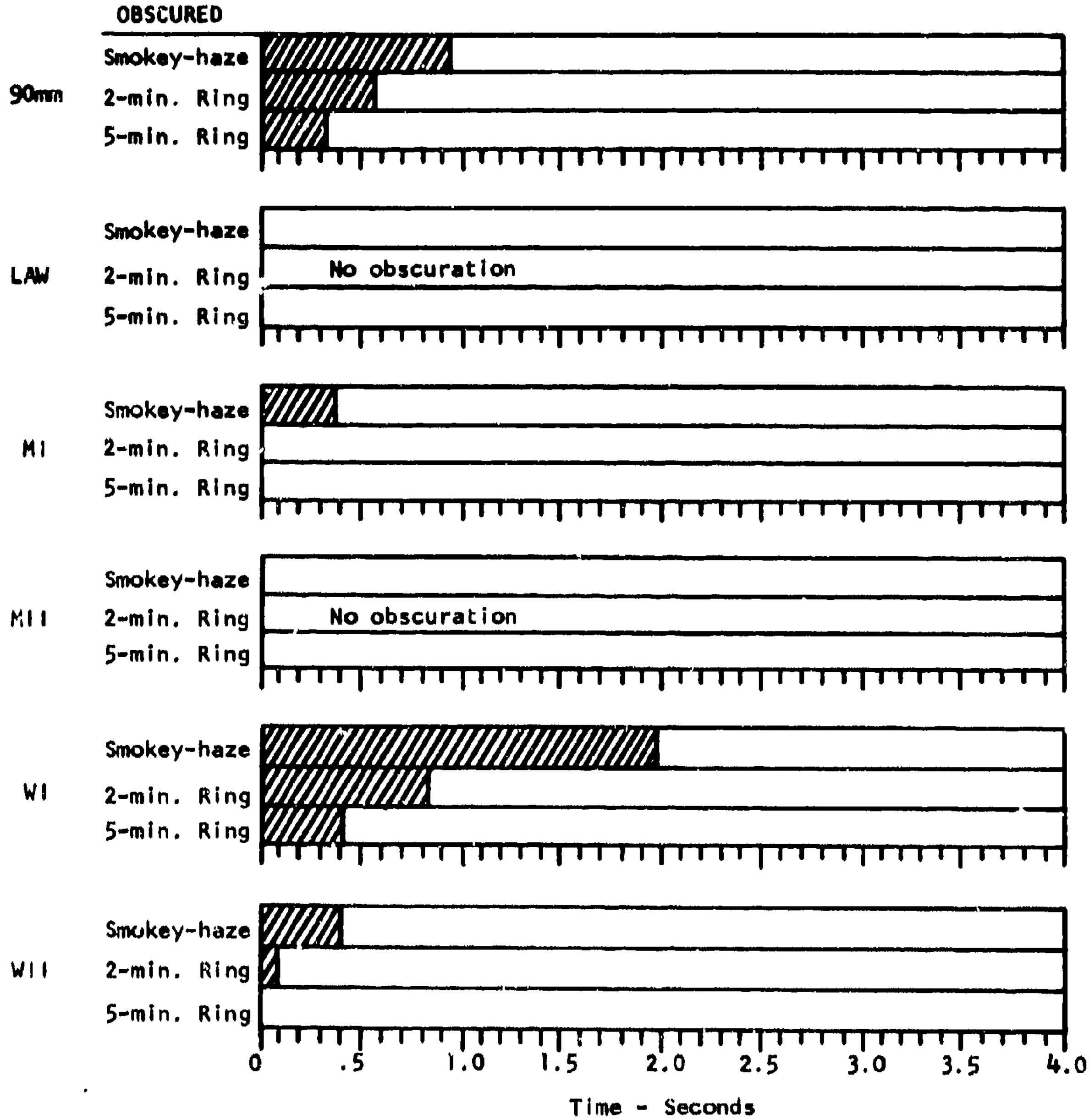

Fig. 6 Average time of gunner's view obscuration by smoke during firings from the wood line.

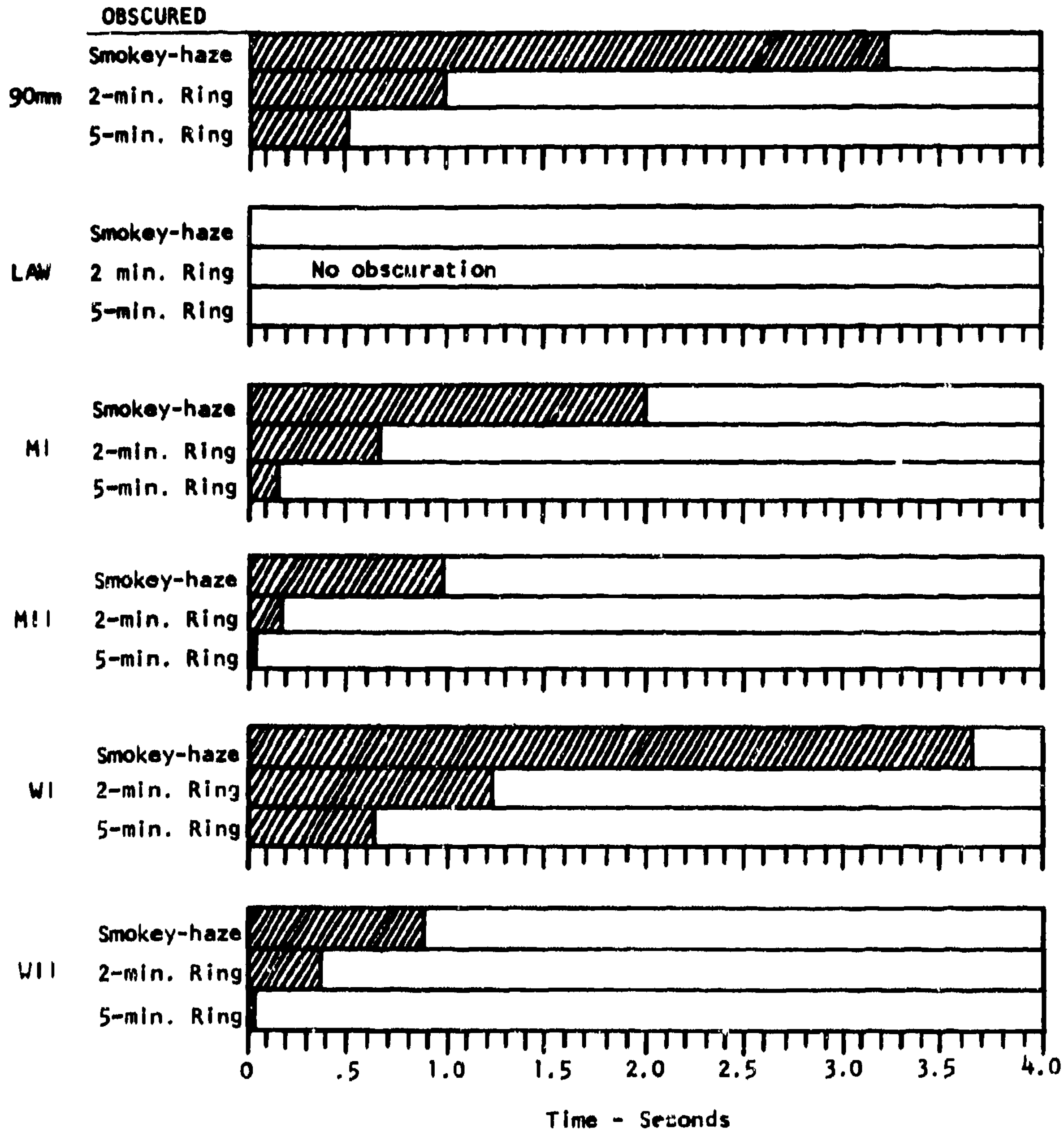

Fig. 7 Average obscuration times of gunner's view obscuration by smoke. Grass line.

