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Operational Requirements for an INFANTRY HAND WEAPON

By Norman Hitchman

Statistical Analysis by Scott Forbush and George Blakemore Jr.

ORO
OPERATIONS RESEARCH OFFICE
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The Johns Hopkins University

Operating Under Contract with the

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The Director
Operations Research Office
The Johns Hopkins University
6410 Connecticut Avenue
Chevy Chase, Maryland

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ORO abstract

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Of what should a rifle be capable in battle today? Since there is a limit as to how accurately the infantryman fires, can one increase hits by giving him a rifle with new operational characteristics? ORO's Project BALANCE studied this by taking data on how often, and by how much, riflemen missed targets (as well as the distribution of hits) at different ranges, by taking data on the ranges of engagement in battle, and by taking data on the physiological wound effects of shots with differing ballistic characteristics. The recommendation is made that Ordnance proceed to determine the technological feasibility of a weapon with operating characteristics analyzed in this memorandum. This follows from conclusions which are listed only sketchily below:

- Hit effectiveness using the M-1 is satisfactory only up to 100 yards and declines very rapidly to low order at 300 yards, the general limit for battlefield rifle engagements.
- A pattern-dispersion principle in the hand weapon would tend to compensate for human aiming errors and increase hits at ranges up to 300 yards.
- Missiles, smaller caliber than now standard, could be used without loss in wounding effects and with logistical advantage, and a great increase in hit lethality could be effected by using toxic missiles.

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Norman A. Hitchman

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George J. Blakemore, Jr.

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SUMMARY

PURPOSE

The study reported upon in this memorandum was undertaken for the purpose of determining the desirable operational characteristics of a general purpose infantry hand weapon.

ASSUMPTIONS

It has been assumed that it is desirable to increase in both <u>number and rate</u> the hits which may be inflicted on the enemy by aimed small arms in the hands of the infantry.

It has been further assumed that it is desirable also to increase the mortality of wounds caused by these hits.

DISCUSSION

In this examination of the basic infantry weapon, the rifle, two commonly accepted considerations or premises were carefully scrutinized, and their bearing upon infantry operations evaluated: 1) the time taken to hit enemy man targets is vital in that hits should be inflicted as early and at as great a range as possible; and 2) these hits should inflict significant injury—should be at least immediately incapacitating (in some circumstances, lethal). The findings are <u>generally</u> affirmative with respect to both propositions.

Study of combat records of operations, as well as field investigations of the man-rifle combination, shows that much is to be gained by increasing the hit capability of aimed rifle fire at the common battle ranges, and that increasing the severity of the hits is also to be sought. How men actually use the rifle in combat, the ranges of engagement most frequently recurring in battle, how terrain limits intervisibility of opposing firing lines, and what is required ballistically to create physiologically desirable wound effects on the enemy, are factors which have been analyzed for the purpose of determining the operational requirements of a general purpose hand weapon.

Study of the various factors involved has yielded a number of independent but related and consistent determinations. Synthesis has permitted comprehensive evaluation of the combat actions bearing in concert upon effective employment of the hand weapon.

Battlefield visibility data show why combat rifle fire is actually so limited in range by normal terrain obstructions to the line of sight as rarely to exceed 300 yd. Studies of the manner in which gunshot wounds are incurred in battle suggest that lesser-included ranges are in reality the important ones. Measurements of marksmanship show that performance is of a very low order beyond a range of 300 yd. Wound ballistic data offer convincing evidence that small caliber, high velocity missiles may be used profitably at such ranges, without loss in wounding effects and with significant logistical gains.

The mutually confirmatory nature of the several findings goes far to explain present rifle operations, and to suggest the desirable characteristics for a general purpose infantry hand weapon. The conclusions which follow have emerged.

CONCLUSIONS

1. The ranges at which the rifle is used most frequently in battle and the ranges within which the greater fraction of man targets can be seen on the battlefield do not exceed 300 yd.
2. Within these important battle ranges, the marksmanship of even expert riflemen is satisfactory in meeting actual battle requirements only up to 100 yd; beyond 100 yd, marksmanship declines sharply, reaching a low order at 300 yd.
3. To improve hit effectiveness at the ranges not covered satisfactorily in this sense by men using the M-1 (100 to 300 yd), the adoption of a pattern-dispersion principle in the hand weapon could partly compensate for human aiming errors and thereby significantly increase the hits at ranges up to 300 yd.
4. Current models of fully automatic hand weapons afford neither these desirable characteristics nor adequate alternatives. Such weapons are valueless from the standpoint of increasing the number of targets hit when aiming on separated man-size targets.

5. Certain of the costly high standards of accuracy observed in the manufacture of current rifles and ammunition can be relaxed without significant losses in over-all hit effectiveness.

6. To meet the actual operational requirements of a general purpose infantry hand weapon, many possibilities are open for designs which will give desirable dispersion patterns (and accompanying increases in hit probability) at the ranges of interest. Of the possible salvo or volley automatic designs,* the small caliber, lightweight weapon with controlled dispersion characteristics appears to be a promising approach. (Low recoil of a small caliber weapon facilitates dispersion control.)

7. To create militarily acceptable wound damage at common battle ranges, missiles of smaller caliber than the present standard .30 cal can be used without loss in wounding effects and with substantial logistical and over-all military gains.

8. A very great increase in hit lethality can be effected by the addition of toxic agents to bullet missiles.

RECOMMENDATIONS

1. It is recommended that the Ordnance Corps proceed to determine the design or technological feasibility of developing a hand weapon which has the characteristics cited in this analysis, namely:

a. Maximum hit effectiveness against man targets within 300 yd range. (This does not mean that the weapon will be ineffective beyond this range.)

b. Small caliber (less than .30).

c. Wounding capability up to 300 yd at least equivalent to the present rifle.

d. Dispersion of rounds from salvos or burst controlled so as to form a pattern such that aiming errors up to 300 yd

*Current military usage of the two words salvo and volley is confused. By "salvo" the Navy and Air Force generally mean, respectively, the simultaneous discharge of several pieces, or the simultaneous release of a number of bombs; the Army usually employs the word to indicate the successive firing of several guns within a single command unit. "Volley" is commonly taken by all services to mean the simultaneous firing of a number of rifles or guns, with the exception that the artilleryman often applies the word to the independent (unsynchronized) firing of a certain specified number of rounds by each of several associated pieces. What is discussed here and in the following pages is either a simultaneous, or a high cyclic rate, burst, with the number of rounds per burst automatically set rather than dependent upon trigger release. In the former design, controlled nutation of the rifle muzzle would provide the desired shot dispersion or pattern; in the latter, the scatter would be obtained and controlled by multiple barrels, a mother-daughters type of projectile, or projection of missiles in the manner of a shotgun.

will be partly compensated, and hit effectiveness thereby increased for these ranges.

2. As one possible alternative to the current "volume of fire" (fully automatic) approach to the problem of increasing the effective firepower of infantry riflemen, it is recommended — subject to tentative confirmation of design feasibility—that a rifle incorporating at least in principle the military characteristics here proposed be manufactured for further and conclusive test.

OPERATIONAL REQUIREMENTS FOR AN INFANTRY HAND WEAPON

INTRODUCTION

The subject of this study is of a basic nature for it applies to the basic weapon of the basic branch—the rifle carried by the infantry. Because the hand arm offers certain capabilities not duplicated by any other means, and because it is basic to the whole weapons system, the effectiveness of that weapon in battle is a subject of first importance in any general consideration of the whole fire system. It follows that any study directed toward a comprehensive examination of the aggregate of weapons for the purpose of designing and proportioning a "balanced" system (the mission of Project BALANCE) may logically take a beginning with this basic ground weapon.

Such an approach is, moreover, timely at the moment in the sense that the NATO is confronted now by an urgent requirement for standardization of a general purpose hand weapon for the infantry. Thus, any information which may be cogently pertinent to such weapons will have a bearing on an immediate problem of some moment.

The study here presented has been carried out not only in full recognition of the importance of improving the effectiveness of infantry, but also in growing awareness that the task—even though so basic in nature—is an exceedingly complex one. The effort has thus far been only preliminary. Limited time, and inadequate knowledge of basic unit operations in combat, have restricted the degree to which the whole problem might be examined. Consequently, no complete solution is offered by this memorandum; rather, some analytical findings are presented, which suggest the principles governing certain measures which could be undertaken to improve infantry effectiveness with respect to aimed rifle fire.

This memorandum bears directly upon the importance and the use by infantry of aimed small arms fire in the front line tactical fire fight, but does not consider expressly the importance, the techniques or the effects of unaimed "covering fire" delivered by small arms. The reason for directing the study effort toward aimed fire is that the common arm of the infantry, the rifle, is designed primarily for the aimed fire role; that is, the weapon is designed expressly to afford a capability of directing missiles at observed man-targets with high inherent precision, in both offensive and defensive action. Delivery by such a weapon of covering fire to neutralize or pin down the enemy and permit friendly maneuver is tactically useful, but nonetheless amounts to a secondary role for which design has provided only incidentally. The important question at hand, therefore, is not so much connected with the varying actual use of the present firearm as with the need of the infantry to engage the close enemy effectively by the use of aimed rifle fire, and with the feasibility of incorporating in the rifle of general issue the capability of answering this real requirement.

Recent ORO investigations in Korea have shed some light on this subject by indicating quantitatively the comparative importance of aimed and unaimed fire as related to offensive and defensive operations. Generally, aimed fire plays a more important part in defense than unaimed or volume fire, whereas in the offensive, the reverse is true Almost irrespective of the part played by the supporting weapons before or during the final phase of close combat, the decision in each small tactical battle rests ultimately in large measure with the infantryman and his ability to use his hand weapon effectively. If hand-to-hand fighting develops at all, decision thus rests almost entirely with the infantry in this last time-phase of the tactical situation. To attach importance to this aspect of battle is therefore logical, and the attempt to maximize the capability of infantry in this role cannot be misdirected effort.

The study has yielded suggestions for increasing infantry effectiveness by improving the effects of aimed rifle fire. It appears almost certain that future large-scale ground operations will involve a numerically superior enemy and necessitate, at first, a defensive strategy on our part. Morever, frequent attempts to overrun infantry positions, with attendant close combat, are to be anticipated. Thus, to increase each infantryman's capability with respect to defensive rifle fire becomes highly desirable.

In the light of such considerations as these, it appears correct to assume that: 1) it is desirable to increase in both number and rate the hits* which may be inflicted on the enemy by aimed small arms in the hands of the infantry; 2) it is also desirable to increase the mortality from wounds caused by these hits.

The research effort has included examination of casualties of past wars, studies of terrain as it limits battlefield visibility, determination of the marksmanship of men, wound ballistics requirements, actual use of the rifle in combat, and other considerations bearing on military operational requirements for the general purpose hand weapon. The determinations arrived at from the study of present rifle fire and its effects are presented in the following sections.

COMBAT CASUALTY STUDIES

Former Studies

Earlier work done by ORO on the defense of the individual in combat,[1] and a preliminary study of the offensive capabilities of the rifle,[2] yielded definite indications that rifle fire and its effects were deficient in some important military respects, and that further study of the problem would be necessary fully to establish the facts. In these former studies it was found that, in combat, hits from bullets are incurred by the body at random: regional distribution of bullet hits was the same as for fragment missiles which, unlike the bullet, are not "aimed." Further, it was found that exposure was the chief factor responsible for the distribution of hits from bullets and that aimed or directed fire does not influence the manner in which hits are sustained.[3] Stated briefly, the comparison of hits from bullets with those from fragments showed that the rifle bullet is not actually better directed towards vulnerable parts of the body.

The discovery of these facts, along with evidence of prodigious rifle ammunition expenditure per hit, strongly suggested the need to extend the study of the rifle problem. The facts known at this point also prompted one to regard with some dubiety the employment of the present, highly accurate, precision-made rifle as a general purpose infantry weapon. It should be noted, however, that complete verification would not suggest elimination of a precision long-range rifle to be used

[1] Footnote numbers refer to publications listed in Bibliography.

* Multiple hits on the same target are much less to be desired than a large number of targets hit.

by some men highly skilled and selected for specialist operations, e.g., snipers.

Lethality of the Rifle

As for the combat importance of hits from rifle bullets as compared to other weapons in the ground system, historical studies show that bullets have accounted for 10 to 20 percent of all hits from all ground weapons in most battles, campaigns, and wars of this century.[4] Although these figures qualitatively provide a measure of the relative capability of hitting the opposed infantryman, they do not disclose capabilities with respect to severity of injury. Of these two factors (simple wounding and extent of injury) which characterize weapons effects, not much is known about either in the sense of cost versus effect because ammunition expenditures and corresponding casualty-producing effects are not usually known with precision. On the other hand, aside from the closely related machine gun, the rifle is the most lethal of all conventional ground arms: its lethal index (ratio of kills to hits) exceeds 30 percent, putting it above other weapons in capability of inflicting severe injury.* The lethal index of the machine gun, of course, exceeds that of the rifle because multiple hits increase over-all lethality. For bullet lethality, the 30 percent figure given for the rifle would be the closest approximation to single round lethality for all ranges in battle.

Rifle Bullet Hits as a Function of Range in Combat

Knowledge of the ranges at which hits have been incurred in past wars is sharply limited. Since this parameter is almost indispensable to the military specialist or operations analyst in determining weapons effects, it is astonishing that greater efforts in the past have not been directed toward gathering information of this kind in combat operations.

*In this analysis, the figure 30 percent refers only to enemy weapons of World War II type but since enemy rifles did not differ greatly from our own, the lethal index value should approximate that of the M-1 rifle. Strictly, lethal refers here to the bullet, rather than the rifle, which is the launcher. What is meant is that a larger fraction of the total bullet hits results in death than from hits from any other weapon. The explanation does not lie in the manner in which rifle bullets are directed, since data show that bullet hits occur on the body at random just as do hits from fragmenting projectiles and therefore their relatively high lethality is not connected with any bias in their distribution over the body. The reason appears to be connected with the higher (and more nearly constant) energy, on the average, than other missiles since they are discharged at short ranges. Fragments, however, vary in energy from a maximum to zero, with the mean value being relatively low because of the preponderance of small fragments per missile burst and because of the rapid deceleration of particle velocities with range.

Only two studies exist which have reference to bullet hits as a function of range in battle, and they are based on indirect and possibly inaccurate measurements. Oughterson[5] analyzed experience on Bougainville in World War II and found that, of those cases studied, almost all rifle bullet hits were received at ranges less than 75 yd.* The Surgeon General recently examined the wounded in Korea, and from a sample of 109 rifle bullet hits suffered among members of the Turkish Brigade, the mean range for these hits was found to be just over 100 yd.[6] It was noted, however, that most of the hits occurred at ranges within 300 yd and in a later section of this report these data along with data on battlefield visibility will be given more extensive treatment.

Man-Rifle Operations Studies

The British AORG during World War II, and ORO in FECOM, have both attempted to study part of the man-rifle complex by interviewing experienced riflemen on their use of the weapon in offensive and defensive combat actions. The British examined officers and NCOs who had experience in the ETO[7] and ORO examined men with experience in Korea.[8] The agreement of the two independent studies is striking. For attack and defense in European actions, it was found that about 80 percent of effective rifle and LMG fire takes place at less than 200 yd and 90 percent at less than 300 yd, according to the estimates made by the men interviewed. About 90 percent of the LMG fire was at less than 300 yd.

Of 602 men questioned about use of the M-1 rifle in Korea, 87 percent said that at least 95 percent** of all their firing was done at targets within 300 yd range (day time offensive fighting).[8] For day time defensive fighting, 80 percent of the men said that rifles were used at 300 yd or less. Figure 1 shows the frequency in which rifles are used as a function of range, based on responses of interrogated infantrymen. The approximate correspondence of the curves in the Figure indicates that the use of the rifle is to at least some extent dependent upon battlefield terrain features as they affect visibility.*** Although it is freely acknowledged that the use of data derived from judgments of the men about the use of their basic arm may be subject to question, the validity of the

*This figure is perhaps atypically low because it refers to jungle fighting in which visibility was abnormally restricted.

**The men were asked to give the outside limit of 95 percent of their firing in order to eliminate those rare shots which might be fired at long ranges without expectation of hitting the target.

***See section on battlefield visibility.

opinion survey has been substantiated by a more recent Korean study conducted in combat areas.[9] Also, as mentioned earlier, the analysis made by AORG tends to support the conclusion that

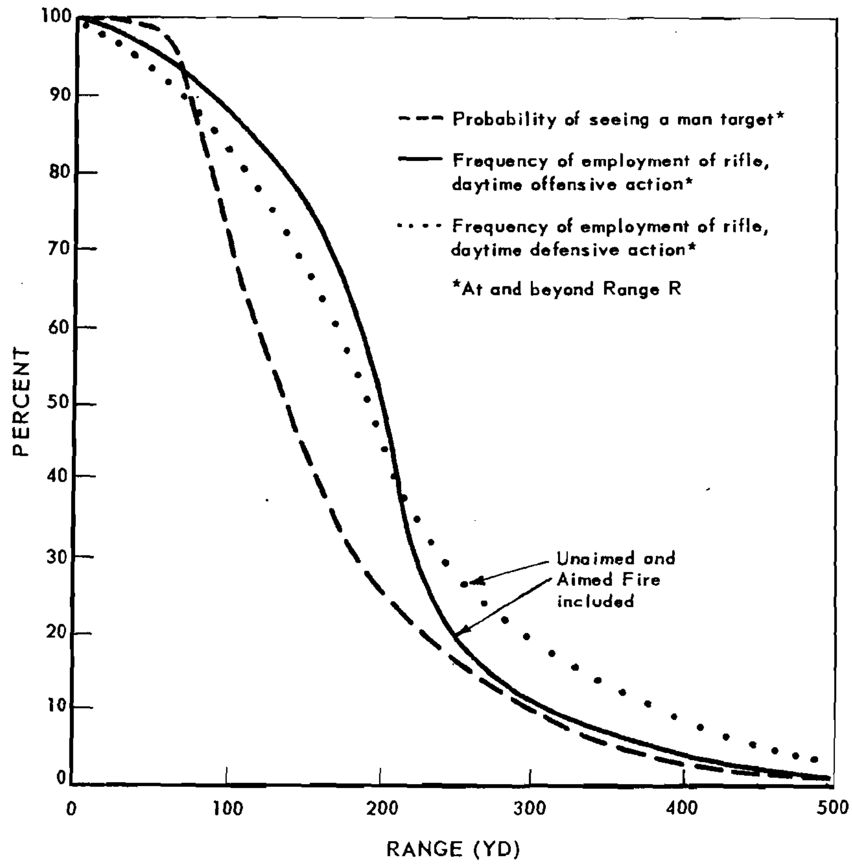


Fig. 1—Comparison of battlefield visibility in Korea and ranges of employment of the M-1 Rifle.

the infantry basic weapon is actually used, on the average, at shorter ranges than commonly believed.