TABLE 6

Average Values Assigned to Usefulness of Signature Components as Target Locators, During Wood Line Firings

		What signs made you realize that a weapon was fired?				What signs first helped you pinpoint location of weapon?				What helped you choose where to lay in your fire?			
		Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement
90	Mean	3.72	4.36	3.72	1.72	3.56	4.40	3.92	1.72	3.36	4.28	3.84	1.72
	S.D.	0.30	0.15	0.35	0.16	0.32	0.28	0.45	0.16	0.41	0.27	0.29	0.16
LAW	Mean	3.68	3.00	2.24	1.80	3.44	3.04	2.40	1.76	3.36	3.10	2.40	1.84
	S.D.	0.39	0.99	0.60	0.22	0.43	1.00	0.55	0.23	0.39	0.95	0.57	0.23
MI	Mean	4.08	4.32	4.64	1.80	3.88	4.44	4.80	1.80	3.52	4.36	4.68	1.76
	S.D.	0.35	0.70	0.34	0.0	0.32	0.60	0.13	0.0	0.10	0.60	0.20	0.08
MII	Mean	3.84	4.24	4.80	1.80	3.76	4.32	4.76	1.84	3.80	4.32	4.84	1.80
	S.D.	0.23	0.50	0.13	0.0	0.15	0.41	0.15	0.08	0.25	0.41	0.15	0.0
WI	Mean	4.08	4.64	4.72	1.80	3.80	4.60	4.64	1.80	3.52	4.56	4.72	1.84
	S.D.	0.24	0.15	0.20	0.0	0.18	0.18	0.15	0.0	0.20	0.23	0.24	0.08
WII	Mean	3.92	4.52	3.48	1.68	3.76	4.64	3.44	1.80	3.44	4.64	3.52	1.80
	S.D.	0.27	0.20	0.30	0.24	0.43	0.27	0.29	0.0	0.23	0.20	0.41	0.0
Grand Mean		3.89	4.18	3.93	1.77	3.70	4.24	3.99	1.79	3.5	4.21	4.00	1.79

TABLE 7

Average Values Assigned to Usefulness of Signature Components as Target Locators During Grass Line Firings

		What signs made you realize that a weapon was fired?				What signs first helped you pinpoint location of weapon?				What helped you choose where to lay in your fire?			
		Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement
90	Mean	3.72	3.64	4.72	1.80	3.20	3.60	4.72	1.80	3.24	3.60	4.72	1.80
	S.D.	0.35	0.59	0.35	0.0	0.40	0.54	0.39	0.0	0.41	0.54	0.39	0.0
LAW	Mean	3.16	2.12	4.12	1.80	3.04	2.12	4.32	1.80	2.84	1.96	4.40	1.76
	S.D.	0.62	0.20	0.47	0.0	0.59	0.20	0.37	0.0	0.54	0.15	0.31	0.08
MI	Mean	4.00	4.60	4.96	1.84	3.52	4.60	4.96	1.84	3.44	4.52	4.80	1.84
	S.D.	0.0	0.13	0.08	0.08	0.23	0.13	0.08	0.08	0.34	0.20	0.31	0.08
MII	Mean	3.72	4.16	4.88	1.84	3.40	4.16	4.84	1.84	3.16	4.16	4.84	1.88
	S.D.	0.16	0.20	0.16	0.08	0.25	0.23	0.15	0.08	0.08	0.23	0.15	0.16
WI	Mean	4.04	4.16	4.88	1.84	3.64	4.16	4.88	1.84	3.64	4.12	4.84	1.76
	S.D.	0.15	0.51	0.16	0.08	0.20	0.51	0.16	0.08	0.15	0.57	0.15	0.20
WII	Mean	3.75	4.28	4.36	1.84	3.24	4.28	4.40	1.84	3.08	4.32	4.48	1.84
	S.D.	0.09	0.30	0.45	0.08	0.32	0.30	0.38	0.08	0.10	0.30	0.27	0.08
Grand Mean		3.73	3.83	4.65	1.83	3.34	3.82	4.69	1.83	3.23	3.78	4.68	1.81

TABLE 8

Average Numerical Descriptions of Amounts of Signature Components

System		Noise		Flash		Smoke	
		Wood line	Grass line	Wood line	Grass line	Wood line	Grass line
90	Mean	3.55	3.32	4.24	3.24	3.08	4.64
	S.D.	0.22	0.39	0.37	0.90	0.41	0.39
LAW	Mean	3.24	2.28	2.72	1.40	2.20	3.95
	S.D.	0.50	0.16	1.11	0.25	0.49	0.59
MI	Mean	4.29	3.88	4.04	4.48	4.44	4.92
	S.D.	0.39	0.16	0.74	0.10	0.41	0.10
MII	Mean	4.09	3.67	3.88	4.00	4.44	4.96
	S.D.	0.28	0.19	0.72	0.31	0.41	0.08
WI	Mean	4.32	3.98	4.40	3.84	4.56	4.92
	S.D.	0.40	0.31	0.46	0.61	0.20	0.10
WII	Mean	3.93	3.28	4.46	4.00	3.36	4.32
	S.D.	0.26	0.48	0.22	0.46	0.41	0.55
Grand Mean		3.90	3.40	3.96	3.49	3.68	4.62

TABLE 9

Average Jury-Judgments of Intensities of Signature Components

System		Describing Flash				Describing Smoke			
		Intensity		Duration		Density		Duration	
		Wood	Grass	Wood	Grass	Wood	Grass	Wood	Grass
90	Mean	3.72	2.84	2.80	2.24	2.12	3.52	2.00	3.36
	S.D.	0.52	0.56	0.46	0.29	0.35	0.64	0.28	0.41
LAW	Mean	2.24	1.32	1.88	1.28	1.92	2.36	1.48	2.44
	S.D.	0.73	0.16	0.41	0.24	0.37	0.34	0.10	0.59
MI	Mean	3.68	4.00	2.80	2.80	2.88	3.92	3.00	3.48
	S.D.	0.27	0.25	0.58	0.42	0.20	0.16	0.68	0.43
MII	Mean	3.68	3.64	2.92	2.24	3.56	3.96	3.28	3.44
	S.D.	0.64	0.34	0.45	0.32	0.34	0.27	0.48	0.27
WI	Mean	4.04	3.56	2.84	2.52	3.08	4.00	2.80	3.72
	S.D.	0.32	0.46	0.54	0.52	0.30	0.42	0.25	0.37
WII	Mean	4.00	3.72	3.32	2.60	2.68	3.24	2.24	2.76
	S.D.	0.38	0.24	0.16	0.18	0.53	0.64	0.48	0.23
Grand Mean		3.56	3.18	2.76	2.28	2.71	3.50	2.47	3.21

TABLE 10

Analysis of Variance of Jury-Judgments of Tactical Usefulness of Signature Characteristics

Source of Variance	What made you realize that a weapon fired?				What first helped you pinpoint location of weapon?				What helped you choose where to lay your fire?			
	Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement	Noise	Flash	Smoke	Movement
System	G	W G	W			W G	W		G	W G	W	

W - Significant during wood line firing.
G - Significant during grass line firing.

TABLE 11

Analysis of Variance of Jury-Judgment
of Signature Component Intensities

Source of Variance	Flash			Smoke		
	A	I	D	A	I	D
Systems	W G	W G	G	W G	W G	W G

Note:

A - Amount
I - Intensity (Density)
D - Duration

W - Significant during wood line phase.
G - Significant during grass line phase.

in attracting the observers' attention nor in helping them to identify and locate target point. Therefore, noise data were excluded from further considerations. These results of the Tukey-a test, relative to the grade rankings of usefulness of signature components, are shown in Table 12 and 13 for the wood line and grass line, respectively

In the wood line, the LAW was rated as producing significantly smaller amounts of flash; although the MII was not rated significantly different than LAW. The intensity of the LAW flash was rated significantly less than all other systems, and there was no significant difference in the rating of flash durations. Relative to the smoke ratings, it was found that LAW produced significantly smaller amounts of smoke than all other systems except the 90; the 90 produced significantly less smoke than MI, MII, and WI; and the WII produced less smoke than MI and MII. The smoke produced by the LAW was judged significantly less dense and shorter lived than MI and MII, with no other significant differences.

In the grass, the LAW was rated as producing the least amount of flash of all the systems, with no other significant differences. Similarly, LAW's flash was judged to be less bright than that of all other systems, with no other significant differences. The only significant differences in flash duration was between LAW, having the shortest lived flash, and MI, the longest lived flash – with no other significant differences. The ratings of smoke showed that LAW produced significantly smaller smounts of smoke than all other systems, except for WII, with no other significant differences. There was no significant difference in the ratings of systems' smoke density; however, the smoke of the LAW was judged shorter lived than MI, MII, and WI, with no other significant difference. These results are summarized in Tables 14 and 15.

The results of the second questionnaire requiring relative paired rather than individual system ratings are shown in Table 16. The observers' ratings of each system pair were totaled to indicate which system was jury-judged as making a better target and was easier to locate and counterfire. Included in the table are the results of structured comparison of the system pair. For the structured comparison, the signature of the first system in each pair was prorated at a constant value of "medium" and designated as a 4 on a 1-to-7 scale. The observers then graded the second system relative to the preset rating of the first system.

Figures 8 and 9 show the normalized results of ratings of the comparisons of signature component magnitudes. To normalize the comparison, the average values assigned to signature components of a system were divided by the corresponding component ratings of the system pair-fired with the first system.

The average times to observers' initial trigger pull are given in Table 17. The means were obtained by averaging the times of the five observers responding to five firings of each system. An analysis of variance (11) showed that there was a significant difference in the times due to variations between observers and systems during the grass line firings. However, there were no significant factors contributing to variations of times during the wood line firings. Similarly, the Tukey-a test (11) showed that the times to trigger pull against the LAW ranked significantly higher (more time required) than for all other systems during the grass line phase and no difference indicated for the wood line firings.

Each observer's aiming films were analyzed by digitizing rear screen projections at quarter-second intervals. The data were converted to error in terms of mils and the quarter-second values averaged to define the average aiming error for the corresponding second. The sign convention was such that a negative azimuth error meant the observer was aiming to the left of the point as viewed from the observation point. Similarly, a negative elevation error meant that the observer was aiming below the target point. Conversely, positive error values indicated right azimuth and high elevation. Runs terminated at fractional seconds were rounded up to the nearest second.

TABLE 12

Results of Tukey-a Test of Jury Assessments of Tactical Usefulness of Signature Components, Wood Line Phase

What made you realize a weapon was fired?

Flash

	LAW	MII	MI	90	WII	WI
LAW			*	*	*	*
MII						
MI						
90						
WII						

Smoke

	LAW	WII	90	MI	WI	MII
LAW		*	*	*	*	*
WII				*	*	*
90				*	*	*
MI						
WI						

What signs first helped you pinpoint the firing point?

Flash

	LAW	MII	90	MI	WI	WII
LAW		*	*	*	*	*
MII						
90						
MI						
WI						

Smoke

	LAW	WII	90	WI	MII	MI
LAW		*	*	*	*	*
WII				*	*	*
90						
WI						
MII						

What signs helped you choose where to lay your fire?

Flash

	LAW	MII	MI	90	WI	WII
LAW			*	*	*	*
MII						
MI						
90						
WI						

Smoke

	LAW	WII	90	MI	WI	MII
LAW		*	*	*	*	*
WII				*	*	*
90					*	*
MI						
WI						

*Indicates significant difference

TABLE 13

Results of Tukey-a Test of Jury Assessments of Tactical Usefulness of Signature Components, Grass Line Phase

What made you realize a weapon was fired?

	Flash						Smoke
	LAW	90	MII	WI	WII	MI	NO SIGNIFICANT DIFFERENCE
LAW		*	*	*	*	*	
90							
MII							
WI							
WII							

What signs first helped you pinpoint the firing point?

	Flash						Smoke
	LAW	90	MII	WI	MI	WII	NO SIGNIFICANT DIFFERENCE
LAW			*	*	*	*	
90							
MII							
WI							
MI							

What signs first helped you chose where to lay your fire?

	Flash						Smoke
	LAW	90	WI	MII	WII	MI	NO SIGNIFICANT DIFFERENCE
LAW		*	*	*	*	*	
90							
WI							
MII							
WII							

*Indicates significant difference.

TABLE 14

Results of Tukey-a Test of Jury Assessment of Visibility (amount) of Signature Components

Was the firing flash invisible or visible?

Wood Line	LAW	MII	MI	90	WI	WII
LAW			*	*	*	*
MII						
MI						
90						
WI						

Grass Line	LAW	90	WI	MII	WII	MI
LAW		*	*	*	*	*
90						
WI						
MII						
WII						

Was the smoke absent or present after firing?

Wood Line	LAW	90	WII	WI	MII	MI
LAW			*	*	*	*
90				*	*	*
WII					*	*
WI						
MII						

Grass Line	LAW	WII	90	MII	MI	WI
LAW			*	*	*	*
WII						
90						
MII						
MI						

*Indicates significant difference.

TABLE 15

Results of Tukey-a Test of Jury Assessments of Intensities and Duration of Signature Components

Was the flash dim or bright?

Wood Line

	LAW	90	MI	MII	WII	WI
LAW		*	*	*	*	*
90						
MI						
MII						
WII						

Grass Line

	LAW	90	WI	WII	MII	MI
LAW		*	*	*	*	*
90						
WI						
WII						
MII						

Was the flash long lasting or fast disappearing?

Wood Line

NO SIGNIFICANT DIFFERENCE

Grass Line

	LAW	MII	90	WI	MII	MI
LAW						*
MII						
90						
WI						
WII						

Was the smoke thin or dense?

Wood Line

	LAW	90	WII	WI	MI	MII
LAW					*	*
90						
WII						
WI						
MI						

Grass Line

NO SIGNIFICANT DIFFERENCE

Was the smoke long lasting or fast disappearing?

Wood Line

	LAW	90	WII	WI	MII	MI
LAW					*	*
90						
WII						
WI						
MI						

Grass Line

	LAW	WII	90	MI	MII	WI
LAW				*	*	*
WII						
90						
MI						
MII						

*Indicates significant difference.