TERRAIN VISIBILITY STUDIES

Range Requirements and Tactical Employment of Hand Weapons

Despite the important role of infantry support weapons (artillery, tactical aviation, armor, and others), the entire ground weapon system hinges in many important ways upon those weapons which depend for their effective employment upon ground observation of the target. These are the direct-fire and observed-fire weapons; they are elemental, basic, and indispensable to the infantry-artillery-armor team.

For infantry, the basic direct fire weapon is the rifle—it is the common denominator upon which the entire fire system is designed, both physically and tactically. Yet all direct-fire weapons suffer a major weakness in that essential observation for their effective employment may be obscured by weather conditions, prevented by darkness or—more importantly and quite unavoidably—interrupted by terrain features. This interruption of the line of sight is one of the principal military effects of terrain, for the ranges at which points on the ground are intervisible are related to the employment and general effectiveness of these direct-fire weapons. Accordingly, terrain limitations to continuous visibility on the battlefield should dictate to a considerable degree the actual design and employment of direct-fire or observed-fire weapons. A study of this subject which was undertaken by Project BALANCE and which is covered in detail in a separate report,[10] has yielded formulary expressions for the relationship between the opening range of engagement for riflemen and the range at which man-targets can be seen. Particularly with respect to the rifle, the study is basic in its concept and possibly, for the first time, data have been obtained which constitute a reasonable quantitative basis for determining the actual range requirements and tactical employment of a general-purpose hand arm.

Because of the importance of these findings to the infantry weapons problem, they should be studied carefully in conjunction with the work presented here on operational requirements for an infantry hand weapon.

Map Analysis

Topographical map studies of a number of large scale (1:25,000) maps of various countries in the world have shown that it is possible to predict, with reasonable accuracy, the probability of being able to see continuously for a given distance from a random point within the area.[10]

For the infantry study, the procedure used in the map analyses was to measure the continuous ranges of visibility between infantrymen, with the position of one man (the defender) being at ground level (foxhole or prone) and the approaching enemy being an erect human target five feet high. This factor was chosen to set realistic limits on the range of intervisibility between opposing forces. The validity of the map readings was verified by actual terrain measurements* and the findings are in general agreement with limited combat data from the Korean experience and ETO experience during World War II.**

From the map study, it was found that all the types of terrain so far considered fall into one of three categories which are illus-

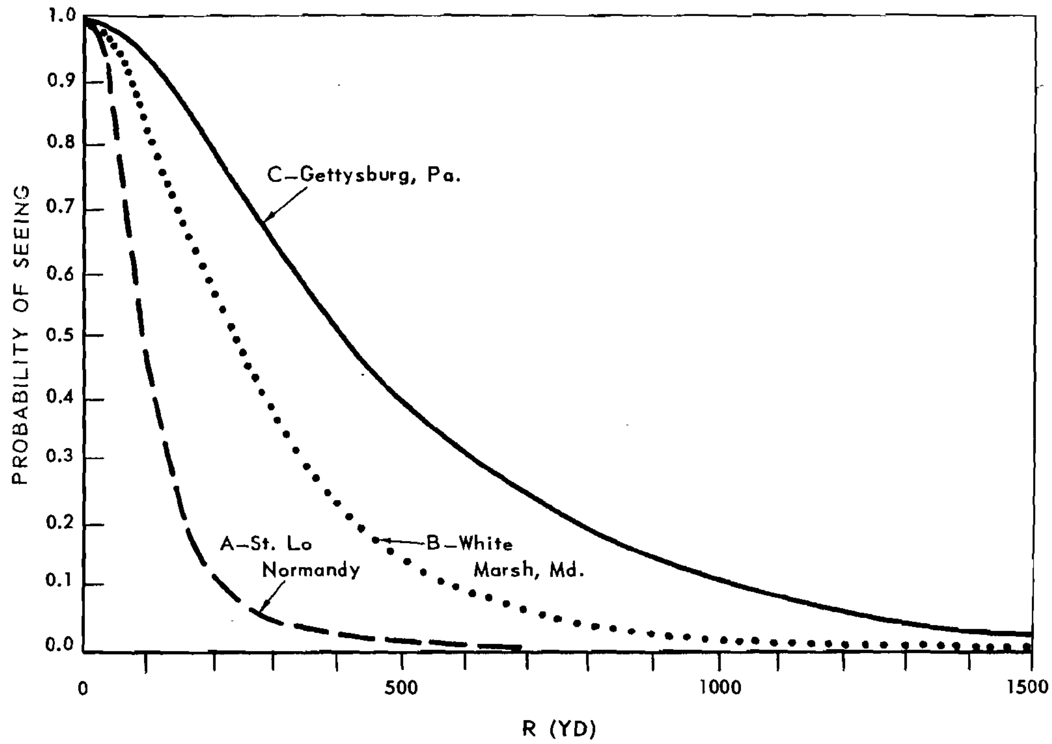


Fig. 2—Frequency distribution for ranges of continuous visibility for Terrain Classes A, B, and C. (Probability of seeing man-targets at ranges greater than R yards from a random point within the area covered by the map analysis.)

*Tests were conducted on the battlefield area of Gettysburg in which a small party of ORO analysts checked map predictions by actually walking over the terrain in accordance with the map bearings and measuring the distance of intervisibility. In every instance, distances of continuous visibility were found to be less than the distances predicted by map measurement because of terrain features and obstacles not shown on maps. Map readings were considered, therefore, to represent maxima.

**The mean ranges of visibility from map analyses of Korea and Normandy show remarkable agreement with limited combat knowledge of ranges of engagement between riflemen and between tanks. In Korea, the frequency of ranges for bullet hits agreed with the frequency of ranges for visibility. For World War II tank battles, both Peterson of Ballistics Research Laboratory and ORO (Ref. 10) have shown that ranges of engagement for tanks correspond with ranges of visibility in the battle areas as determined from map analysis. These two samples of combat data tend to validate the use of the map data for predicting range requirements.

trated by the three curves in Fig. 2. The frequency distribution for Type A terrain is typical for a country like the Saint-Lô area in Normandy, where visibility is sharply limited by the masses of hedgerows, small cultivated fields, orchards, and the nature of the terrain itself. Type A also describes rugged, mountainous terrain like Korea. The distribution curve for Type C describes relatively open country where the topography is gently rolling and large, open, cultivated areas exist. Type B is intermediate between the two extremes cited and describes an average type of cultivated countryside.

The importance of these data to the infantry study is related to the range requirements for infantry weapons and, as shown in Fig. 2, 95 percent of all observations include ranges which are much less than the range capabilities of many of the infantry direct fire weapons. The implication that such weapons may be over-designed is appreciated when it is considered that the rifle alone has a maximum range capability of 3,500 yd.

The following description of the procedure used in the map study is presented so that the practical application of the data may be recognized.

Figure 3 shows diagrammatically a corner section of a 1:25,000 map. The method of measurement was adopted from a suggestion by Peterson of Ballistics Research Laboratory who used map grid lines as guides for sampling any given terrain.

The analysis of each map is begun at Point A (northwest corner). Proceeding along the east-west grid line, the distance is measured from the edge of the map to the point where an erect (five feet) infantryman would just be obscured from the sight of a defending prone infantryman at Point A. In this case, the crest of a hill (contour) is the factor which obstructs visibility. After recording the distance A to B, the next point of obscuration is measured by proceeding along the grid line from Point B to Point C where a railroad embankment interrupts the line of vision. Distance BC is then recorded and so on along the grid line to the far edge of the map. It will be noted that a house or building limits visibility at Point D and woods limit vision at Point E.

After all horizontal grid lines are measured in this way, the same method is used on all vertical grid lines. Then all the obscurations from one map are used to plot a frequency distribution. Examples of such frequency distribution have been given already in Fig. 2.

Although the frequency distribution curves yield predictions as to the probability of seeing man targets at Range R, from any random point on the terrain, it may be argued that infantrymen are not randomly located along the front but actually take up positions which have been selected for point of advantage (for example, high ground in the defence). So far as this is true for small units such as squads and platoons especially in defensive positions, such biases as a result of the placement of men are not systematic, and when division or corps fronts are considered, the density of men and their positions across a broad front can be considered to be more

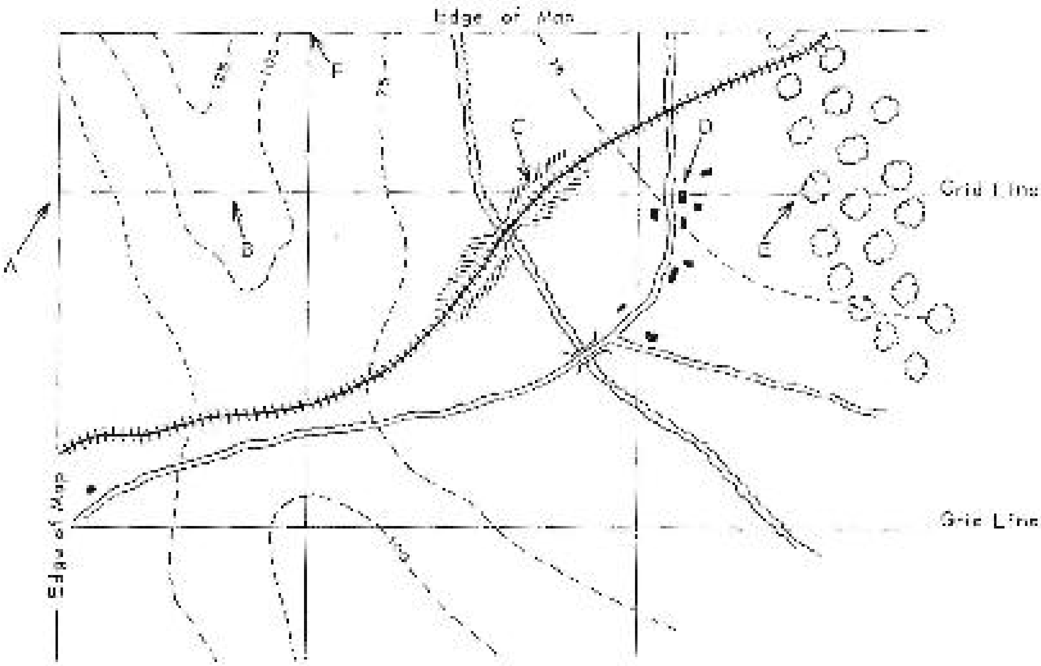


Fig. 3—Method used in measuring range of visibility on maps.

Starting at the northwest corner of the map one looks from the point A, where the first horizontal grid line begins, along that grid line to the point B where, because he has gone over the crest of a hill, the standing infantryman (the target) ceases to be visible. The distance AB is measured and recorded. Next, starting from B, one finds that the target is continuously visible until the railroad embankment at C causes obstruction to view; the distance BC is then measured and recorded. Similarly, starting from the top of the embankment, it is clear that there is no obstacle until one reaches the house at D; CD is measured and recorded. Next the distance DE is recorded; then, starting from the eastern edge of the wood, the distance to the next obstruction is measured, and so on across the map to the right margin. After all horizontal grid lines have been followed in this way, one starts again at the northwest corner and reads from F down the first vertical grid line and all the other grid lines. All the readings obtained in this way are used to plot a frequency distribution. Figures 2 through 7 are examples of such frequency distributions.

or less uniform. Thus, in relation to terrain, their position is more nearly random. Also, no systematic selection of ground is permitted either side during a battle, since position, which is fluid and constantly changing, is dependent upon the whole battle situation and not just upon ground features. Therefore, the random selection on a map of a battlefront in any given terrain should predict the actual ground condition of the battlefield. In general, it is felt that men move in battle in a more or less random manner, so the data obtained in the visibility study are reasonably valid for predicting the probability of seeing targets over any area, particularly since the method used measured the type of movement used by troops in battle, that is, from cover to cover.

Employing this method, map studies of Canada, France, Germany, Korea, North Africa, and the US, to a total of some 18,000 readings, showed that 70 percent of the ranges at which an erect human target can be seen by a defending prone rifleman are less than 300 yd (and that 90 percent are less than 700 yd).

Since range requirements exert a considerable if not dominating influence upon such characteristics as weight, caliber, and missile velocity, the data from the map analyses have a very important bearing upon the design of an infantry hand weapon. Comparing the range analysis data with the maximum range of the present M-1 rifle (3,500 yd), and its design for incapacitating clothed personnel up to 1,200 yd, it may be concluded that the effective ranges of the greater part of infantry hand weapons could be reduced materially to an order suggested by the terrain analysis. (A reduction of the range of the rifle for maximum effectiveness up to 300 yd does not mean that the weapon would not be effective at ranges beyond this.)

THE RIFLEMAN AND HIS WEAPON

Marksmanship: Tests and Analyses

The preceding sections have described, to some extent, certain major factors dictating the actual operational requirements for the general-purpose hand arm of infantry. Since marksmanship obviously plays a major role in the over-all effectiveness of hand weapons employment in the military situation, the measure of the varying capabilities of combatants to use their weapons with tactical effectiveness becomes, along with target visibility, a significant parameter in the whole infantry study.

To provide meaningful data on this subject, field tests were conducted at Fort Belvoir, Virginia, where 16 expert riflemen (highest grade) and 16 marksmen (lowest qualified grade) were used in a series of experiments designed to simulate some of the conditions of combat. The 32 men were divided into groups for two sets of tests. Firing the M-1 rifle from the prone position, using battle sights, they shot at a man-silhouette target operated on a transition-type range, at distances of 100-300 yd. Mounted behind the silhouette was a 6 foot high by 12 foot wide screen; on this could be measured the dispersion of rounds. The target butts were draped with OD cloth so that short rounds, not striking the target, could also be recorded. (These experiments and the results are described in detail in the Appendix.)

Further data were procured from a range test on automatic rifles at Fort Benning, Georgia.*

In the tests at Belvoir, a variety of conditions was imposed on the participants chiefly by changing the time of target exposure and imposing forms of psychological duress. It was found that best results were obtained when single rounds were fired on an individual basis at static man-size targets. Marksmanship declined when group firing (4-man groups) was performed at the same targets. With slight psychological load, in the form of limited target exposure time and random order of presentation at varying ranges, a further decline in effectiveness was noted. Hit probability as a function of range for both grades of riflemen is shown in Fig. A4 (Appendix).

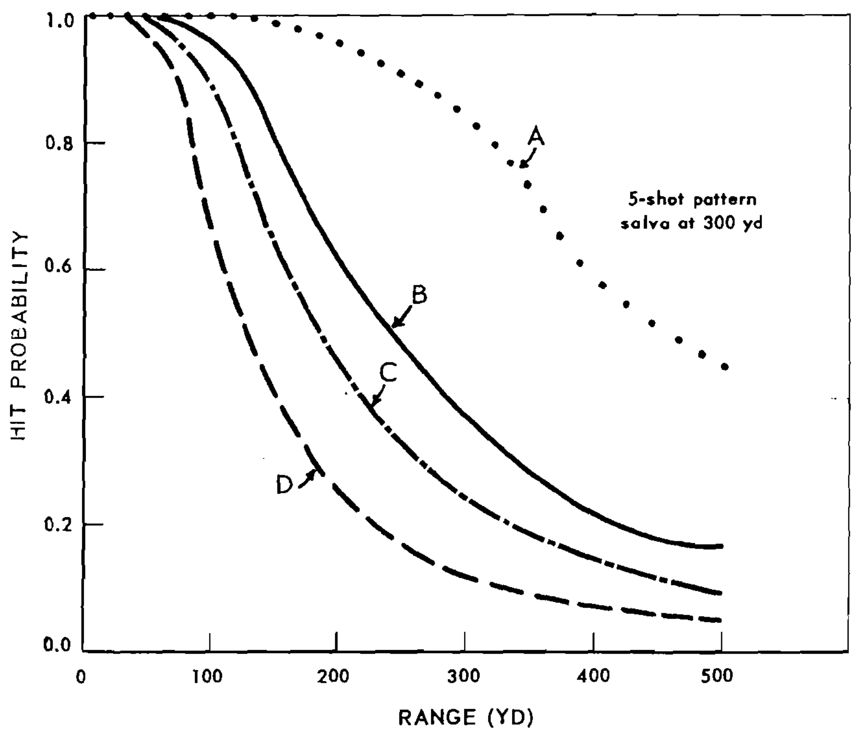
Significant results from these analyses are: (a) hit probability is high for both grades of riflemen at ranges up to 100 yd; (b) at ranges beyond 100 yd, a sharp decline in hit probability occurs and this decline in effectiveness is most marked at the common battle ranges, between 100 and 300 yd; (c) at 500 yd, both experts and marksmen perform unsatisfactorily, a performance quite inconsistent with the design capability of the weapon and with military specifications.**

These findings provide part of the explanation for most frequent battle use of rifles at ranges less than 300 yd and for the

*The author acknowledges the assistance of Lt Col D. E. Munson of ORO in arranging for these tests and in helping with test designs which were in keeping with the practical aspects of conditions of combat.

**For the issue M-1 rifle and standard M-2 ammunition, the mean radial dispersion is about ten inches at a range of 500 yd. An indication of the discrepancy existing between the inherent accuracy of the weapon and ammunition, on the one hand, and that of the man-rifle combination, on the other, may be found by comparing miss probabilities at the range of greatest interest, namely 300 yd. In a machine or bench rest, the probability that the rifle-ammunition combination will miss the type E silhouette target (which approximates the head and torso region of an erect human target—projected area about 4.6 sq ft) at 300 yd is about PM = .040; whereas, for marksmen firing individually, the probability of a miss is Pm = 0.76.

incurrence of the majority of rifle bullet wounds in combat within this range. Since deflection errors in aiming are independent of range (Appendix), the sharp decrease in hits beyond 100 yd is not to be attributed to men becoming less accurate at the longer ranges; the hit probabilities shown by the curves are a function of target size and range.



A Experts individually firing new weapon
B Experts firing individually
C Marksmen firing individually
D Marksmen firing simultaneously

Fig. 4—Marksmanship using the M-1 Rifle
(Probability of hitting target as function of range)

The difference between expert riflemen and marksmen, although significant at some ranges in these tests, may or may not be meaningful in actual combat where man targets will be in movement and psychological duress will be high. In fact, in the rapid fire tests using targets randomly presented (see Appendix, Test 3), the marksmanship of experts declined significantly when compared to simultaneous firing in Tests 1 and 2. The same comparison for marksmen showed that the rapid fire test did not significantly affect their performance, indicating, perhaps, that under the rigorous conditions of combat, only slight differences exist in marksmanship among the several qualifications as determined on the range.

In a fire fight, it is reasonably certain that marksmanship will be less effective than shown by the curves in the tests which, for this reason, are presumed to be optimistic as relating to the actual situation.

In connection with the dispersion inherent in the weapon and in the ammunition used, it is interesting to note that, at all common ranges, weapon errors are without significance in the man-weapons system. As already pointed out, considerable discrepancy exists between the accuracy of the weapon and that of the riflemen. In the Appendix, it is shown that the dispersion of the weapon could be more than doubled without materially affecting the probability of hitting the target. As shown in Fig. A43, weapons-design standards which seek perfection by making the rifle more accurate (approach zero dispersion) would not be reflected in improved marksmanship or musketry. Such high standards of precision and accuracy on the part of present designers are not supported by this analysis as genuine military requirements. Results of the analysis on marksmanship were also used to predict the value of using a weapon which would tend to compensate for man-aiming errors by firing a pattern salvo, or volley.* In Fig. 4, one of the examples of hit effectiveness for such a weapon is presented (from the Appendix).

The Pattern Salvo Weapon

As shown by field test, errors in aiming have been found to be the greatest single factor contributing to the lack of effectiveness of the man-rifle system. In particular, the men who are graded by Army standards as expert riflemen do not perform satisfactorily at common battle ranges, a fact which casts grave doubt on any

*The results of the tests on marksmanship already have astonished many persons because it was not expected that men would exhibit such low performance at the common ranges. The factors which possibly explain the disparity between the higher marksmanship scores from Army training methods, when firing on known distance ranges, and the lower scores from the ORO tests are apparently connected with the conditions of the tests which neither simulated Army methods of scoring or approached the true conditions of combat. Perhaps by adopting training methods along the lines of the tests conducted, the performance of men might show some general improvement. In any case, the test results are believed to be more indicative of the actual capabilities of riflemen in a military situation than the qualification score made when firing for record on the range. The ORO test data already have been used in other analyses relating to the weapons system and have proven of great value. Because they may prove useful to other workers in military analysis, the Appendix has been written to include most of the raw data in the form of tables and figures, resulting in "bulk" for which there is no other warrant.

attempt at the development of skills through training which would begin to approach the accuracy of the weapon itself. Although careful selection and intensive training of personnel in the use of the rifle may accomplish much in improving marksmanship in peace time, the problems of rapid Army expansion and accelerated training in time of national mobilization preclude the opportunity to develop highly skilled riflemen in large numbers by selection or through prolonged training. This point is often overlooked by those who argue for better training as the only solution for the rifle problem. Actually, to reach truly proficient standards in marksmanship, the time required in training would greatly exceed the practical limits imposed on Army training schedules by the needs of mobilization.*

In the search for alternatives to an extensive (and impracticable) training program, consideration was given to the possibility of compensating for man-aiming errors through a weapon-design principle. The results of the marksmanship study indicate that a cyclic or salvo-type automatic fire arm offers promise of increasing hit effectiveness if the missiles in a burst or salvo were projected so as to be dispersed randomly or uniformly around the point of aim. Obviously, a uniform type of dispersion would be more desirable than random dispersion if hit effectiveness were to be maximized. In considering such a weapon, two points required determination: (a) a practical limit on the number of rounds per burst or volley; and (b) the pattern design of the rounds to be delivered.

In the Appendix, the consideration of four- and five-round salvos was not arbitrary. Wound ballistics data show that small caliber missiles of high velocity could be used in the new weapon (see section on Wound Ballistics), which suggested the possibility of obtaining logistic equivalence (that is, equivalence in weight of weapon and ammunition carried) between a four-round salvo and present single-shot rifle fire**; also, not less than four rounds would be required to form a symmetrical pattern (diamond-shaped)

*One expert rifleman at Fort Benning, Georgia, estimated that it required nine years of continuous training on fire arms to develop marksmanship to the proficient level which he now enjoys. Sgt. Justice's performance in demonstrating the use of infantry hand weapons is most dramatic. His skill in marksmanship actually approaches the accuracy of the weapon; he has attained a level of performance roughly commensurate with the design precision of the weapon. However, it is estimated that less than 10 percent of the men in the normal recruit stream could possibly reach this level of small arms proficiency, even if time allowed for training were long.

**Calculations actually reveal that, for a high velocity, .21 cal missile of 60 grains, the ratio of cartridge weights for M-1 standard ball ammunition and the small caliber rounds would be about 1.6 : 1.

around the point of aim which would tend to maximize hit probability on the human-target shape.*

As shown in the Appendix, a cyclic or salvo-type hand weapon would materially increase the effectiveness of aimed fire among the infantry. Although not all possibilities in pattern dispersions and numbers of rounds were analyzed, it appears that the best design (for the greatest practical gains) is one using the four-round salvo with 20 in. spacing among rounds at 300 yd range. The development of a salvo weapon having these characteristics represents an ideal toward which effort might be directed; it is not suggested that this is the only solution.

By considering the need to maintain minimal logistic requirements (number of rounds) and minimum weight, a weapon which conformed to the principle of this design would tend to optimize the military effects of a fire arm, per se. To add to these gains materially, an impractical number of rounds per salvo or burst, or an entirely different weapon would be required.**

From the analysis of the dispersion of shots fired at various ranges, it was possible to calculate the relative effectiveness of a hypothetical new type, salvo automatic weapon, which was assumed to differ from the M-1 rifle only in the manner in which the missiles were projected. Examples of the effectiveness of four- and five-round salvos with 20 in. spacing among rounds at varying ranges are given in Figs. A41 and A42. It will be noted that a four-round salvo of 20 in. spacing at 300 yd would more than double hit effectiveness at this distance. Coincidentally, this increase, through a design change alone, would raise the performance of common marksmen using the salvo weapon to the level of expert riflemen using the M-1.

From this analysis of marksmanship and its relation to a given weapon, it is concluded that: (a) The marked decrease in

*The analysis (Appendix) suggests that the human target is represented reasonably well by a circular shaped target. Since the average projected area of the body in combat is less than 2 sq ft[3] and a man is about 20 in. wide, the average human target is thus more nearly represented by a rectangle approximately 12 in. × 20 in. if the profile of the head on the shoulders were not considered. Considering the head, however, the average human target in combat does approximate a circle.

**A hand weapon could be designed like a Very pistol and project small fragmentation shells which could be directed at the enemy in much the same way as grenades. By using the new principle of controlled fragmentation shells and employing some unique time fuze, it might be possible to reach a level of true maximum effects for fire arms. The problem would be connected with the fuze and not the launcher if missile bursts were to be controlled over the heads of the enemy. Such a weapon would require considerable technical development, involving, probably, a longer range program than a pattern-dispersion-type fire arm. Any contemplated plan for proceeding with the development of fragmentation hand arms should cause the dispersion weapon to be an intermediate step in the developmental chain.

hit probability occurring between 100 and 300 yd suggests that significant improvement in effectiveness at these ranges cannot be achieved by increasing the ballistic accuracy of the weapon: aiming errors are too great to be compensated by any improvement in the accuracy of the rifle alone. (b) A cyclic or salvo automatic weapon could compensate largely for these aiming errors if the missiles were projected with a dispersion pattern designed to maximize the probability of a hit on the human target at ranges which most frequently recur in combat (up to 300 yd).

Full-Automatic Fire

The last conclusion prompted an examination of the operational performance of current models of fully automatic rifles to determine whether these desirable characteristics obtained. Two questions were salient: (a) As the fully automatic rifle is ordinarily aimed and fired, what is the nature of the shot dispersion from short bursts? (b) Does automatic fire in short bursts increase the probability of a hit on a man-size target, especially at ranges of 100 to 300 yd?

To answer these questions, tests were arranged at Fort Benning, Georgia, in which both expert riflemen and marksmen used current models of full automatic rifles. Type E silhouette targets were mounted in front of six by six-ft target screens. The first firing serial was at 100 yd using controlled bursts of five rounds each. Never did more than one round hit the target or screen from any of the short bursts, and consequently no information could be obtained at 100 yd on the nature of the dispersion pattern. To obtain more than one strike on the six by six-ft screen, the range had to be closed to 50 yd. At this short range it was noted that the man-silhouette target in front of the screen was not hit more than once from any burst. Since single round firing with the M-1 rifle at 50 yd yields a probability of hit of near unity, the effectiveness of automatic fire at such short ranges was of no interest.

The results of these trials (although preliminary) strongly suggested that the emphasis and impetus currently being placed by the US and other NATO countries on the development of fully automatic hand weapons should be questioned on the basis of actual military requirements for the automatic feature. ORO plans to make further tests* of infantry weapons and some of these tests will include further work on shot dispersions of

*It is planned to establish a tactical research laboratory at Fort Benning, Georgia.

infantry hand arms. However, any work bearing on the establishment of military requirements for weapons, especially automatic hand arms, should provide operational data upon which decisions can be made. In this connection, it might be pointed out that the tests on automatic rifles conducted at Fort Benning, Georgia, do not constitute the type of weapons evaluation from which such requirements can be established. In the reports of these tests,[11] the weakness of automatics from an operational effectiveness standpoint was not revealed, and it is unfortunate that such large-scale trials should not have been designed scientifically to produce data upon which such facts might be determined. Any comparison of automatic and semiautomatic weapons should be designed to determine military effectiveness by relating hit effectiveness with fire power, to include rate of expenditure.

From the preliminary, yet informative, tests conducted by ORO on automatic hand arms it may be stated that:

1. Regardless of the skill of the rifleman, only the first round in a short, fully automatic burst can actually be directed at a point target.

2. At normal battle ranges, all shots after the first fall off a man-size target in an approximately linear pattern, the progressively greater departures* depending in magnitude upon the characteristics of the weapon and the manner in which it is held.

3. At all common battle ranges, with present hand-held automatics, the strike dispersion is so great that moving the center of impact for the burst to the center of the target would not increase the number of hits.

4. Even at much reduced ranges, where more than one hit from a short burst is scored on a man-size target, the use of a burst can be justified only in a limited sense, since at these ranges single rounds (semiautomatic) have a probability of near unity of striking the target. It follows that reducing the range does not increase the probability of <u>hitting</u> with automatic fire,** but only of obtaining multiple hits. Moreover, when at ranges of 50 yd or less, multiple hits become probable, the

*The rifleman, by a more or less difficult compensating effort, may exert a type of control. Such control is in itself erratic and is not noticeable before 5 - 10 rounds have been fired, according to the cyclic rate of the weapon.

**This result is inconsistent with current rifle design, which provides a high rate of fire in an effort to increase the number of targets hit, as compared with, say, the model 1903 rifle. Thus, automatic fire is not to be justified on the basis of an increased probability of obtaining <u>a</u> hit on separated man-size targets.

lethality of the burst increases much more slowly than does the number of hits (see section on lethality).

5. The full automatic feature of current infantry weapons is valueless from the standpoint of increasing the number of targets hit when aiming at separated man-size targets.*

Wound Ballistics: Missile Caliber, Mass, and Velocity

Wound ballisticians have recently determined that the "wounding power" or damage capability of a missile is more nearly proportional to the cube of the velocity than the square.[12] A reasonable (and acceptable) measure for wound severity is the maximum volume of the temporary cavity produced in the tissue by a penetrating missile. It has been found, for example, that the effect of increasing the velocity of a small caliber missile more than compensates for the reduced mass. Recent work[15] has shown that, if extreme ranges are not important, a smaller caliber bullet than the present .30 cal US military standard might well be used. Moreover, evidence shows that at common ranges, .22 cal bullets can produce wounds of measurably greater severity than .30 cal bullets striking with the same velocity, providing these velocities at target are greater than a certain critical value.

Although more extensive work will be required in investigating the effects of nose shape, weight, and other factors as they affect flight characteristics and wounding ability, it has been established that smaller bullets can be used to produce battlefield physiological effects at least equivalent to those of the present standard .30 cal. Substantial logistics savings would also accrue from the introduction of substantially lighter and less expensive cartridges, although actual savings cannot be expressed quantitatively until further research indicates the most practical weight and shape of bullet to employ. The areas of incomplete research should be investigated at the Biophysics Laboratory, the Army Medical Center, Edgewood, Maryland, where facilities and skilled personnel offer the opportunity to advance knowledge in this field in a reasonable length of time and in an important way.

*During the course of this study, the author considered the various possible uses of present automatics in combat where the automatic feature (and the wide dispersion of rounds) would be militarily useful. Discussion with experienced infantry combat commanders and other military specialists led to the conclusion that although the feature was useful in tight, close-in positions, usually another weapon (e.g., a grenade) could be used to greater advantage than could a burst from an automatic. Also, it was indicated that, for the average rifleman, such occasions were rare and did not constitute a basis for justifying the feature.

Quite apart from the idealized concept of a salvo weapon, sufficient evidence is at hand to be quite certain that a light, high-velocity, small caliber rifle could be designed for military use and could fulfill effectively the role of a general purpose, lightweight hand arm.

In a recent study[14] conducted by D.L. Hall of the Terminal Ballistics Laboratory, Aberdeen Proving Ground, a theoretical comparison of the effects and military usefulness of various calibers of rifles shows that, when the combined weight of weapon and ammunition is held constant to 15 lb, the over-all expected number of kills for the .21 cal rifle is approximately 2.5 times that of the present standard .30 cal rifle. When compared to M-1 ammunition, a .21 cal missile of high velocity (about 3500 feet per second muzzle velocity) creates equal or greater damage than the standard .30 cal missiles at ranges up to 800 yd. This evidence, combined with the work of Project BALANCE (ORO) on ranges of visibility, marksmanship, and actual operational needs, lends considerable support to the major conclusion that lighter hand weapons of smaller caliber may well be provided without losing military effectiveness, while offering both impressive logistical gains and improved operations.

In addition to these gains, the advantages of low-recoil effects offered by the smaller caliber weapons would be reflected in improved skill in the use of the weapon by allowing a higher rate of single-round aimed fire. Such weapons would also be much less fatiguing to handle. Since recoil of a small caliber weapon would be less than that of present weapons, the dispersion of rounds in a short, fully automatic, burst could be considerably less than the dispersion of current models. This important characteristic, yet to be determined by actual trial of small caliber automatics, might possibly be the most practical solution to the problem of developing an automatic fire arm which will project missiles in a burst such that the dispersion of rounds, at ranges up to 300 yd, would approach the ideal dispersion for maximum effects as indicated in the Appendix.

The studies and experimental development work* currently being undertaken by the Ordnance Corps at Aberdeen Proving

*Discussion with G. A. Gufstafson of the Small Arms Section of BRL indicated that it is feasible to design small caliber, high velocity, automatic rifles, which would exhibit short-burst dispersion patterns at ranges up to 300 yd, tending to approach dimensionally the ideal patterns outlined in the Appendix.

Ground should be encouraged to proceed toward a rifle development which will fulfill these important military characteristics. Although such a light weapon would not compensate for human aiming errors when fired semiautomatically, it is quite possible that automatic fire in short bursts at common battle ranges would produce dispersion patterns commensurate with the requirements of the idealized salvo weapon. In particular, the low recoil of a small caliber rifle offers the chance to employ a muzzle compensator with significant effects, lending added promise to a satisfactory development. If the development of this light, high velocity weapon could proceed to include the ideal salvo principle, obviously a truly effective hand arm could be provided.

LETHALITY

Weapons in General

The history of the development of weapons and tactics shows an interesting process of self-adjustment. It has been found, from an examination of many campaigns from Marathon to Korea, that battles are no more bloody now, despite vastly "improved" weapons, than they were in the days of the short sword: the casualties incurred per number of men engaged per unit of time remains about constant.* In fact, it may well be that the sword is much more lethal than conventional weapons because it can be directed with more control at the vulnerable areas. It remains to be seen whether the tactical use of atomic and new CBR weapons will alter this trend.

The explanation for this apparent constancy in the intensity of battle effects seems to be related to the compensating changes in tactics which each new weapon introduces. Most advances in weapons either increase the distance over which a blow can be delivered (improved launcher) or increase the lethal radius or radius of effect (improved missile), or both. The ratio of the lethal area to the concentration (or density) of enemy targets appears to have remained constant. Since logistics costs have markedly increased since the early wars, war itself has become vastly more costly in terms of the effect-cost ratio, yet little if any more effective in terms of personnel casualties per unit time or per unit effort.

*From an unpublished ORO study.

Although these are measures of gross intensity for war (total casualties only), it is interesting to note that severity of weapons as measured by their lethality has not changed, at least in the past century. If the lethal indices of weapons (also a constant) could be raised, efficiency and effect might well be improved materially, and no compensating tactical adjustment would be practicable. It is believed that the means for doing this are at hand, and, with special reference to one weapon (the infantry hand arm), an estimate is made in a following section of expected results if bullet lethality were increased, as seems technologically feasible.