TABLE 16

Comparison of Signatures of Systems
Fired in the Wood Line and Grass Line

System	Easier to Locate		Easier to Counterfire		Made Better Target		Signature Rd.2 vs. Rd.1 Woods		Grass	
	Woods	Grass	Woods	Grass	Woods	Grass	Avg.	S.D.	Avg.	S.D.
90	5	5	5	5	5	5				
LAW	0	0	0	0	0	0	1.40	0.49	2.00	0.63
90	0	0	0	0	0	0				
MI	5	5	5	5	5	5	5.40	1.20	6.00	0.0
90	0	1*	0	1*	0	1*				
MII	5	5	5	5	5	5	5.40	0.49	5.40	0.80
90	3	0	2	0	2	0				
WI	2	5	3	5	3	5	4.40	1.20	5.40	0.49
90	4*	1	4*	1	4*	1				
WII	2	4	2	4	2	4	3.60	1.36	5.20	1.33
LAW	0	0	0	0	0	0				
MI	5	5	5	5	5	5	6.40	0.80	6.20	0.40
LAW	0	0	0	0	0	0				
MII	5	5	5	5	5	5	6.60	0.49	6.20	0.75
LAW	1	0	1	0	1	0				
WI	4	5	4	5	4	5	6.60	0.49	5.80	0.40
LAW	1	0	1	0	1	0				
WII	4	5	4	5	4	5	6.20	0.98	6.00	0.63
MI	3	1	3	1	4	1				
MII	2	4	2	4	1	4	3.60	1.75	5.00	1.26
MI	0	1	0	1	0	1				
WI	5	4	5	4	5	4	6.00	0.84	5.00	1.55
MI	5	4	5	4	5	5*				
WII	0	1	0	1	0	1	2.60	1.36	3.00	0.63
MII	1	1	0	1	1	1				
WI	4	4	5	4	4	4	5.40	1.20	5.20	1.60
MII	3	5	3	5	3	5				
WII	2	0	2	0	2	0	4.40	1.36	2.40	0.49
WI	4	4	4	4	4	4				
WII	1	1	1	1	1	1	4.00	1.20	4.00	1.41

*Includes data where ties were scored.

System normalized on	Normalized Flash — Comparing System					
	90	LAW	MI	MII	WI	WII
90		0.39	0.96	1.17	0.90	1.00
LAW	2.57		2.27	2.10	1.50	1.77
MI	1.04	0.44		0.92	1.07	0.85
MII	0.86	0.48	1.08		1.33	1.38
WI	1.11	0.66	0.93	0.75		0.76
WII	1.00	0.57	1.18	0.73	1.31	

System normalized on	Normalized Smoke — Comparing System					
	90	LAW	MI	MII	WI	WII
90		0.37	1.60	1.36	1.06	0.74
LAW	2.71		1.85	2.00	2.75	1.38
MI	0.63	0.54		1.11	1.33	0.74
MII	0.74	0.50	0.91		1.47	0.83
WI	0.95	0.36	0.75	0.68		0.60
WII	1.36	0.72	1.36	1.20	1.67	

Fig. 8 Normalized comparisons of the relative grades assigned to systems signature components during paired firings from the wood line.

Normalized Flash

System normalized on	Comparing System: 90	LAW	MI	MII	WI	WII
90		0.32	1.33	2.50	1.27	2.25
LAW	3.14		1.36	2.00	1.70	1.82
MI	0.75	0.74		1.18	1.38	0.89
MII	0.40	0.50	0.85		1.11	0.60
WI	0.79	0.59	0.73	0.90		1.06
WII	0.44	0.55	1.12	1.67	0.94	

Normalized Smoke

System normalized on	Comparing System: 90	LAW	MI	MII	WI	WII
90		0.43	1.67	1.14	1.12	1.00
LAW	2.33		1.35	2.67	1.47	1.53
MI	0.60	0.74		1.14	1.10	0.68
MII	0.88	0.38	0.86		1.05	0.66
WI	0.89	0.68	0.91	0.96		0.84
WII	1.00	0.65	1.47	1.50	1.20	

Fig. 9 Normalized comparisons of the relative grades assigned to systems signature components during paired firings from the grass line.

TABLE 17

Mean Time to Trigger Pull of Observers After Systems Were Fired

System	Time to Trigger Pull			
	Wood Line		Grass Line	
	Mean	S.D.	Mean	S.D.
90	3.87	1.07	2.16	0.40
LAW	4.19	1.31	3.02	1.06
MI	3.33	1.28	1.76	0.40
MII	3.32	1.24	1.96	0.28
WI	3.39	1.00	1.90	0.29
WII	4.43	1.84	1.90	0.35

Figure 10 shows the averaged counterfiring error recorded by the observers against the test systems, as a function of time. Also shown are the averaged drifts of the test systems' smoke clouds. It must be remembered that the smoke drift was recorded from a location separate from the observation point. At this location, the apparent displacement – to the left of the systems – of the smoke cloud did not become evident because the recording camera was almost on the test systems' line of fire.

For further aiming error data analysis, it was assumed that all observers started counterfiring simultaneously. This assumption simplified pooling of aiming data to define aiming error as a function of counterfiring time. The mean aiming error, as a function of time, was averaged for five observers and five firings of each system. The overall mean was obtained by averaging an observer's performance in counterfiring five firings of a system; then, the means and variances of the five observers were averaged to define the overall mean (bias) and standard deviation (dispersion). The results for the azimuth and elevation errors as a function of time are given in Tables 18 and 19, respectively, for the wood line firings, and Tables 20 and 21, respectively, for the grass line firings.

The azimuth errors recorded against the LAW showed wide variations in 8 out of 25 observer/system-firing combinations. It was noted that the error and variance were much higher for these eight cases than in the remaining LAW firings. Checking the responses on the questionnaires, it became evident that the higher azimuth errors corresponded to those cases for which the observers reported seeing very little (no) flash and very little (no) smoke. Therefore, it was decided to group the azimuth error against LAW as follows:

a. All LAW data.

b. LAW data obtained in cases in which the observers reported seeing both very little flash and very little smoke.

c. Those LAW data obtained in cases in which the observers reported seeing flash or smoke, or both.

On the other hand, there was no variation in the elevation data. Therefore, it was decided not to separate the LAW elevation data.

To obtain an estimation of post-firing survivability of each system, the aiming data were used to calculate hit probabilities against the systems. Several simplifying assumptions were made concerning the counterfiring weapons:

a. Projectile trajectory was flat.

b. Normal distribution of projectile impact.

c. Nonfragmenting projectiles.

d. Weapon characteristics omitted.

The target used to represent the firing point was a vertical rectangle, 6 feet wide and 3 feet high. The calculated hit probabilities (impacting a projectile in the target area) are given in Table 22.

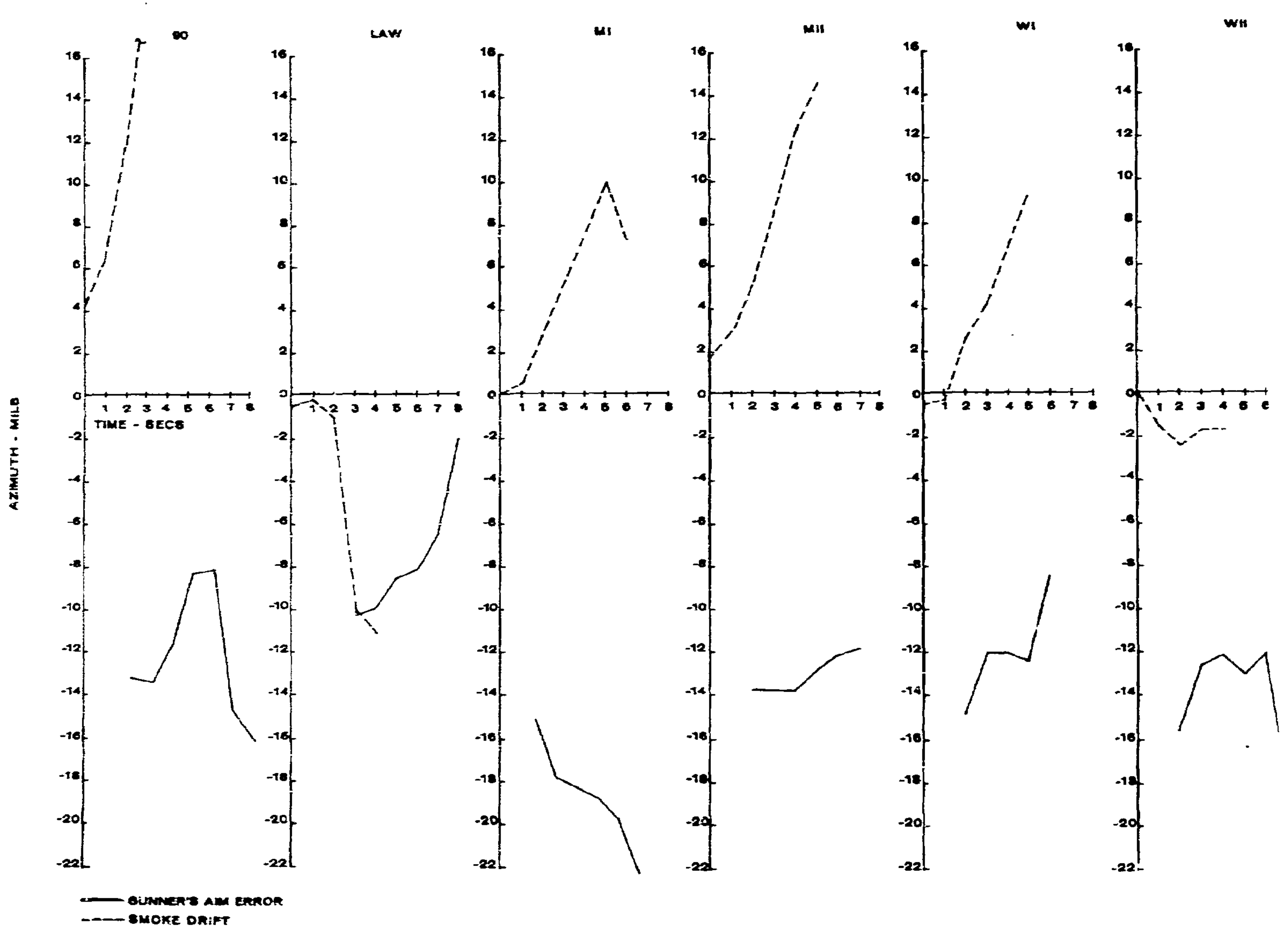

Fig. 10 Firing smoke drift and observers' aiming error

TABLE 18

Mean Azimuth Aiming Performance by Downrange Observers, Wood Line Firings. All Tracking Information in Mils

System	Time - Seconds							Overall	
	0	1	2	3	4	5	6	Mean	S.D.
90	-17.03	-18.18	-15.62	-14.23	-16.77	-20.17	-20.55	-16.05	12.67
LAW A	-16.11	-14.21	-11.34	-12.68	-10.30	-14.60	0.27	-12.54	25.94
LAW B	-14.67	- 8.20	- 2.08	-13.41	-11.76	-16.10	21.42	- 9.57	29.65
LAW C	-17.13	-18.49	-17.10	-12.28	- 9.33	-13.10	-10.30	-18.55	13.47
MI	-14.87	-15.64	-17.61	-19.21	-18.89	-18.94	-19.74	-17.28	10.08
MII	-20.42	-20.30	-20.51	-21.09	-19.73	-21.44	-25.98	-19.82	15.38
WI	- 8.44	- 9.05	- 6.85	- 4.86	-12.11	-16.10	- 7.13	- 9.19	12.84
WII	1.94	1.79	1.64	- 0.05	0.17	1.77	- 1.96	2.41	13.18

LAW A - All LAW firings.
LAW B - LAW firings for which observers reported seeing no flash and no smoke.
LAW C - LAW firings for which observers reported seeing either flash or smoke, or both.

TABLE 19

Mean Elevation Aiming Performance by Downrange Observers, Wood Line Firings. All Tracking Information in Mils

System	Time - Seconds							Overall	
	0	1	2	3	4	5	6	Mean	S.D.
90	1.07	1.52	2.15	1.78	2.54	2.67	2.54	1.82	3.85
LAW	0.0	0.64	0.78	0.83	1.05	2.99	2.93	0.45	2.95
MI	1.13	2.34	2.92	2.85	3.33	2.64	3.26	2.82	3.66
MII	3.78	4.11	3.34	4.17	4.91	5.99	6.26	4.22	3.91
WI	2.93	3.97	4.50	5.55	5.73	5.99	2.52	4.50	4.07
WII	2.17	0.97	1.39	1.38	1.87	2.64	5.58	1.66	6.43

TABLE 20

Mean Azimuth Aiming Performance by Downrange Observers, Grass Line Firings. All Tracking Data in Mils

System	Time - Seconds							Overall	
	0	1	2	3	4	5	6	Mean	S.D.
90	-13.29	-13.42	-11.75	- 8.36	- 8.08	-14.74	-16.12	-11.37	8.74
LAW	-10.36	- 9.99	- 8.66	- 8.17	- 6.57	2.03		- 8.54	11.52
MI	-15.13	-16.72	-18.30	-18.72	-19.73	-22.35		-17.68	7.52
MII	-13.80	-13.83	-13.81	-12.89	-12.13	-11.80		-13.35	7.86
WI	-14.81	-12.04	-12.02	-12.38	- 8.47			-11.97	10.50
WII	-15.54	-12.55	-12.08	-12.92	-12.04	-18.35		-12.36	8.66

TABLE 21

Mean Elevation Aiming Performance by Downrange Observers,
Grass Line Firings. All Tracking Data in Mils

System	Time - Seconds							Overall	
	0	1	2	3	4	5	6	Mean	S.D.
90	0.87	1.28	1.89	2.23	2.07	2.99	4.62	1.77	3.48
LAW	0.76	0.35	0.68	1.36	2.08	0.71		1.06	2.95
MI	-1.01	-0.04	0.47	0.50	2.36	0.37		0.22	4.71
MII	0.60	2.46	1.86	2.13	2.50	2.95		1.85	2.91
WI	0.84	2.01	2.60	2.15	2.75			1.64	3.54
WII	-1.48	1.05	0.91	1.05	1.64	1.39		0.69	3.17

TABLE 22

Calculated Hit Probability (P_H) Using Observer's Overall Azimuth and Elevation Data Against Systems

System	Hit Probability: Wood line	Hit Probability: Grass line
90	0.0192	0.0352
LAW A	0.0263	0.0576
LAW B	0.0300	-
LAW C	0.0256	-
MI	0.0111	0.0056
MII	0.0096	0.0246
WI	0.0190	0.0354
WII	0.0262	0.0362

LAW A - All LAW data.
LAW B - LAW firings for which observers reported seeing no flash and no smoke.
LAW C - LAW firings for which observers reported seeing either flash or smoke, or both.