The Rifle

The lethal index of a weapon corresponds roughly with tactical effectiveness since it refers to those wounds which are speedily lethal, the condition of which cannot be reversed by medical intervention. Since, by this definition, "lethal" effects result in death very quickly (or death is assured), the lethal index is a measure of tactical effect. Therefore, in the forward areas of the combat zone, where bitter hand-to-hand fighting occurs, there is no sound basis for arguing against the merit of disposing of the enemy in the shortest possible time by inflicting maximum physical trauma. For the infantry hand arm, the infliction of severe wounds, that are immediately incapacitating, is important.

As stated earlier, the lethal index of the rifle exceeds 30 percent when hits at all ranges are considered, and, with the exception of the machine gun, it is the most lethal weapon of all conventional missile projecting ground arms.

Comparison of Lethality of an Ideal Dispersion Automatic with M-1 Single-Shot Fire

From Table A9 and Fig. A40 in the Appendix, it is possible to estimate the lethality of an ideal dispersion weapon at the various battle ranges and compare these effects with those of the rifle. Because no exact information exists concerning the vital area complex of the body or the effects on lethality of multiple hits, it was necessary to assume that all bullets from a salvo, or burst, are independently lethal and that multiple hits are incurred at random relative to the vulnerable areas. Obviously, this assumption ignores the fact that physiological effects of multiple wounds are cumulative (shock, exsanguination, and the like), and that hits from the ideal dispersion weapon follow a pattern design and do not, therefore, strike at random. Since cumulative effects of multiple wounds add to lethality, and since any lack of randomness in the hits may or may not favor the probability of striking mortally vulnerable areas, the estimates given may be strengthened perhaps by the compensating effects of these two indeterminate factors. For each weapon, it is assumed that the lethal probability of a bullet hit is 0.3.[*]

From Table A9 (Appendix), the lethality for the dispersion weapon (five-round salvo pattern) can be estimated for each category of single and multiple hits for each range. An example of the method used is given for a range 200 yd:

Probability of kill per bullet hit, Pl = 0.3;
Probability of not killing per hit, Ps = 0.7.

Thus, for each category of possible hits from a five-round salvo:

Hits	Ps	Pl
1	0.700	0.300
2	0.490	0.510
3	0.343	0.657
4	0.240	0.760
5	0.168	0.832

For range 200 yd (Table A9), the probabilities of obtaining exactly 1, 2, 3, 4, and 5 hits with the five-shot patterns are:

Hits	1	2	3	4	5
Ph[**]	0.388	0.122	0.284	0.0580	0.000

therefore,

Ph x Pl = 0.116 0.0622 0.187 0.0441 0.000

At range 200 yd, the probability of killing an enemy per burst is the sum of the lethal probabilities = 0.409.

For single rounds from the M-1 rifle at 200 yd, the kill probability is 0.135 (Ph = 0.45 and PL = 0.3, Fig. A40). In

[*] The lethal index of the rifle bullet exceeds 30 percent. It is assumed that the smaller caliber bullet for the new weapon would be equally lethal since it will have a wounding capability equal to or greater than the M-1 at the ranges involved.

[**] The variations noted in the probabilities for obtaining more than one hit are due to the shape of the human target as it affects a strike of two or more hits from the dispersion pattern.

this way, the lethality of the two weapons may be compared as shown in Fig. 5.

The curves giving the lowest lethal limit* and the probable upper limit for the dispersion weapon show that a considerable relative increase in lethality over the rifle may be expected through the use of the dispersion weapon for ranges beyond 100 yd. The theoretical upper limit would

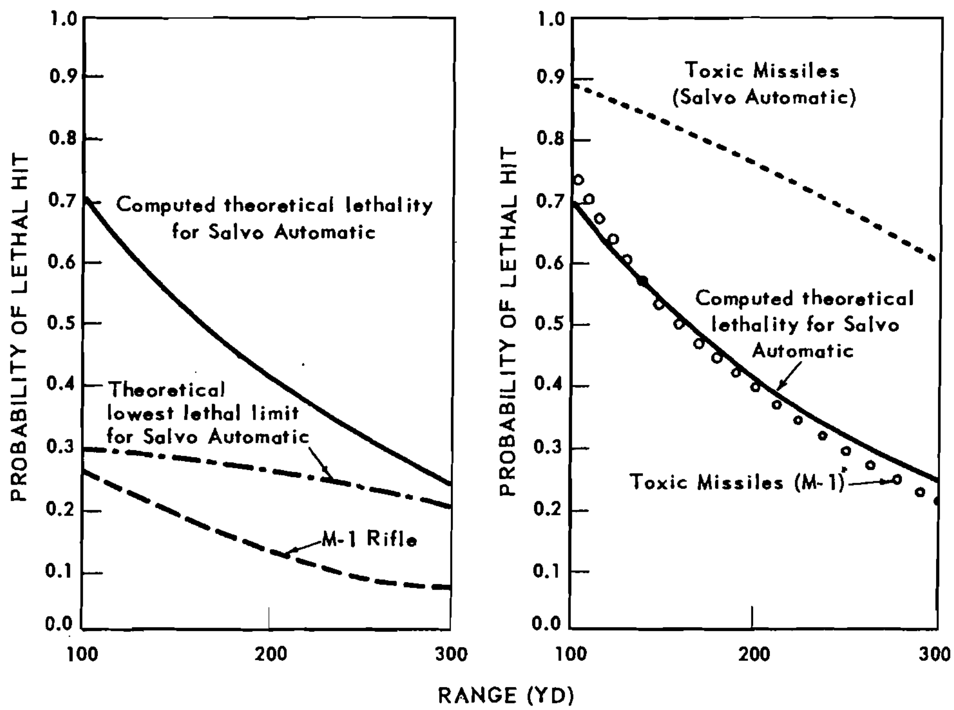


Fig. 5—Comparison of lethality per aimed shot or burst for the M-1 Rifle and the Salvo Automatic.

exceed the M-1 rifle by about a factor of three, if the basic assumptions used in the estimates can be accepted as reasonably valid. Obviously, at ranges less than 100 yd, the dispersion of the rounds in the salvo pattern becomes greatly diminished as range is decreased. Consequently, the lethal effects will not differ greatly from the single-round rifle especially when zero range is approached. This variation in pattern size with range points up the difficulty of attempting to assess comparative lethal effects at the shorter ranges and also reveals the weakness of the estimates at the greater distances.

*Calculated on the basis of at least one hit (Table 9).

Quite apart from any consideration of or comment upon, the protocols and conventions according to which the rules of land warfare have been codified, it is proper to estimate in a purely physical way the results of the use of toxic missiles in such weapons.

Consequently, Fig. 5, the two weapons have been compared for a use of toxic missiles.* It is interesting to note that, by the addition of toxic missiles to the M-1 rifle, the lethal effects thus produced are about equivalent to the theoretical upper limit on physical effects given for the dispersion weapon. On the other hand, the employment of toxic missiles in the dispersion weapon offers, in toto, still greater gains; such effects would constitute an order of lethality not achieved by any missile projecting ground weapon yet devised.

Can Lethality Be Increased?

The lethal indices of present weapons cannot be improved materially (if at all) by increasing the effective "hitting power" alone, since the mortally vulnerable regions of the body set a limit to the gain. However, by combining chemical toxicants with physical missiles, it is possible to make the entire body vulnerable by utilizing the circulatory system as, in effect, a "missile track" which produces certain lethal effects. Rather than 30 percent fatalities derived from bullet hits, this procedure would cause the body to become mortally vulnerable to virtually all of the hits received. Quite apart from the relative increase in lethality brought about by the design of a dispersion weapon as shown in the preceding section, the following analysis on toxic missiles has been included to show the nature of the relative gains to be expected in the dispersion weapon if toxicants were introduced in future warfare. The gains to be described are purely speculative and would provide additional gains only to the physical lethality of the dispersion weapon. Although not a necessary adjunct, should toxicants be employed, the smaller missiles suggested for the new weapon would be more efficient vehicles of the agent than the larger .30 cal bullets.

Developmental work in the field of toxic missiles is reasonably complete and shows that up to 90 percent of hits from agent-loaded bullets at common ranges may be expected to

*As indicated later, a lethal probability P = 0.9 was assigned to each toxic loaded round. The curves were established by taking the product of the probability of a hit and the probability of lethality for toxic missiles. (See Table A9 and Fig. A40.)

incapacitate in a matter of minutes and bring about death regardless of the region of the body struck.[15] The agent used is stable (in storage, it is as stable as any other part of the round); it can be manufactured in large supply at low cost; its toxicity is about as high as any substance known. The physiological effects produced by the agent are similar to the G-agents: death is rapid and the course of the effects is violent. The progress of the physiological symptoms is demoralizing to witness; thus real psychological effects not normally characteristic of weapons design are added.*

Since it has been found that small missiles (such as .22 cal) are more efficient vehicles for such toxic agents than are the larger calibers,[15] the application of toxic missiles to a small caliber hand weapon as herein proposed is particularly adaptable. To the increase in hit effectiveness brought about by the use of the dispersion weapon, an impressive gain in the lethality of these hits might be added. Thus would be achieved a genuine innovation in a weapons system which has exhibited through history a constancy in lethal effects.**

Data from the last two World Wars show that for ground troops the ratio of killed to wounded (all ground weapons) was, for both periods, about 1:4.1. About 20 percent, then, are killed in action.[1] With the single addition of toxic bullets for small arms to the whole weapons system, the ratio of KIA to WIA in these past two wars would have been raised from 1:4.1 to about 1:2.1, or, on the average, the lethal index of all weapons would have increased 12 percent, from 20 percent to 32 percent.***

Although these figures are crude estimates of the gross or over-all gain which might be expected by the employment of toxic missiles, it is probable that the gain would be a

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*Apart from flaming weapons, ordnance development has not taken advantage of possible designs to produce fear in the enemy as well as physical damage. Toxic missiles do offer the possibility of combining the elements of physical and psychological trauma for maximum effects. [See also ORO-R-3, Appendix H, (SECRET)]

**Against toxic missiles, certain defense measures could be adopted. A suitable antidote could be carried by each man in the form of an ampule and injection could be performed through the clothing using the same methods as planned for defense of G-agent poisoning. Also, if small caliber missiles were used and the bullets were designed to encourage rapid disintegration in the wound track, light (plastic) armor might be used. In both of these areas of defense, the Soviet may be weaker than the US in the initial phases of toxic missile employment but it is certain that, like all other technical advantages in warfare, a process of neutralization will occur whereby neither side has a material advantage because of the equalizing effects of the defense measures which both sides eventually adopt. Furthermore, speedy retaliation in kind should not be difficult for either side.
Enemy reactions must be anticipated.

strategic one rather than tactical. In an ORO analysis of battle casualties as to their period of non-effectiveness,[16] data indicate that ideal toxic missiles would do little further to reduce enemy strength during any battle situation but may exert considerable influence over an extended campaign. Finally, it must be remembered that only by improving the hit capability of the weapon, as herein proposed in the dispersion weapon, would one expect maximum gains in the tactical situation if toxic missiles were introduced.

THE DISPERSION WEAPON

Basis of Issue (T/O&E)

It is to be emphatically stated that the new type hand arm, as proposed in this study, should not entirely replace the longer-range rifle in the unit organization. In most tactical situations there is a definite requirement for sniper (highly specialized) fire. It is also important to maintain a degree of versatility responsive to the dynamic tactical situation. Consequently, it is believed that the precision-aimed, long-range rifle must be retained for that limited but existing employment which its design characteristics actually fit. Limited knowledge of sniper fire indicates that at squad level it is not employed frequently in the fire fight but has an important role in the defense or in the less fluid conditions (maneuvering for build-up, and so forth) preceding a hot action. As far as can be determined by questioning combatants, the ranges of sniper fire are mostly within the tactical damage range of the small caliber, high velocity missiles (i.e., up to 800 yd). This suggests the possibility of using weapons of the same caliber as the general purpose hand arm, but designed for precision, long-range use. However, the whole question of sniper fire in battle is yet to be analyzed from an operations point of view; until this is done little can be said concerning weapons requirements for specialists in this role.

*** About 20 percent of the total hits of these past wars have been bullet hits. Of those hit, roughly 30 percent are KIA. (On limited knowledge of enemy Japanese rifles of WW II.) Thus, toxic bullets would result in 90 percent KIA among those hit and increase the lethality of the bullet by a factor of 3. Thus the total killed by bullets would increase from $20 \times 0.3 = 6$ percent to $20 \times 0.9 = 18$ percent. The total killed (all weapons) would then increase from 20 percent to 32 percent of those hit. (Note: The figure, 6 percent, for fatal bullet hits may be low for small arms fire; Tribby's analysis of 1,000 KIA in the ETO attributed about 11 percent of those killed to small arms fire.)

The question of a general purpose hand arm is not one of supplanting a long-range precision arm, but rather of replacing a certain number with a different weapon, each type having its own proper and effective tactical application.

It is believed that a practical and useful beginning can be made in deciding upon the optimum ratio of short-range hand arms to long-range precision rifles by noting the figures for ranges of engagement which have been presented earlier. On the average, it has been found that 70 percent of the ranges over which a man-size target is visible to a defending rifleman lie within 300 yd. Since the short-range weapon will be designed according to specifications for maximum effect up to 300 yd, it may be suggested that 7 in every 10 infantry hand weapons should have the characteristics desirable for short-range use. Although this target-visibility criterion, employed to set an upper limit to the range of engagement, ignores certain variables within the small infantry unit which bear on control and communications as well as many of the problems of musketry and maneuver, it may be received as a tentative and preliminary basis for issue.

Another approach to the determination of an optimum ratio for hand weapons is to consider the aptitudes of enlisted men normally received from the manpower pool. From experience at Fort Benning,* the development of no more than two expert riflemen per squad may be expected from the normal recruit stream without special training. Unless present training schedules and methods are altered to permit improvement in marksmanship skill, this tends to set an upper limit on the number of highly skilled riflemen that it is feasible to assign to the squad from the standpoint of natural aptitudes available to the Army, and of the training effort.

The figure(two experts per squad) is consistent, however, with that already given as the apparent actual requirement. This does not mean that it would not be desirable to have much higher performance in marksmanship among all the men in the squad; the suggested assignments for experts merely emphasize the operational need for <u>at least</u> two experts per squad if training is unavailing in raising present standards of performance.

*It was not possible to obtain data from the AGO, G-3, or OCAFF on the number of enlisted men who could be expected on the average to pass as experts. In private communication with Fort Benning, the Infantry School has indicated that about 10 percent of the men receiving marksmanship training could be expected to pass as experts by known distance range firing standards.

To arrive with assurance at an optimum ratio, much more knowledge of small unit operations in combat would be required than is now known in ORO or elsewhere. Determinations at a "tactical laboratory," such as ORO is eager to see established at Fort Benning, could contribute much to the solutions.

Training

The increases in effectiveness which have been proposed in this analysis all follow from innovations in design of the weapon for the purpose of overcoming deficiencies in skill or training and for adapting the weapon to the nature of its actual operational employment. Since there is no reason to suppose that the new weapon would be characterically unlike the present rifle in its method of operation, no increased demands for training time or facilities are visualized. In fact, the short range of the weapon offers a chance for considerable reduction in weight and for less precision in working parts. Consequently, development of a lighter weapon, with low recoil, should facilitate training in its use.

Also, it is felt that men would react favorably to a weapon which increased their own marksmanship performance since it would add to their confidence in being able to hit the enemy at ranges where M-1 rifle fire is comparatively ineffective. It does not seem reasonable to assume that a man's confidence in his weapon would be affected adversely by a design which increased his chances of hitting the enemy and therefore increased the probability of his own survival.

In connection with present marksmanship training, the results given in the Appendix suggest strongly that considerable improvements are needed if skills are to approximate the precision capabilities of the M-1 rifle. An examination of the current basic training program shows that 76 hours are allowed for marksmanship training with the rifle, of which only 48 hours are involved in "wet" exercises, that is, actual range firing of the weapon.[17]

In the 48 hours of training, each man fires at least 400 rounds, which indicates roughly the total amount of time spent in the actual employment of the rifle. Any question of the adequacy of this training program could only be settled by field tests designed to determine the best methods and the time required to produce optimum results among men in their marksmanship skills. As shown in the Appendix, it is not likely that training alone could be effective in materially raising the standards of all men to exceed the level of expert performance indicated by the Belvoir tests. Significant gains in man-weapon effectiveness are to be obtained only by combining improvements in weapon design with good training. By the adoption of design principles in a hand weapon, as proposed in this study, an opportunity is offered to realize gains of considerable magnitude.

Design Feasibility

No insoluble problems appear to be involved in the engineering of a weapon possessing the recommended characteristics. To accomplish ideal dispersion in an automatic hand arm, as idealized in the Appendix, many design difficulties will stand in the way of preserving desirable military characteristics such as light weight, durability, reliability, automatic loading, and other factors. A salvo-type automatic which projected volleys of rounds to form the desired pattern at the range giving maximum hit effectiveness probably would represent the best type of design for deriving the greatest gains. This would entail designs which include the multi-barrel principle, high cyclic rate single-barrel types with a design feature for allowing the barrel to nutate at the muzzle on recoil for controlled dispersion, frangible missiles, aerodynamically controlled missiles, compensators, deflectors, and the like, all of which present a variety of engineering difficulties to be overcome before the weapon would function satisfactorily. The point of chief concern, however, is to strive for the attainment of the pattern dispersion principle so that the greatest possible gains can be derived, and in the striving, let the engineering difficulties argue for themselves.

In studying the design problems, it was apparent that the smaller caliber weapon, with its bullets of smaller mass, would have considerably less recoil than present automatics, and that the reduced dispersion of a burst, along with the employment of a muzzle compensator, should have significant effects in reducing muzzle "walk-off." As stated previously, it may well be that a light automatic of small caliber (in the region of .20 cal) would produce dispersions of rounds in short bursts which are not incongruous with the pattern dispersions specified in the Appendix. At least the tendency would be a significant reduction in dispersion as compared to present automatics with their high recoil effects. Such reduction may be sufficient to regard the dispersion as approaching the optimum requirements.

Considering all factors, this approach to the problem appears to be straightforward, practical, and relatively simple, and it offers promise of fulfilling the desirable optimum dispersions for maximum hit effectiveness. Tests on prototype models of new weapons of small caliber should be made to determine the practicality of this approach to the problem.

A THEORY FOR DETERMINING RELATIVE EFFECTIVENESS OF DIRECT FIRE WEAPONS

The analysis would not be complete if advantage were not taken of possible valuable theoretical applications which may be made using the two major parameters given in the analysis of the man-rifle system. These parameters relate to the probability of seeing a man target on the battlefield and the probability of hitting the target with aimed fire.

To test an hypothesis, according to which effectiveness might be evaluated, use was made of battlefield visibility data for the area of Korea where ranges were known for a small sample of rifle bullet hits among members of the Turkish Brigade.

Method Used

The method which has been used in estimating the expected distribution of hits as a function of range may be open to serious question because of the possible weakness of the assumptions made about actual rifle operations. Although the need was recognized for more adequate knowledge of the factors which exert a major influence on aimed rifle fire, it was felt that the data on visibility and hit probability might be useful for computing the expected distribution of hits as a function of range for different weapons. As shown in Table 1, the probability product of the hit data and of the visibility data for each range interval yields predictions on the relative distribution of hits, if one assumes expenditure proportional to targets seen and targets seen proportional to the map measurements on visibility.

In Table 1, the data given for Ps are the fraction of all cases where a man can be seen continuously in the 50-yd interval. Employment of the data sets up a model which visualizes the enemy approaching a defender who fires on the enemy when he first appears. The results of the repetition of many cases of this simple dual situation should permit prediction of the type of distribution of hits as a function of range, for aimed rifle fire over the Korean terrain. While it is possible to calculate the number of hits to be expected as a function of range using column 4 of the Table, the calculated number of hits cannot be compared with the observed number because the sample of combat data did not provide information on the total number of men involved or the expenditure of rifle ammunition. For this reason, the percentage distribution of expected hits was compared to the observed distribution.

TABLE 1

COMPUTED DISTRIBUTION OF HITS AS FUNCTION OF RANGE R

Range Interval, yd	Ps[a]	Ph[b]	Ps × Ph	Ps × Ph, Normalized	Accumulated "Expected Fraction of Hits"
0-49	0.360	1.00	0.360	0.457	1.000
50-99	0.254	0.93	0.234	0.297	0.543
100-149	0.162	0.76	0.123	0.156	0.246
150-199	0.070	0.54	0.037	0.047	0.090
200-249	0.047	0.38	0.018	0.023	0.043
250-299	0.028	0.28	0.008	0.010	0.020
300-349	0.024	0.22	0.005	0.006	0.010
350-399	0.016	0.17	0.003	0.004	0.004
Totals			0.788	1.000	

[a]Probability of seeing target within each interval.
[b]Probability of hit.

In Fig. 6, the distribution for the calculated fraction of hits corresponds roughly with the distribution of actual hits in combat in Korea.

As a matter of interest, the M-1 rifle and the five-round salvo type weapon were compared in this way for the two extreme types of terrain, Class A and Class C. The expected distribution for hits from both weapons at ranges greater than R for the Korean terrain and for the Normandy terrain is given in Fig. 7. Since these distributions do not show the relative effectiveness of the two weapons, the same model was used to provide an indication of the merits of the salvo weapon over the rifle as terrain influences effectiveness.

In this instance, as shown in Table 2, the hits were calculated on the basis of 100 shots fired for each weapon at man targets distributed over terrain in accordance with the distribution given for Ps.

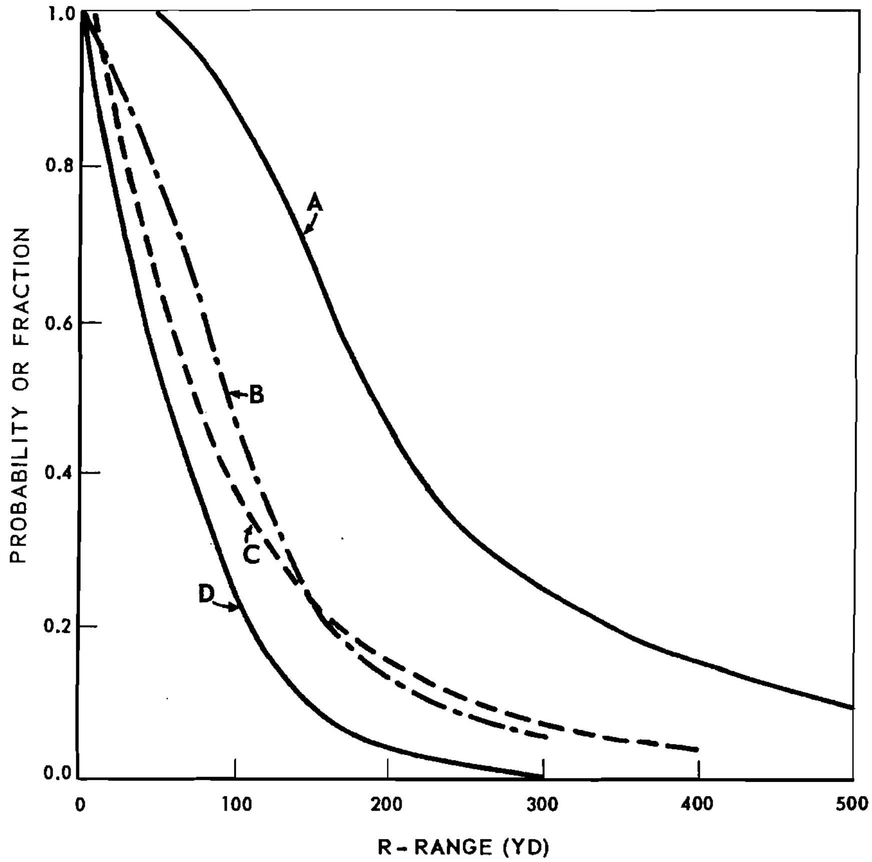

Fig. 6—Rifle marksmanship, battlefield visibility, and hit probability in combat. A: Ph, probability of hitting man-target as function of range; B, observed fraction of hits occuring at ranges greater than R; C, probability of seeing target at ranges greater than R(1-Ps); D, computed fraction of hits expected* to occur at ranges greater than R(Ps × Ph, where Ps is converted to frequency of visible areas occuring in each 50 yd interval, and where Ph is averaged in each interval by assuming the mean P value).

*Assumes expenditure proportional to targets seen and targets seen proportional to Ps.

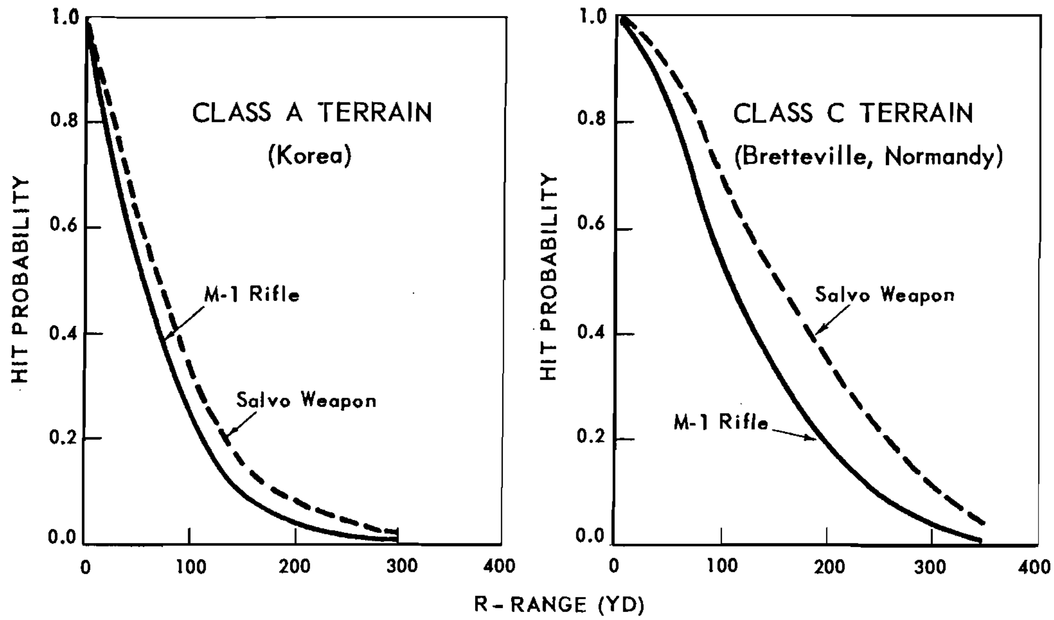

Fig. 7—Theoretical distribution of hits as function of range for M-1 Rifle and a Salvo-Type Hand Weapon for Class "A" and "C" Terrains.

TABLE 2

RELATIVE EFFECTS OF M-1 SINGLE-ROUND FIRE AND SALVO FIRE AS FUNCTION OF RANGE FOR TERRAIN TYPES A AND C

Range Interval, yd	Ps[a]		Ph[b]		Expected Hits		Ps × Ph, Normalized	
	Class A	Class C	M-1	Salvo	M-1 Class A	Salvo Class A	M-1 Class C	Salvo Class C
0-49	0.360	0.05	1.00	1.00	37	37	9	9
50-99	0.254	0.10	0.93	0.99	24	26	16	17
100-149	0.162	0.09	0.76	0.96	12	16	12	15
150-199	0.070	0.09	0.54	0.89	4	6	8	14
200-249	0.047	0.09	0.38	0.81	2	4	6	12
250-299	0.028	0.06	0.28	0.71	1	2	3	9
300-349	0.024	0.06	0.22	0.60	1	1	2	6
350-399	0.016	0.04	0.17	0.49	0	1	1	3
Totals	0.961	0.58			81	93	57	85

[a]Probability of seeing target within each interval.
[b]Probability of hit.

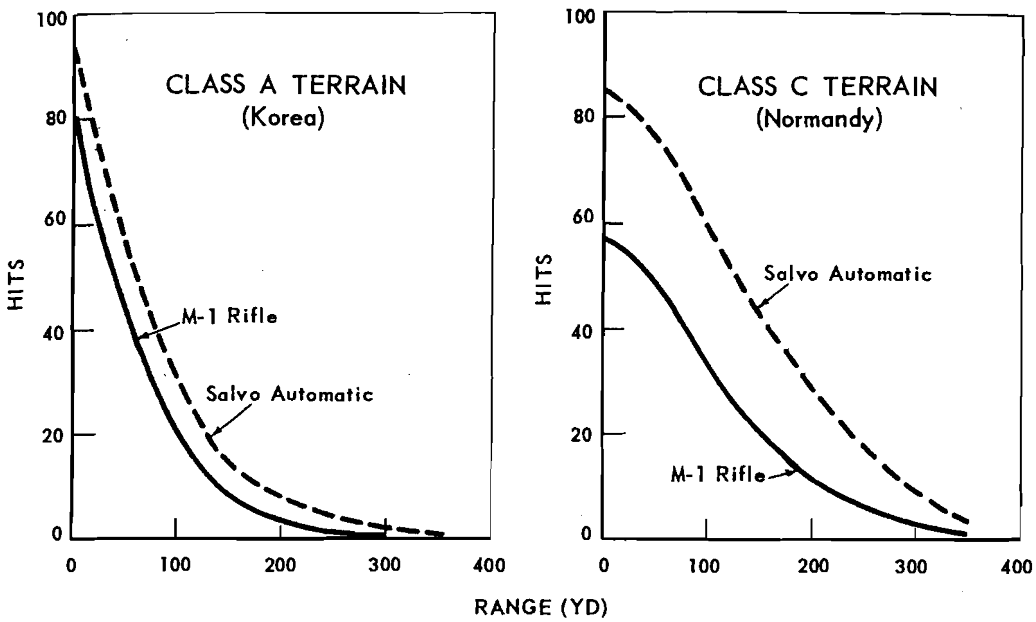

Fig. 8—Relative effectiveness of M-1 Rifle and Salvo Automatic for Class "A" and "C" Terrains.

It will be noted in Fig. 8 that the comparative effectiveness of the salvo weapon is much greater for open terrain types like Class C than for terrain types of Class A because of the greater hit effectiveness of the salvo weapon at the longer ranges. Such information, although only relative, suggests that the dispersion type hand weapon would offer material advantages over the M-1 rifle in areas of combat such as western Europe. On the other hand, the advantages of the new weapon in areas like Korea are not as great and the comparison made in Fig. 8 supports the contention that a hand weapon designed for semiautomatic use in the short ranges and for full automatic use in the longer ranges with controlled dispersion would offer a good solution for the common hand arm.

If theory, as herein presented, can be confirmed by more extensive knowledge of expenditure and ranges of hits incurred in combat by the rifle and other direct fire weapons to include machine guns, recoilless rifles, antitank weapons, and the like, the method would constitute a promising basis for evaluating a balanced weapons system, and T/O&E for units might be established on a quantitative basis.

CONCLUSIONS

1. The ranges at which the rifle is used most frequently in battle and the ranges within which the greater fraction of man targets can be seen on the battlefield do not exceed 300 yd.

2. Within these important battle ranges, the marksmanship of even expert riflemen is satisfactory in meeting actual battle requirements only up to 100 yd; beyond 100 yd, marksmanship declines sharply, reaching a low order at 300 yd.

3. To improve hit effectiveness at the ranges not covered satisfactorily in this sense by men using the M-1 (100 to 300 yd), the adoption of a pattern-dispersion principle in the hand weapon could partly compensate for human aiming errors and thereby significantly increase the hits at ranges up to 300 yd.

4. Current models of fully automatic hand weapons afford neither these desirable characteristics nor adequate alternatives. Such weapons are valueless from the standpoint of increasing the number of targets hit when aiming on separated man-size targets.

5. Certain of the costly high standards of accuracy observed in the manufacture of current rifles and ammunition can be relaxed without significant losses in over-all hit effectiveness.

6. To meet the actual operational requirements of a general purpose infantry hand weapon many possibilities are open for designs which will give desirable dispersion patterns (and accompanying increases in hit probability) at the ranges of interest. Of the possible salvo or volley automatic designs, the small caliber, lightweight weapon with controlled dispersion characteristics appears to be a promising approach. (Low recoil of a small caliber weapon facilitates dispersion control.)

7. To create militarily acceptable wound damage at common battle ranges, missiles of smaller caliber than the present standard .30 caliber can be used without loss in wounding effects and with substantial logistical and over-all military gains.

8. A very great increase in hit lethality can be effected by the addition of toxic agents to bullet missiles.

RECOMMENDATIONS

1. It is recommended that the Ordnance Corps proceed to determine the design or technological feasibility of developing a

hand weapon which has the characteristics cited in this analysis, namely:

a. Maximum hit effectiveness against man targets within 300 yd range. (This does not mean that the weapon will be ineffective beyond this range.)

b. Small caliber (less than .30).

c. Wounding capability up to 300 yd at least equivalent to the present rifle.

d. Dispersion of rounds from salvos or bursts controlled so as to form a pattern such that aiming errors up to 300 yd will be partly compensated, and hit effectiveness thereby increased for these ranges.

2. As one possible alternative to the current "volume of fire" (fully automatic) approach to the problem of increasing the effective firepower of infantry riflemen, it is recommended—subject to tentative confirmation of design feasibility—that a rifle incorporating at least in principle the military characteristics here proposed be manufactured for further and conclusive test.

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APPENDIX

ANALYSIS AND APPLICATION OF RESULTS OF RIFLE-RANGE TESTS

APPENDIX

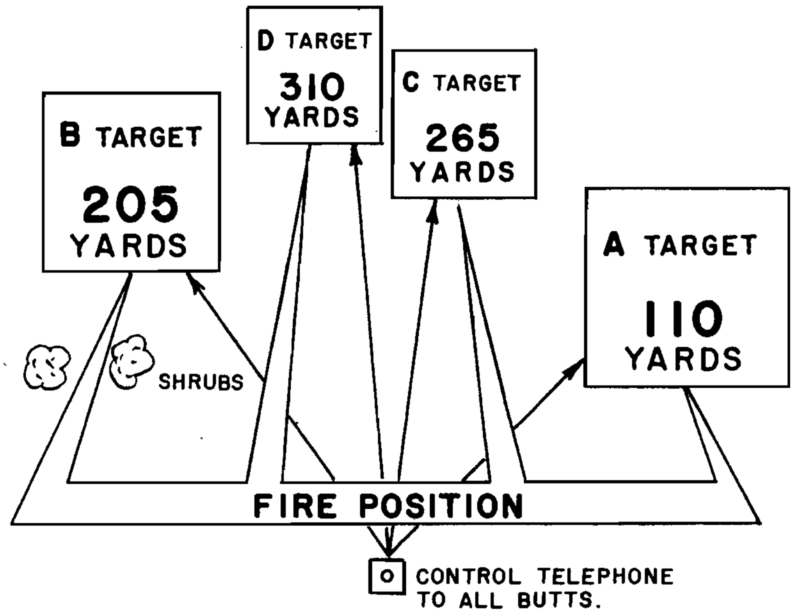
ANALYSIS AND APPLICATION OF RESULTS OF RIFLE-RANGE TESTS

CONTENTS

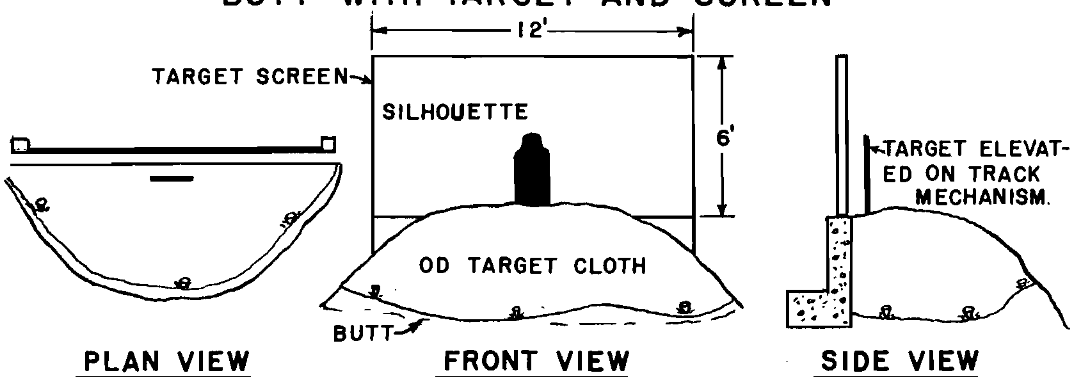
CONTENTS (Continued)

CONTENTS (Continued)

TARGET RANGE DIAGRAM



BUTT WITH TARGET AND SCREEN



The range area can be described as a common-looking open-field area with gentle undulations in the ground and with heavy grass, shrubs, and the like covering the surface area as one would see in relatively open country in many parts of the world.