A second approach was taken to evaluate system vulnerability. This was done by the U. S. Army Systems Analysis Agency (AMSAA). The aiming error data were given to AMSAA and used to define the aiming bias and dispersion for weapons counterfiring against the six systems tested. The three foreign systems used as possible defensive weapons against the six test systems tested were:

a. Weapon A, similar to the caliber .50 machinegun, firing armor-piercing(AP) ammunition.

b. Weapon B, an automatic cannon system of the 20- to 30-millimeter size, firing high-explosive (HE) ammunition.

c. Weapon C, a large bore system, suitable as a main weapon system.

A 20-second engagement was allocated for Weapon A and a 10-second engagement for Weapon B, and the following assumptions were made:

a. Engagement times included time required for target acquisition.

b. Target was a kneeling gunner (39 inches high) located at the center of a 6-by 3-foot horizontal rectangle.

c. Specific system characteristics were to be included in the calculations.

It was noted that aiming biases were large and mostly to the left of the firing points. It was decided to set the azimuth bias equal to zero and use only the azimuth standard deviation values in the computation of fractional kill probabilities for Weapons A and B. This was used as a rough approximation of the case where the counterfirer would be much closer to the test systems' line of fire (rather than being offset 45 degrees), and would not see the apparent displacement of the smoke cloud from the firing point. The calculated fractional kill probabilities for the three weapons are given in Table 23. For Weapons A and B, the assumed in-line (no offset) values are shown. For Weapon C, it was decided not to obtain an in-line value; however, fractional kill probabilities were calculated for first and second rounds.

The jury judgments of flash visibility and smoke visibility were tested for correlation with measurements of the respective components. The smoke dimensions were taken at 3 seconds after firing, while the modified length-time measurements of the flash were used. Then the flash and smoke assessment grades were tested for correlation with absolute values of azimuth biases and simple hit probabilities (Table 24). Positive correlations were found to exist between assessment grades and measurements of flash and smoke. It is interesting to note that the bias values were directly related to smoke size assessments during wood and grass line firings. The azimuth biases were inversely proportional to flash size assessments in the wood line, but directly proportional to the assessments in the grass line. Table 25 shows that the fractional kill probabilities were generally inversely proportional to the size assessments of the flash and smoke.

Table 26 shows the percent of change in average judgments of amounts, densities, and durations of flash and smoke during the wood and grass line firings. For reference, the changes in meteorological data are included.

TABLE 23

Fractional Kill Probability Calculated at 300-Meter Range

	Weapon A				Weapon B				Weapon C			
	Wood line		Grass line		Wood line		Grass line		Wood line		Grass line	
System	With Offset	No Offset	With Offset	No Offset	With Offset	No Offset	With Offset	No Offset	1st Round	2d Round	1st Round	2d Round
90	.14	.21	.19	.33	.30	.48	.45	.60	.076	.145	.097	.183
LAW	.11	.15	.25	.28	.32	.30	.39	.53	.081	.153	.108	.204
MI	.074	.27	.072	.31	.29	.56	.25	.54	.076	.145	.075	.141
MII	.12	.19	.13	.37	.19	.37	.38	.59	.053	.102	.099	.187
WI	.23	.24	.16	.26	.33	.54	.35	.53	.066	.125	.088	.166
WII	.17	.16	.16	.34	.37	.37	.39	.61	.068	.128	.101	.189

TABLE 24

Results of Tests for Correlations Between Various Test Results

Correlated Items	Correlation Coefficient	
	Wood line	Grass line
Flash grades and flash length-time	+ 0.49	+ 0.43
Flash grades and flash height-time	+ 0.56	+ 0.41
Smoke grades and smoke height	a	+ 0.76
Smoke grades and smoke width	a	+ 0.94
Flash grades and absolute azimuth bias	- 0.23	+ 0.84
Smoke grades and absolute azimuth bias	+ 0.71	+ 0.24
Flash grades and P_H	- 0.23	- 0.86
Smoke grades and P_H	- 0.77	- 0.80

a No smoke data obtained during wood line firings.

TABLE 25

Results of Tests for Correlation Between Fractional Kill Probabilities and Jury Judgments of Signature Components

Correlated Variables	Correlation Coefficient							
	Weapon A		Weapon B		Weapon C Rd.1		Weapon C Rd.2	
	Wood line	Grass line	Wood line	Grass line	Wood line	Grass line	Wood line	Grass line
Flash grades and P_K	+ 0.51	- 0.91	+ 0.16	- 0.18	- 0.39	- 0.71	- 0.40	- 0.71
Smoke grades and P_K	+ 0.19	- 0.79	- 0.40	- 0.53	- 0.64	- 0.72	- 0.64	- 0.72

TABLE 26

Percent of Change of Average Values Obtained During Grass Line Firings Relative to Those Recorded During Wood Line Firings

Item	Percent Change
Temperature	+ 1.4
Humidity	+ 5.9
Pressure	- 2.9
Flash amount	- 11.7
Flash intensity	- 10.7
Flash duration	- 17.4
Smoke amount	+ 25.5
Smoke density	+ 29.2
Smoke duration	+ 29.6

DISCUSSION OF RESULTS

Firing noise and movement of the surrounding vegetation were not dominant tactical discriminators between systems. Analysis of variance of the jury judgments of tactical usefulness of signature components (noise, flash, smoke, and movement) showed that there were no significant variations due to systems in the assessments of movement associated with firings of the different systems during both the wood line and grass line phases. The Tukey-a test, used to define significant differences in ordinal rankings of noise assessments, showed that there were no differences in the noise rankings during both the wood line and grass line firing phases. Perhaps if all the firings were not done from a defined and limited sector, the noise would have been of more significant tactical value in aiding the observer to locate firing points. For safety reasons, of course, all firings had to be confined to established firing lines relative to the position of the downrange observers and minimized the importance of target detectability for a more random environment. Importance of firing movement may have been diminished by the lack of tall, easily swayable vegetation. Springtime vegetation was stubby and the interactions with firing over pressures were probably minimal.

On the other hand, firing flash and smoke were consistent discriminators between systems, as was shown by both the analysis of variance and the Tukey-a test. The relative judged importance of flash and smoke was influenced by the contrast ratio provided by the surroundings, such that the predominance of tactical usefulness and subsequent description of amounts, intensity, and duration of a signature component depended on high contrast ratio. For example, during the wood line firing phase, the flash was judged to be tactically more important than smoke. Conversely, during the grass linefiring phase, the smoke was judged to be more important in aiding to locate and aim at firing points. Simply, the observer responded more to, depended more on, and used that signature component which had the highest contrast ratio with the surroundings, and tended to minimize their dependence on the other components.

In terms of firing signature size based on jury judgments, the systems divided into three groups. The LAW produced the smallest judged signature, both in terms of flash and smoke. On the other extreme were the candidate recoilless and rocket systems which were judged as producing the largest and tactically most useful signatures. The 90mm was judged lower than the candidate systems, but higher than the LAW. The judgment grades of signature component size showed good direct correlation to the respective measurements of flash and smoke taken from films. Measurements showed that of the candidate systems, the WII produced most flash and MI produced the most smoke.