SUMMARY

Results of expert riflemen and marksmen firing at man-size targets at different ranges were analyzed to determine aiming errors as function of range. The aiming errors in mils were found to be independent of range. Results of the analysis were used to compute the probability of hitting targets smaller than the man-size target and, therefore, more realistically representative of the average area presented by men in combat. Results of the analysis were also used to predict the probabilities of hitting targets with a hypothetical weapon firing a five-shot pattern and a four-shot pattern salvo. The probability of obtaining at least one hit from a single-salvo firing was found to be decidedly greater than the probability of hitting with a single-shot weapon. Probabilities of obtaining multiple hits with the salvo-weapon were also computed. Finally, the effect of weapon dispersion on the probability of hitting was determined. These computations show that eliminating the weapon-ammunition dispersion would not materially improve the rifleman's hit probability.

INTRODUCTION

In the BALANCE study of the Army weapons system, examination of the basic hand arm of the infantry, the rifle, indicated a need to study the effectiveness of aimed rifle fire on man-size targets at ranges of combat interest. Heretofore, marksmanship has been measured by scoring hits on target only, and sufficient evidence could not be obtained on the nature of the dispersion (magnitude of errors) of all rounds fired.

To provide basic parameters for the whole rifle study, a field test was conducted at Fort Belvoir, Va., where expert riflemen and marksmen were used in a series of experiments designed to provide data from which meaningful conclusions could be drawn. Two grades of riflemen (expert and marksman) were used so that by Army standards the upper and lower limits of marksmanship could be studied. By having the men fire on man-silhouette targets (type E) at battle ranges of 100-300 yd on a transition type range, an element of combat realism was provided. In order to record and measure the dispersion of rounds, target screens 6 ft high and 12 ft wide were mounted behind the silhouette target at each range. The Appendix Frontispiece shows the design of the range used and the manner in which targets were located.

Dimensions of the screens and test procedures were products of preliminary trials designed to determine the methodology and physical requirements necessary to study the man-rifle complex on the desired basis. The target butts were draped with OD target cloth so that rounds below the target and screen could be taken into account by the perforations made in the cloth. The target cloth also was useful in camouflaging the mounds of earth at each target location.

In the test plan, psychological factors which might have arisen in group firing were eliminated by arranging groups of experts and marksmen with equal representation on the fire line. Also, to remove any learning effects in the experiment, the order of fire on targets was arranged in a manner to follow a latin square type of plan. This plan allowed each man to complete his firing serial on four ranges by ending the serial on the target with which he had begun, making a total of five target shoots on four ranges. Learning was not found to be a significant variable, and is not included in the analysis.

Test personnel were selected according to marksmanship scores from 13 training companies in the Engineer Replacement Training Center, Fort Belvoir, Va. Sixteen riflemen (eight experts and eight marksmen) were used on each of the two tests which were conducted on different days. Since different men were used in each test, a total of 32 men were employed in the whole experiment. The following outline shows the variety of conditions studied and the plan of tests. The shots on target and screen were color-coded in each experiment to make identification possible. All firing was done from the prone position using M-1 rifles and battle sights.

ANALYSIS

Objective

The objective of the analysis was to determine accuracy of aimed rifle fire, and its dependence on target range, for marksmen and experts firing the M-1 rifle under the conditions previously described. The accuracy thus obtained was required as a basis for predicting with reasonable reliability, the results which might be obtained with a hypothetical weapon of comparable accuracy which could fire several bullets in a predetermined pattern.

Data from Tests

The locations of bullet holes, derived from the tests are

PLAN OF RIFLE MARKSMANSHIP TESTS
Fort Belvoir, Va., 27 Oct and 10 Nov 1951

Plan of Tests 1 and 2

Purpose	Subject	Order of Fire	Conditions
To evaluate individual marksmanship	E	A-B-C-D-A	Targets (silhouettes) exposed for 3 sec every 3 sec. For each exposure, each man fired one round; 8 rounds fired per man per target. Firing done in 4-man serials.
	M	C-D-A-B-C	
	E	B-A-D-C-B	
	M	D-C-B-A-D	
	E	A-D-C-B-A	Conditions repeated.
	M	B-C-D-A-B	
	E	D-A-B-C-D	
	M	C-B-A-D-C	
	E	A-B-C-D-A	Conditions repeated.
	M	C-D-A-B-C	
	E	B-A-D-C-B	
	M	D-C-B-A-D	
	E	A-D-C-B-A	Conditions repeated.
	M	B-C-D-A-B	
	E	D-A-B-C-D	
	M	C-B-A-D-C	
To evaluate group marksmanship	8 experts	B-A-D-C-B	Target exposed for 3 sec every 3 sec. Group fired simultaneously at each range, single round firing for each exposure, 4 rounds per target per man.
	8 marksmen	B-A-D-C-B	Same conditions as for experts.

Test No. 3

Purpose	Subject	Order of Fire	Conditions
To study effects of rapid fire when order of target appearance is unknown	4 marksmen	C-A-C-C-A-A-C-A	Targets exposed for only 1 sec, alternate snap shooting at two target ranges, schedule of exposure shown was unknown to the men. Experiment was done for group or simultaneous firing and for individual firing.
	4 experts	C-A-C-C-A-A-C-A	Same as above conditions.

KEY

E = Expert	B = Tgt at 205 yd
M = Marksman	C = Tgt at 265 yd
A = Tgt at 110 yd	D = Tgt at 310 yd

shown in Figs. A1 to A32, on which are also indicated the number of shots which were fired and the number of these which hit the screen. In most of the tests, some of the rounds did not hit the screen. Most, if not all, of these were observed to have hit the ground in front of the screen. While the percentage of shots hitting the target, as tabulated in the last column of Table A1 is, of course, a function of accuracy, it does not provide complete information on the nature of the dispersion of the shot-pattern.

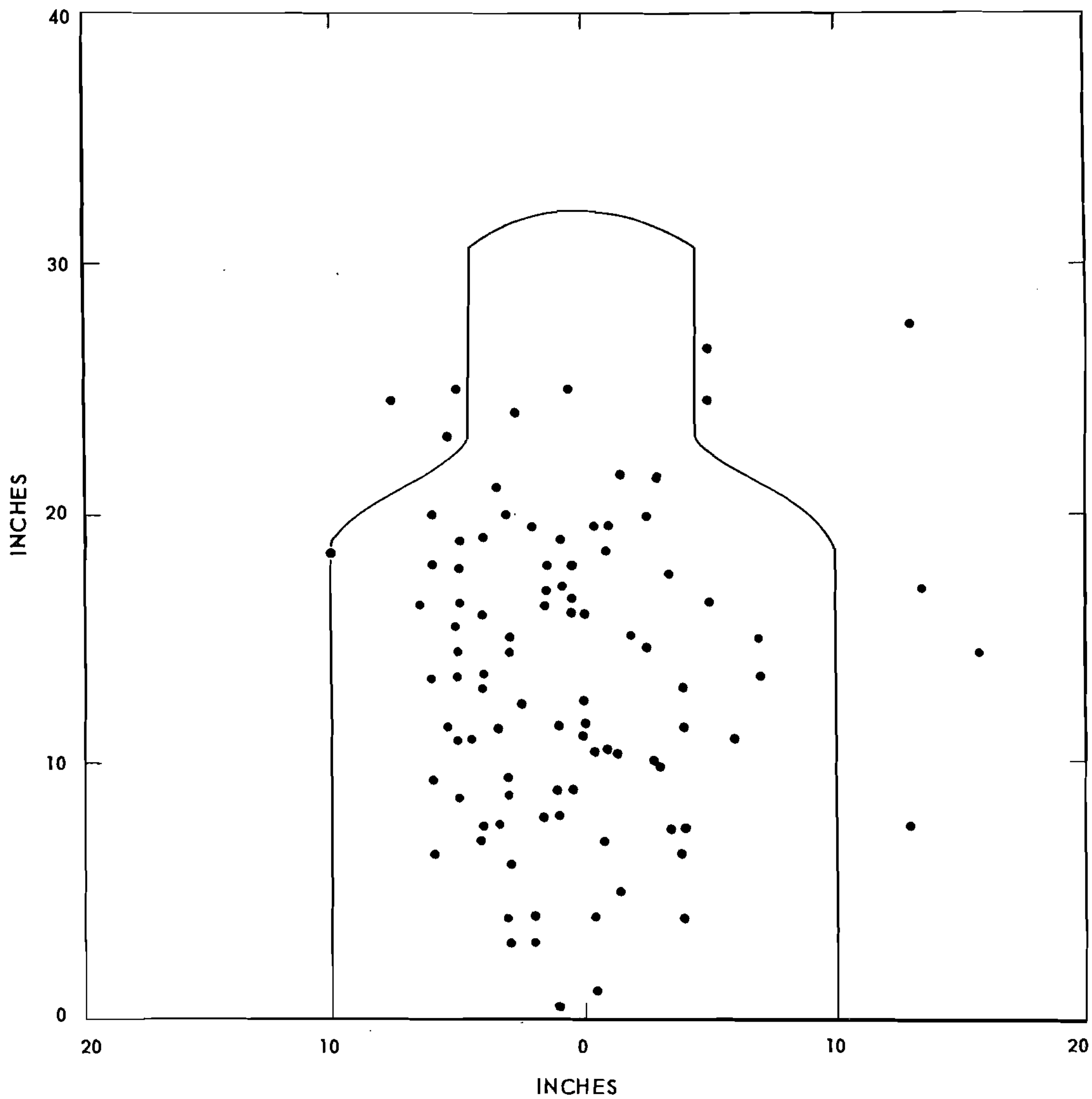


Fig. A1—110 yard range (Test No. 1), expert riflemen firing individually, 96 rounds fired (8 each by 12 men), 96 rounds on target cloth, 88 rounds on target

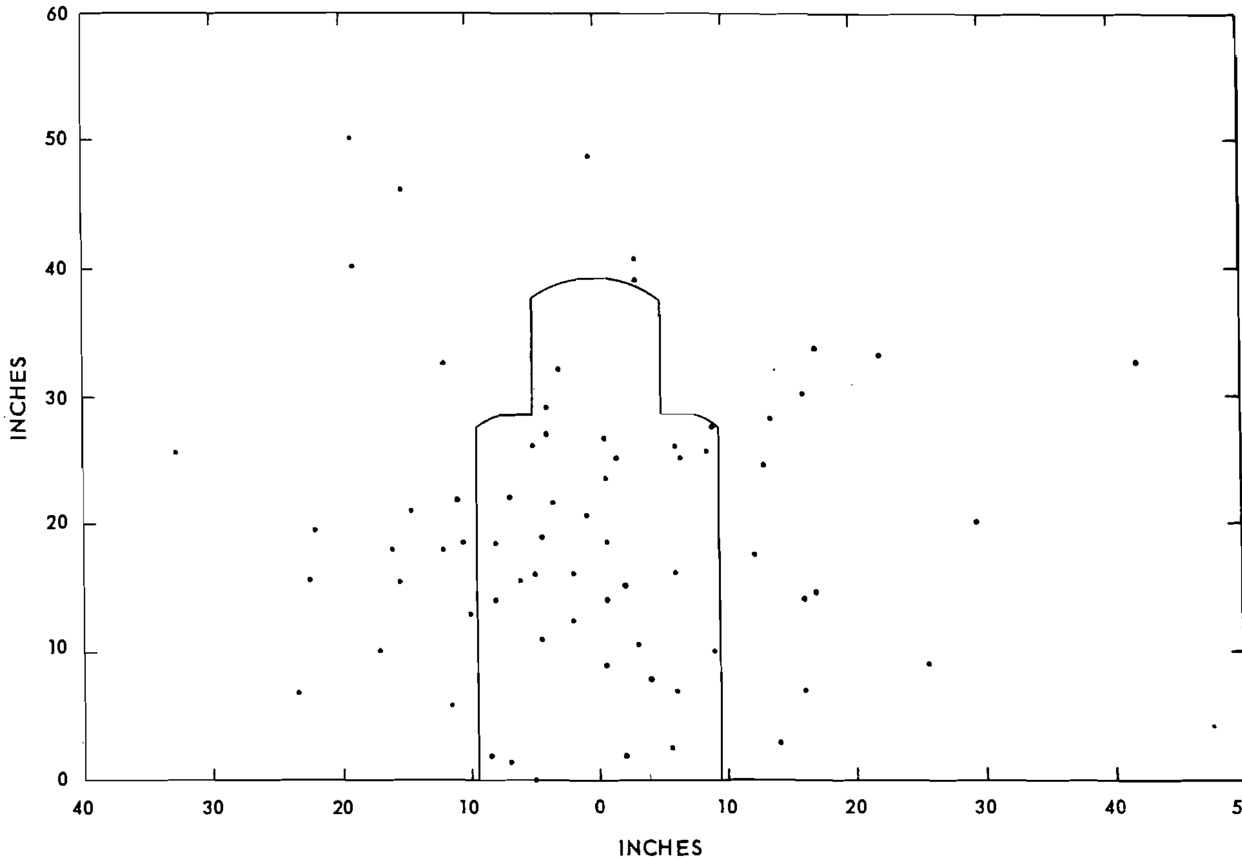


Fig. A2—205 yd range (Test No. 1), expert riflemen firing individually, 80 rounds fired (8 each by 10 men), 69 rounds on target cloth, 36 rounds on target

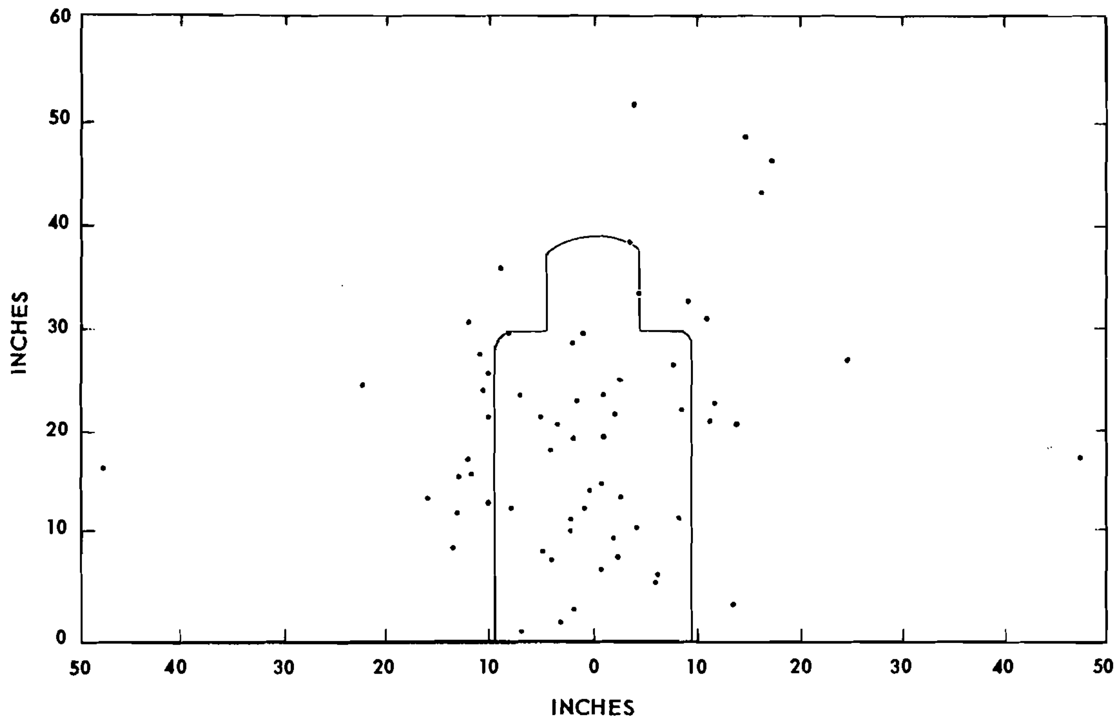


Fig. A3—265 yard range (Test No. 1), expert riflemen firing individually, 72 rounds fired (8 each by 9 men), 62 rounds on target cloth, 34 rounds on target

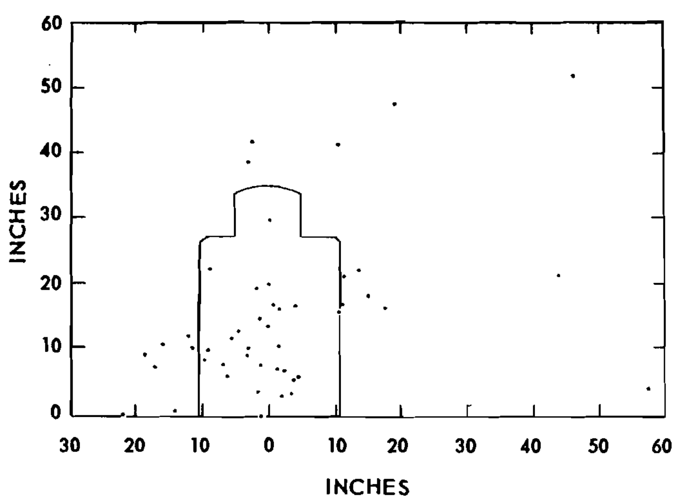


Fig. A4—310 yard range (Test No. 1), expert riflemen firing individually, 72 rounds fired (8 each by 9 men), 47 rounds on target cloth, 28 rounds on target

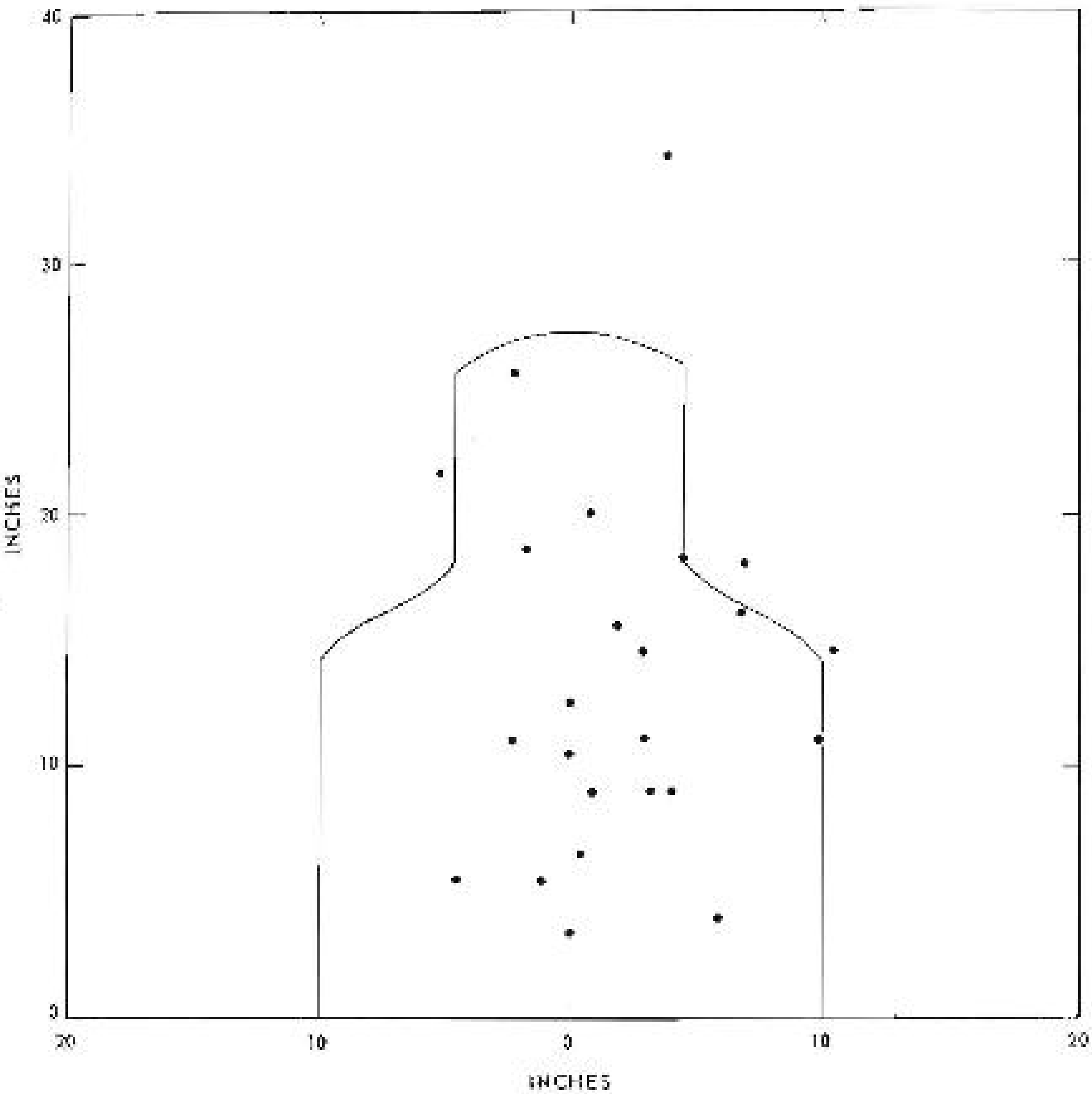


Fig. A5—110 yard range (Test No. 1), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 24 rounds on target cloth, 20 rounds on target

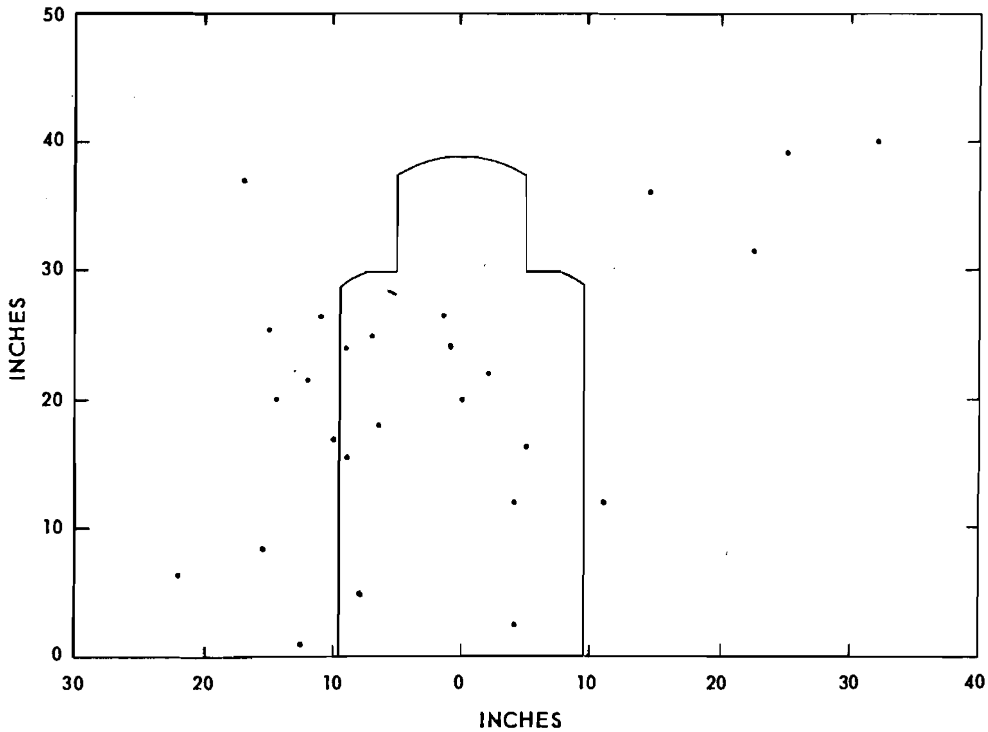


Fig. A6—205 yard range (Test No. 1), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 26 rounds on target cloth, 12 rounds on target

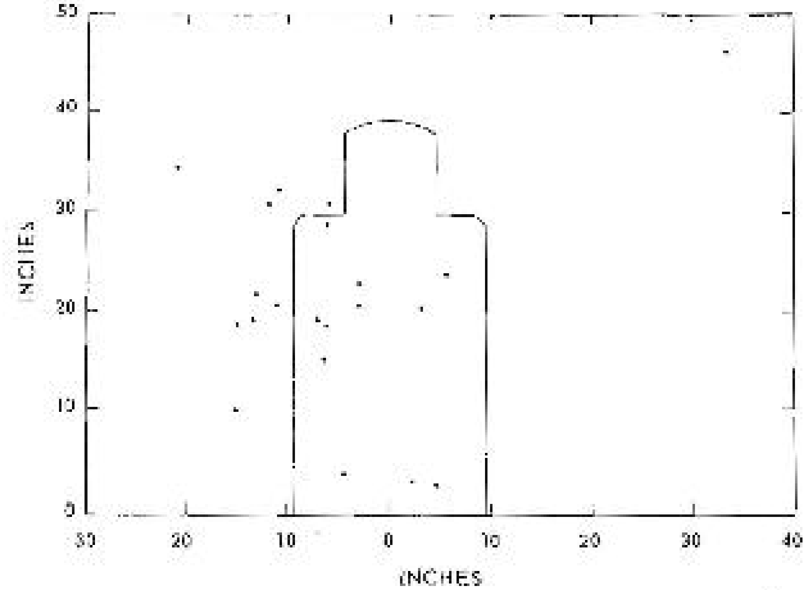


Fig. A7—265 yard range (Test No. 1), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 21 rounds on target cloth, 11 rounds on target

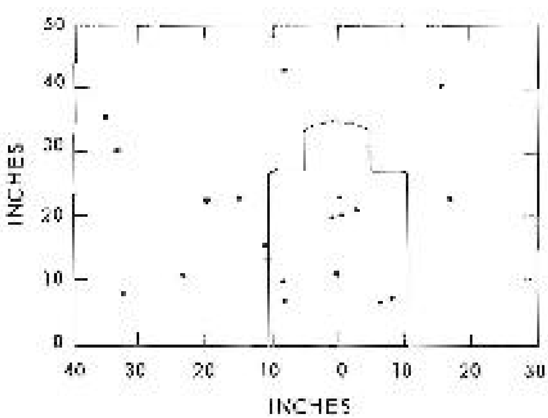


Fig. A8—310 yard range (Test No. 1), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 19 rounds on target cloth, 9 rounds on target

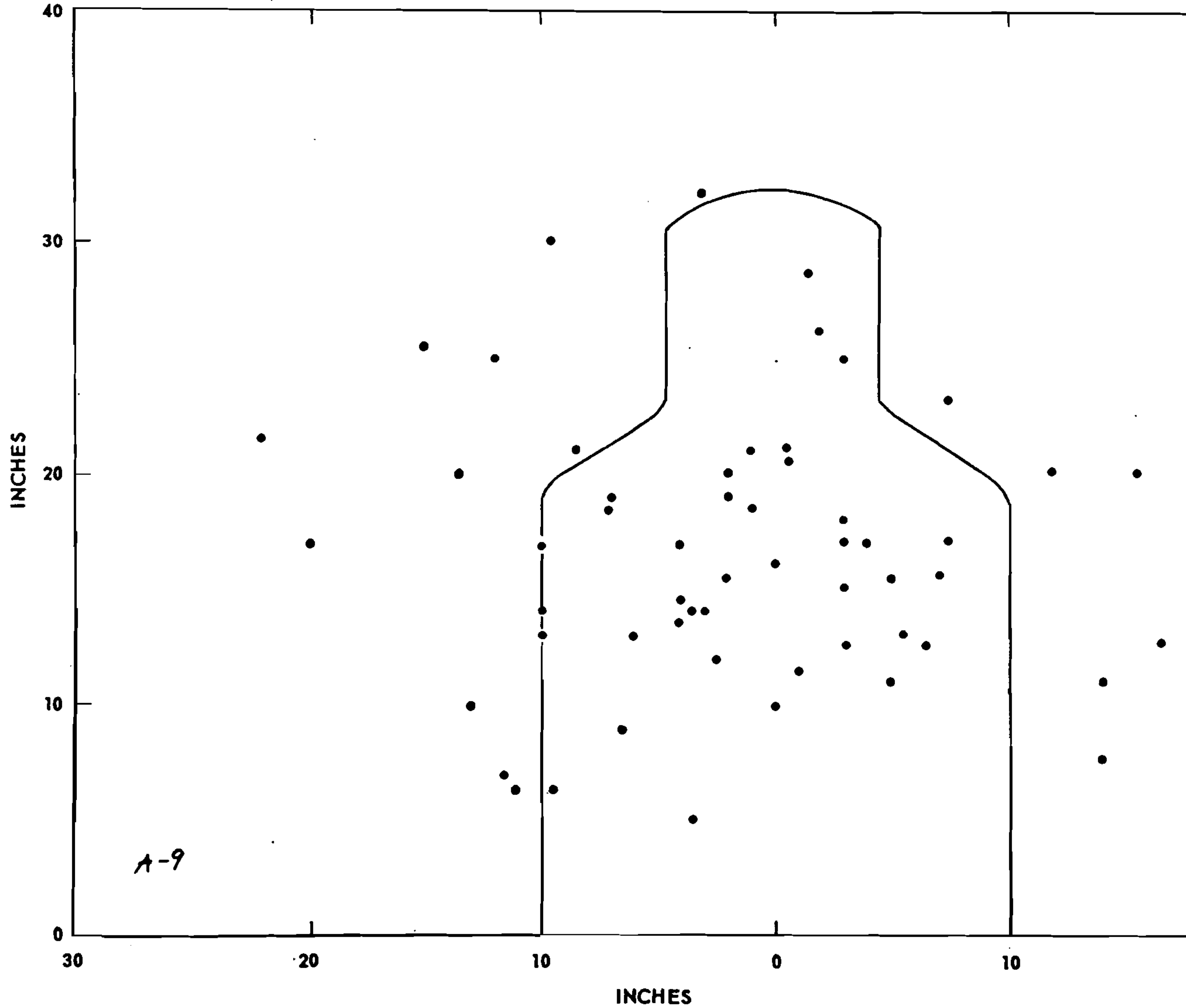


Fig. A9—110 yard range (Test No. 1), marksmen firing individually, 56 rounds fired (8 each by 7 men) – 8 r
fired by Bates not included–56 rounds on target cloth, 39 rounds on target

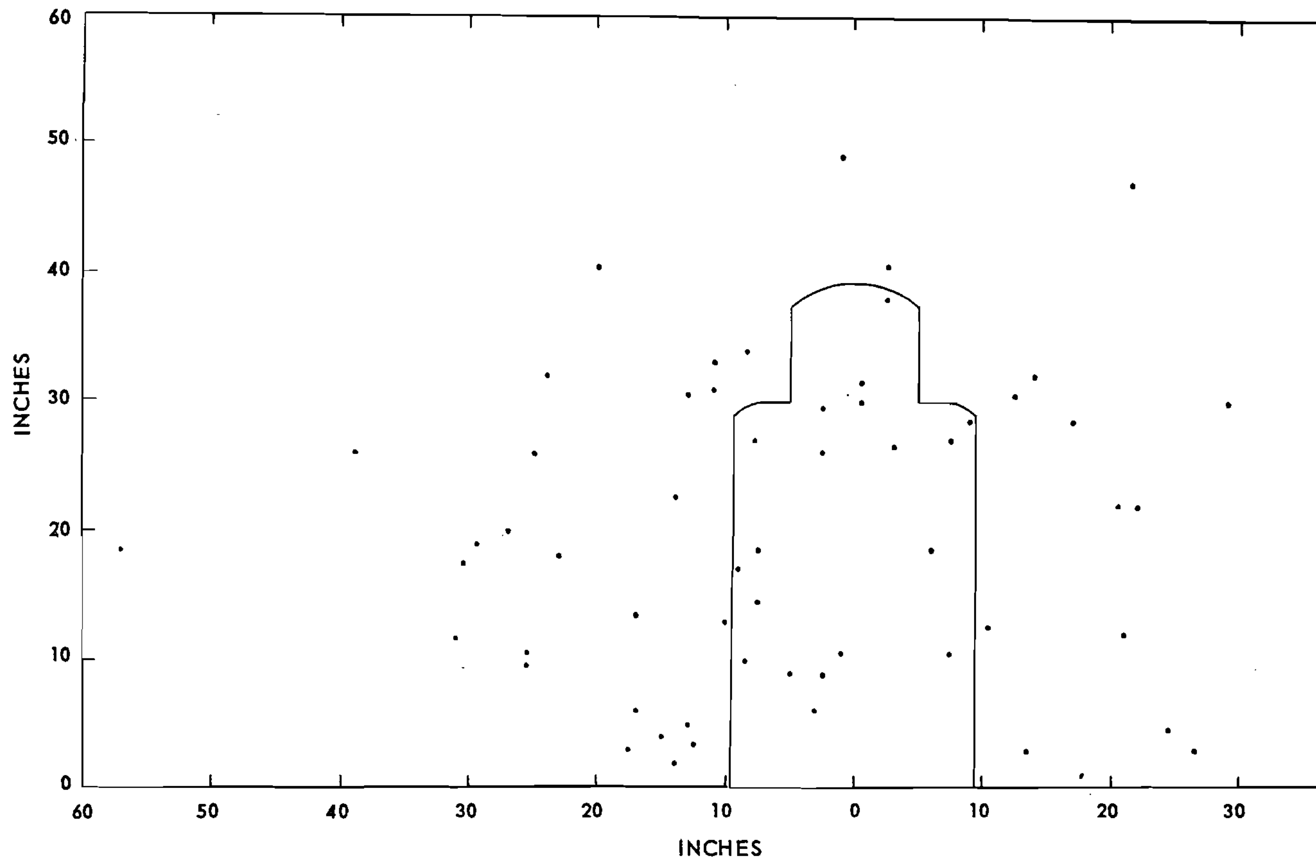


Fig. A10—205 yard range (Test No. 1), marksmen firing individually, 72 rounds fired (8 each by 9 men), 58 ro
on target cloth, 19 rounds on target

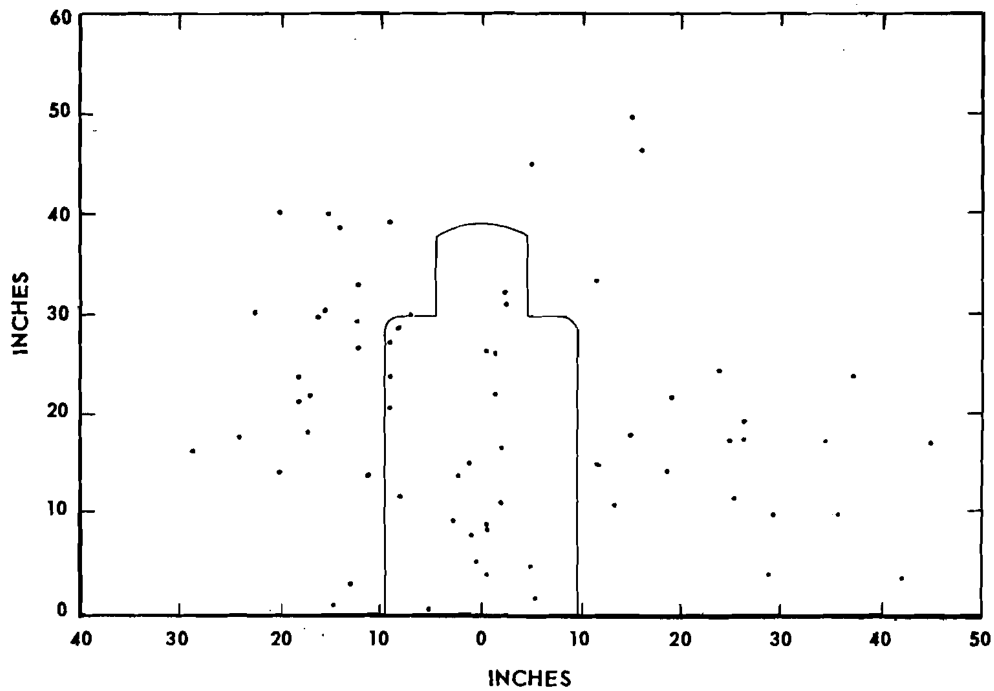


Fig. A11—265 yard range (Test No. 1), marksmen firing individually, 72 rounds fired (8 each by 9 men), 65 rounds hit target cloth, 25 rounds hit target