It should be noted that there was no provision for the observers to indicate that they saw no flash and no smoke. For either case, only the judgments of very little flash and very little smoke were provided. For two of the LAW firings from the wood line, three of the observers reported seeing very little flash and smoke. There were two other individual instances for which single observers made the same judgment. It was interpreted that these eight data points represented the times that none of the LAW signature was seen. Another variable, which had not been anticipated and no provisions made, was that on a few occasions during the wood line firings the proposed rocket systems left an exhaust trail consisting of smoke and some flame. This phenomenon became evident when the downrange films were being analyzed.

The paired comparisons of systems reflected he general trichotomy evidenced from rankings of signature size. The observers judged the LAW as a more difficult target than all other systems, and its overall signature as much smaller than all others. The two candidate rocket systems were judged as easier targets than the 90mm, while the two candidate recoilless systems were judged almost evenly with the with the 90mm. There were no dominant preferences (due to judgments as easier targets) among the candidate systems. The observers relied most on the firing smoke to locate firing points and used the smoke to direct their counterfire – for those systems which produced more smoke were rated as easier targets to identify and counterfire.

Of the total flash produced by the systems, an overall average of 76.5 percent – for all firings – of the flash was produced at the rear of the systems. Based on the viewing angle during the test, relative to the line of fire, the smoke was displaced to the (observers') left of the firing point. The average biases showed that the observers did aim to the left (at the smoke) and the observers' aim drifted to the right as the winds carried the smoke clouds to the right.

Since this was not a detection study, the times to observers' initial trigger pulls are not indicators of the ease with which targets were located. However, these times may be used as indicators of the ease with which the observers were able to choose their aim points. For example, even though the observers knew the limits of the firing lines, when the LAW (small signature) was fired they required more time to select an aim point. Conversely, when they saw a large and plainly visible signature, they started firing much sooner.

By considering and intuitively combining the various data, it is possible to characterize the observers' counterfiring tendencies. When a system, such as the LAW, produces a small signature – little flash and smoke – and the signature is not apparently displaced away from the system, the observers tend to take more time to choose and come on target aim point but are then fairly accurate in laying counterfire. On the other hand, when a system, such as the candidate systems, produces a large flash and a lot of smoke which is expelled well away (to the rear) from the system, the observers start firing much quicker but are less accurate. Furthermore, they tend to aim at the smoke and follow the cloud as it drifts.

The vulnerability – in terms of fractional kill probability – of the systems depended on the firing line under consideration and the type of foreign weapon system (theoretically) used to counterfire against the test systems. Furthermore, vulnerability was a function of whether the original data were used or whether the modified data were used to approximate in-line engagements.

When a foreign .50 caliber-like machinegun engages the systems during wood line firings, MI appears to be the least vulnerable due to the large aiming offset; and the most vulnerable system appears to be WI against which the observers recorded small offsets and standard deviations. When the recorded offsets were set equal to zero (approximating engagements along the test systems' lines of fire), the fractional kill probabilities against all the systems were similar; however, the 90, MI, and WI appear most vulnerable because the smallest deviations were recorded during counterfirings against these systems. When the approximately 20mm HE was (theoretically) used against the test systems, it appears that all systems are approximately alike. However, only MII looks appreciably less vulnerable because it had the largest offset and standard deviation (if the cases of non-seen LAW firings are eliminated) recorded during counterfirings.

For counterfirings with the .50 caliber-like weapon against the test systems fired from the grass line, the MI appears least vulnerable since it possessed the largest offset and the LAW appears most vulnerable since it possessed the smallest standard deviation recorded during counterfirings. When the offset was set equal to zero, the vulnerability of the test systems became about equal. When considering the 20mm-like HE system, no major differences appeared for the unbiased (excluding offset) counterfiring condition. However, for the biased (including offset) counterfiring condition, the MII appears to be least vulnerable since it has not only a large offset but the largest elevation sigma.

A note of caution should be emphasized here. The no-offset condition — approximated by setting aiming bias equal to zero and using only the standard deviaiton — was done primarily as a sensitivity study. The assumption that the dispersion (standard deviation) would remain the same as viewing angle was changed was, at best, an approximation.

Post-firing survivability of a system may be defined in many terms; however, it was decided to consider vulnerability (hit and fractional kill probabilities) and time to observers' trigger pull as indicators of survivability. Higher hit/kill probabilities were defined as decreases in survivability and longer times to trigger pull indicate increases in survivability. Therefore, considering these two items, there were no major differences in the defined survivability. Those systems against which lower hit/kill probabilities were scored also required less time to trigger pull. Conversely, when the observers required more time to trigger pull, the resulting hit/kill probabilities were higher. Therefore, it was felt that the results of this test did not indicate major differences between post-firing survivability of the systems.

Results of the gunner-view obscuration showed that LAW produced no obscuration. The WI produced most obscuration. Furthermore, the obscuration was a function of the firing location; that is, whether the firing was done in the open or in the woods (shaded). In the open, the back-scatter of the smoke increased and the obscuration times increased. The WI recorded the longest obscuration times, with total obscuration lasting 1.1 seconds with impairment of sight lasting for 3.6 seconds during the grass line firing phase.

CONCLUSIONS

It was concluded that:

1. Compared to the LAW, all systems produce more flash and smoke.

2. Downrange observers respond and use that component of the signature (flash or smoke) which has the highest contrast ratio with the surroundings. Due to test limitations, noise and firing movement were not significant discriminators between systems.

3. Large smoke clouds are preferred by downrange observers and are judged tactically more important. However, large diffuse smoke clouds do not result in more accurate aiming performance by the observers. On the other hand, large or long-lasting firing flash results in increased counterfiring accuracy of the observers.

4. Vulnerability of the test systems is dependent on the relative viewing angle between the firing system and the downrange observer.

5. Aiming accuracy is dependent on proximity of the signature to the weapon, and how the soldier has been taught to interpolate location of weapon relative to display of firing smoke.

6. Of the systems included in this test, none showed a superiority in the defined post-firing survivability.

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APPENDIX A

SAMPLE QUESTIONNAIRES USED TO OBTAIN JUDGMENTS OF FIRING SIGNATURES

APPENDIX A

1A - Questionnaire Used to Get Judgment Data on Each Round Fired

What signs made you realize that a weapon was fired?

		very	somewhat	neutral	somewhat	very	
Noise:	unimportant	1	2	3	4	5	important
Flash:	unimportant	1	2	3	4	5	important
Smoke:	unimportant	1	2	3	4	5	important
Movement:	unimportant	1	2	3	4	5	important

What signs first helped you pinpoint location of weapon?

		very	somewhat	neutral	somewhat	very	
Noise:	unimportant	1	2	3	4	5	important
Flash:	unimportant	1	2	3	4	5	important
Smoke:	unimportant	1	2	3	4	5	important
Movement:	unimportant	1	2	3	4	5	important

What helped you choose where to lay in your fire?

		very	somewhat	neutral	somewhat	very	
Noise:	unimportant	1	2	3	4	5	important
Flash:	unimportant	1	2	3	4	5	important
Smoke:	unimportant	1	2	3	4	5	important
Movement:	unimportant	1	2	3	4	5	important

Was the noise from firing

	very	somewhat	neutral	somewhat	very	
Faint	1	2	3	4	5	loud
Sharp	1	2	3	4	5	rumbling

IA (continued)

Was the flash from firing

	very	somewhat	neutral	somewhat	very	
Invisible	1	2	3	4	5	visible
Dim	1	2	3	4	5	bright
Brief	1	2	3	4	5	lasting

Was the smoke from firing

	very	somewhat	neutral	somewhat	very	
Absent	1	2	3	4	5	present
Thin	1	2	3	4	5	dense
Fast disappearing	1	2	3	4	5	lasting

Was the movement of surroundings from firing

	very	somewhat	neutral	somewhat	very	
Not apparent	1	2	3	4	5	apparent
Brief	1	2	3	4	5	lasting
Localized	1	2	3	4	5	wide-spread

APPENDIX A

2A - Questionnaire Used to Get Paired Comparisons Between Rounds

Which round was easiest to locate?

_______ Round 1 _______ Round 2

Which round was easiest to lay your "counterfire" on?

_______ Round 1 _______ Round 2

Which round would you rather have as a target (which fired but missed you) to fire back on

_______ Round 1 _______ Round 2

Grade the smoke-cloud from firing

		very	somewhat	neutral	somewhat	very	
Round 1	easy to see	1	2	3	4	5	hard to see
Round 2		1	2	3	4	5	

Grade the movement associated with firing

		very	somewhat	neutral	somewhat	very	
Round 1	not apparent	1	2	3	4	5	apparent
Round 2		1	2	3	4	5	

2A (continued)

Grade the noise from firing

		very	somewhat	neutral	somewhat	very	
Round 1		1	2	3	4	5	
	faint						loud
Round 2		1	2	3	4	5	

Grade the flash from firing

		very	somewhat	neutral	somewhat	very	
Round 1		1	2	3	4	5	
	easy to see						hard to see
Round 2		1	2	3	4	5	

If 4 were assigned to the firing signature of round 1 and its position revealing characteristics, how would you grade the position revealing characteristics of round 2?

	very			same			very	
Less revealing	1	2	3	4	5	6	7	more revealing

APPENDIX B

ROUND-BY-ROUND SEQUENCE AND PAIRING

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TABLE 18

Firing Schedule and Meteorological Data for Wood Line Firing Phase

Date	Pair No.	Rd. No.	Pos. No.	System	Time	Wind (mph)	Temp °F	Humidity (Percent)	Pressure (corrected)	Visibility
May 10	1	1	1	MI	1341	4-8	67	72	28.86	Bright
		2	2	MII	1416	4-8	70	66	28.84	Bright - slight haze
11	2	3	3	MI	1016	6-10	62	50	28.98	Bright
		4	2	WI	1056	6-8	63	45	28.99	Very broken overcast
	3	5	3	MI	1216	4-6	65	44	28.97	Broken overcast
		6	4	WII	1252	4-6	66	43	28.98	Broken overcast
	4	7	5	MII	1325	2-6	66	42	28.99	Broken overcast
		8	4	WI	1349	4-6	67	42	28.98	Broken overcast
14	5	9	2	MII	1006	4-6	57	54	29.27	Bright
		10	3	WII	1030	4-6	58	48	29.25	Bright
	6	11	5	WI	1104	4-6	60	40	29.25	Broken overcast
		12	4	WII	1126	4-6	61	40	29.24	Overcast
	7	13	1	90	1259	0-2	62	39	29.21	Overcast
		14	2	LAW	1315	0-2	63	39	29.21	Overcast
	8	15	3	90	1350	2-4	63	37	29.20	Overcast
		16	2	MI	1408	8-10	63	37	29.20	Overcast
	9	17	4	90	1444	2-4	62	39	29.19	Overcast
		18	3	MI	1504	2-4	62	39	29.19	Overcast
	10	19	4	90	1521	2-4	62	40	29.19	Overcast
		20	5	WI	1544	2-4	61	43	29.18	Overcast

TABLE 1B (continued)

Firing Schedule and Meteorological Data for Wood Line Firing Phase (continued)

Date	Pair No.	Rd. No.	Pos. No.	System	Time	Wind (mph)	Temp °F	Humidity (Percent)	Pressure (corrected)	Visibility
May 15	11	21	2	90	0951	0-2	54	51	29.29	Bright
		22	1	WII	1020	2-4	54	50	29.28	Broken overcast
	12	23	3	LAW	1043	0-2	54	48	29.28	Broken overcast
		24	4	MI	1103	0-2	54	48	29.28	Broken overcast
	13	25	5	LAW	1121	0-2	55	46	29.27	Heavy broken overcast
		26	4	MII	1133	0-2	55	46	29.27	Heavy broken overcast
	14	27	3	LAW	1244	0-2	56	45	29.26	Dark overcast
		28	4	WI	1301	0-2	56	44	29.25	Dark overcast
	15	29	2	LAW	1320	0-2	57	45	29.24	Dark overcast
		30	3	WII	1342	0-2	57	45	29.23	Dark overcast

TABLE 2B

Firing Schedule and Meteorological Data for Grass Line Firing Phase

Date	Pair No.	Rd. No.	Pos. No.	System	Time	Wind (mph)	Temp ^oF	Humidity (Percent)	Pressure (corrected)	Visibility
May 17	1	1	4	90	1045	2-4	53	46	29.00	Bright
		2	3	MII	1104	2-4	53	46	29.00	Bright
	2	3	4	90	1119	2-4	55	43	29.01	Bright
		4	5	WI	1144	0-2	57	40	29.01	Bright
	3	5	2	90	1245	2-4	57	40	29.01	Broken clouds
		6	1	WII	1315	0-2	57	40	29.01	Overcast
	4	7	3	LAW	1335	0-2	57	40	29.01	Overcast
		8	4	MI	1350	0-2	57	40	29.01	Overcast, broken
	5	9	5	LAW	1407	2-4	57	40	29.01	Overcast, broken
		10	4	MII	1421	2-4	57	40	29.01	Overcast, broken
18	6	11	3	LAW	0928	2-4	54	60	28.98	Bright
		12	4	WI	0958	2-4	56	53	28.98	Bright
	7	13	2	LAW	1015	2-4	59	49	28.98	Bright
		14	3	WII	1037	4-6	59	48	28.98	Bright
	8	15	1	MI	1059	2-4	62	41	28.98	Hazy overcast
		16	2	MII	1111	2-4	62	39	28.97	Hazy overcast
	9	17	3	MI	1228	0-2	63	36	28.96	Hazy overcast
		18	2	WI	1247	2-4	63	36	28.95	Hazy overcast
	10	19	3	MI	1300	2-4	64	36	28.95	Dark overcast
		20	4	WII	1319	0-2	64	35	28.95	Dark overcast

TABLE 2B (continued)

Firing Schedule and Meteorological Data for Grass Line Firing Phase
(continued)

Date	Pair No.	Rd. No.	Pos. No.	System	Time	Wind (mph)	Temp °F	Humidity (Percent)	Pressure (corrected)	Visibility
May 21	11	21	5	MII	0947	0-2	63	70	29.01	Bright haze
		22	4	WI	1002	2-4	63	70	29.01	Bright haze
	12	23	2	MII	1019	0-2	65	66	29.01	Bright
		24	3	WII	1034	0-2	66	64	29.01	Bright
	13	25	5	WI	1051	0-2	67	62	29.01	Bright
		26	4	WII	1107	0-2	67	62	29.01	Bright
	14	27	1	90	1219	0-2	70	55	29.00	Bright
		28	2	LAW	1230	0-2	71	52	28.99	Hazy overcast
	15	29	3	90	1251	0-2	71	50	28.99	Bright
		30	2	MI	1304	0-2	71	49	28.99	Bright