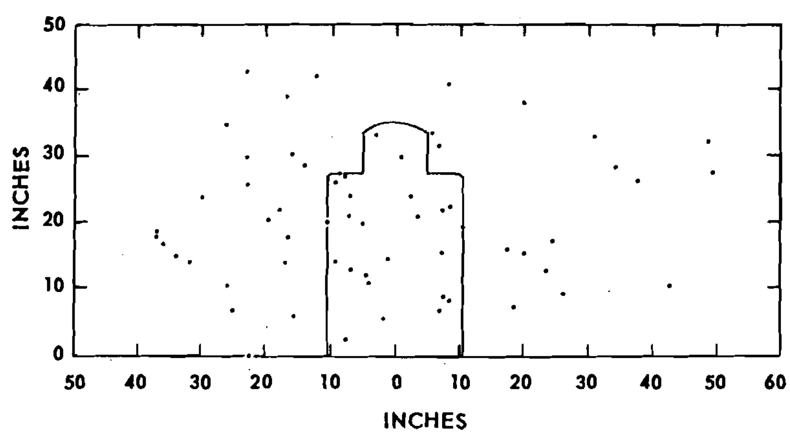


Fig. A12—310 yard range (Test No. 1), marksmen firing individually, 80 rounds fired (8 each by 10 men) – Bates excluded, 61 rounds on target cloth, 24 rounds on target

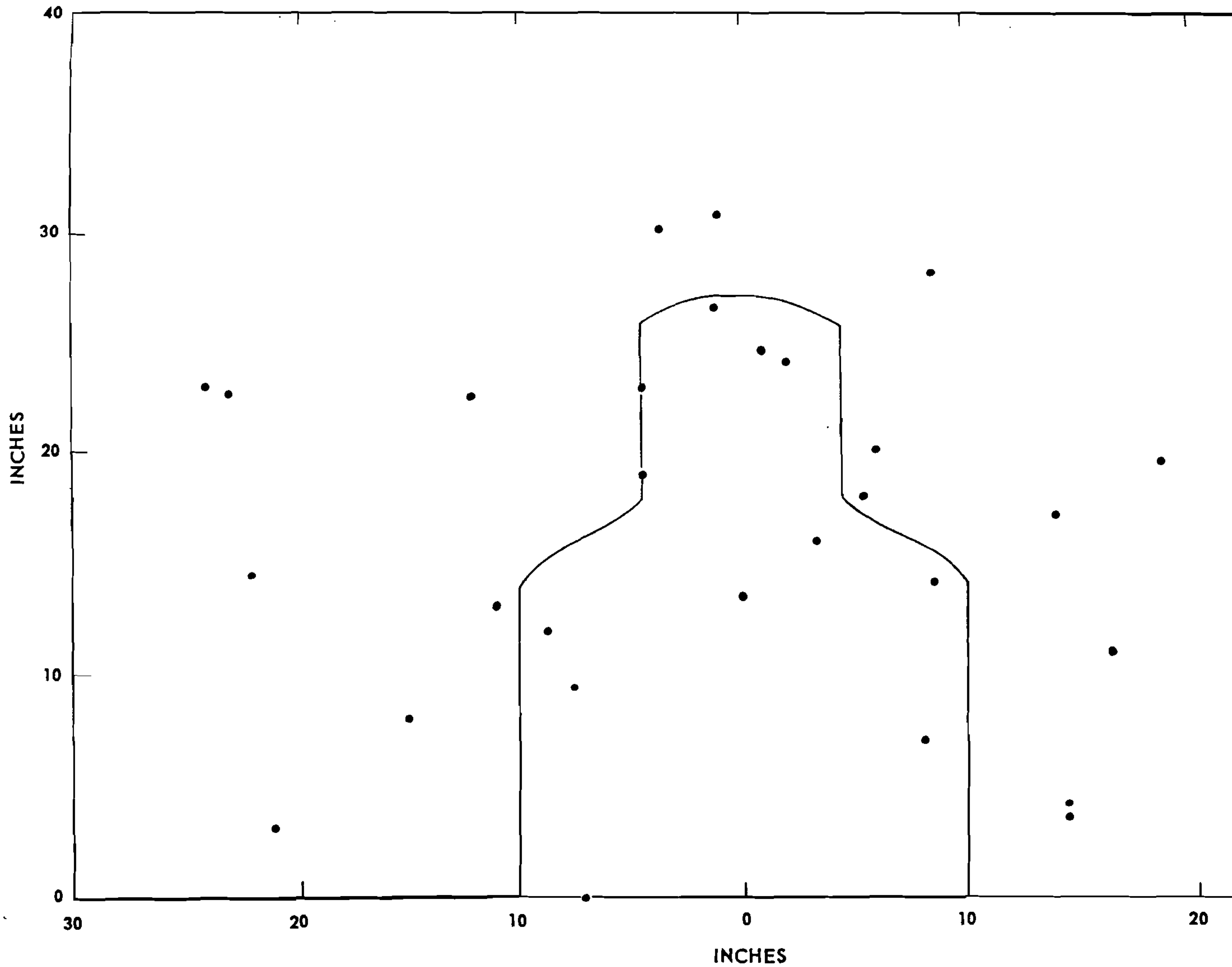


Fig. A13—110 yard range (Test No. 1), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 30 round
12 rounds hit target

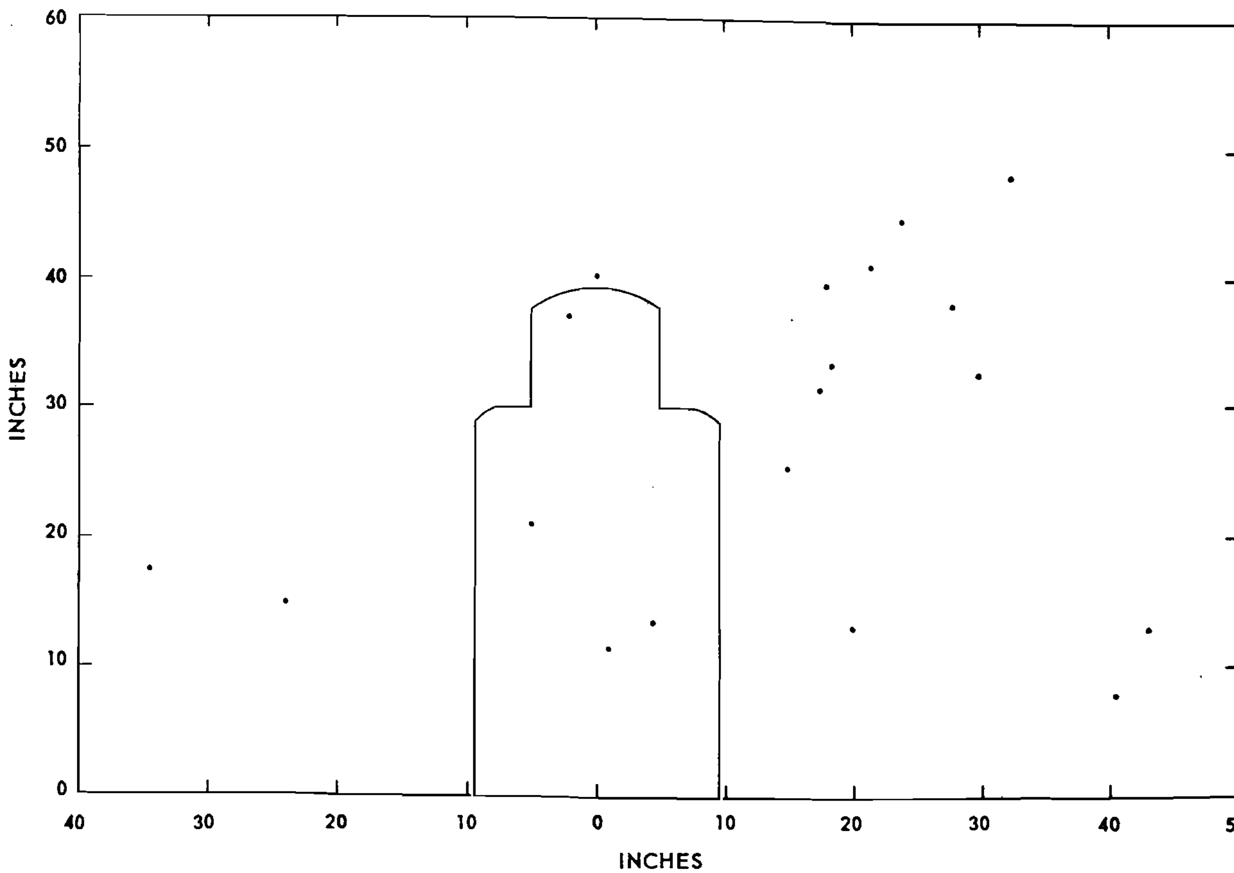


Fig. A14—205 yard range (Test No. 1), marksmen firing simultaneously, 32 rounds fired (4 each by 8 mer
19 rounds on target cloth, 4 rounds on target

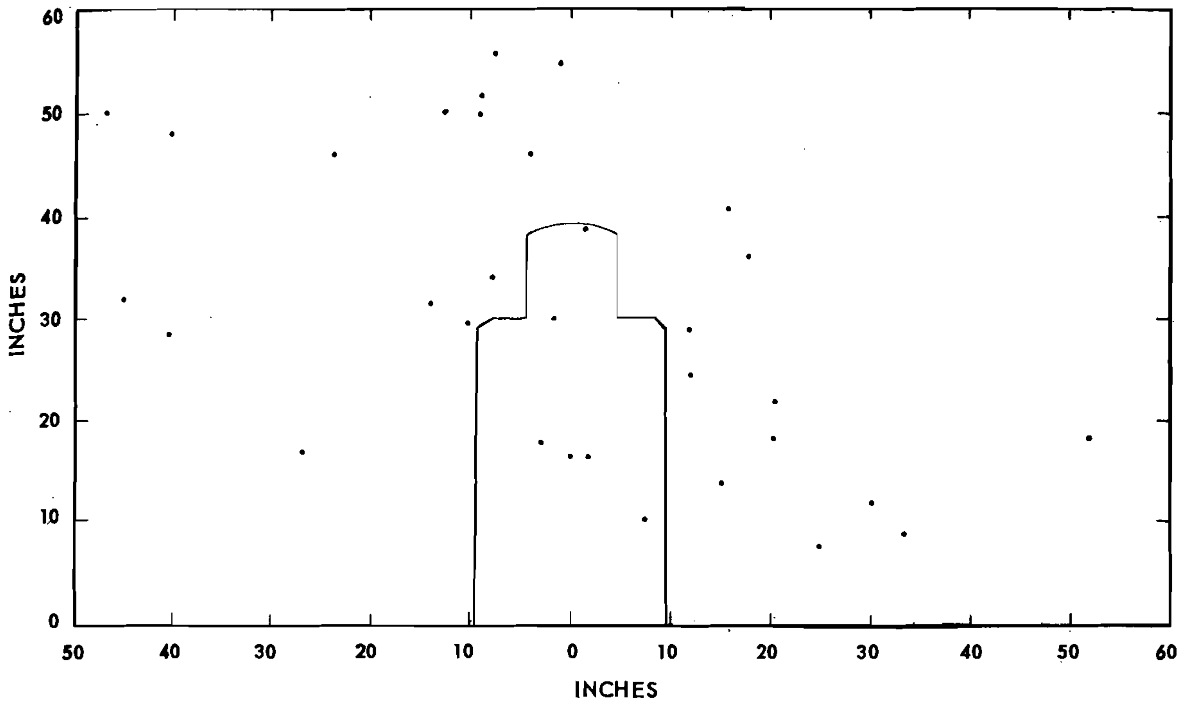


Fig. A15—265 yard range (Test No. 1), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 32 rounds hit target cloth, 6 rounds hit target

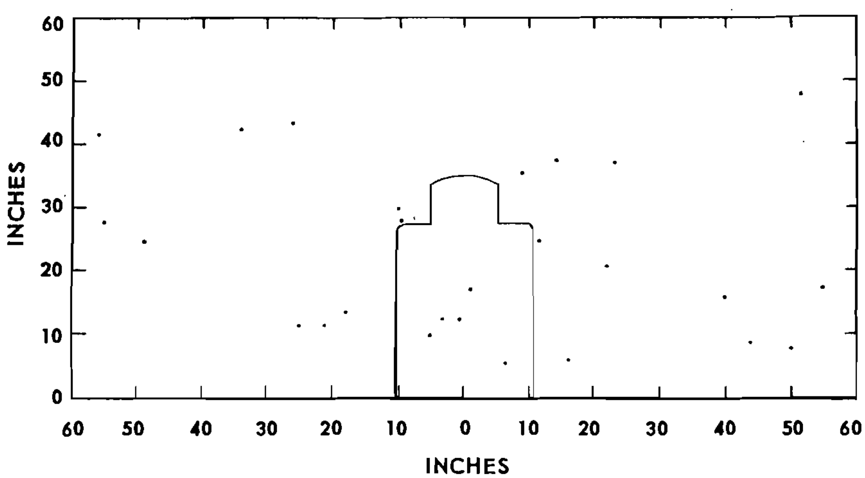


Fig. A16—310 yard range (Test No. 1), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 25 rounds hit target cloth, 4 rounds hit target

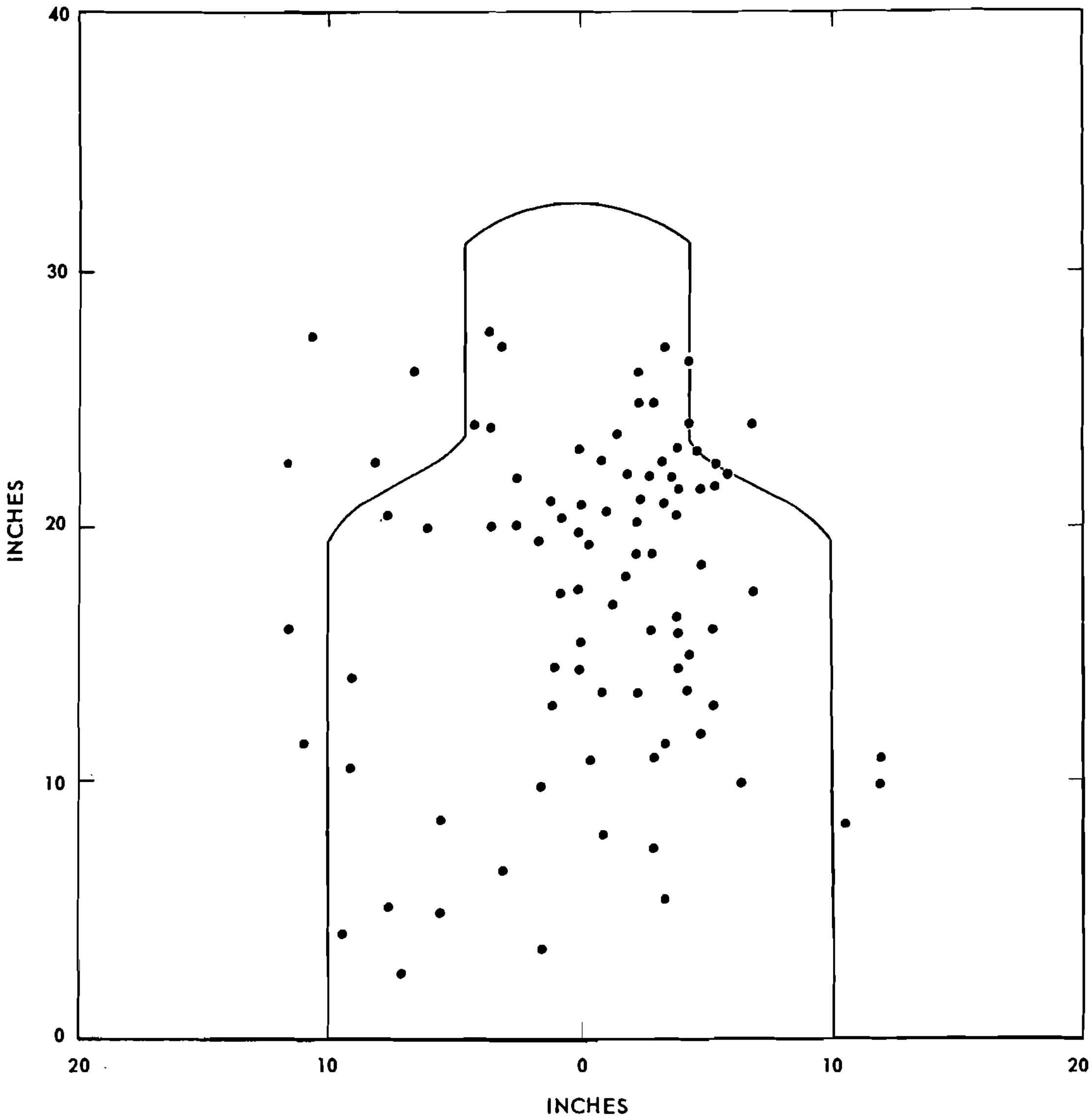


Fig. A17—110 yard range (Test No. 2), expert riflemen firing individually, 96 shots fired (8 each by 12 men), 91 rounds hit target cloth, 81 rounds hit target

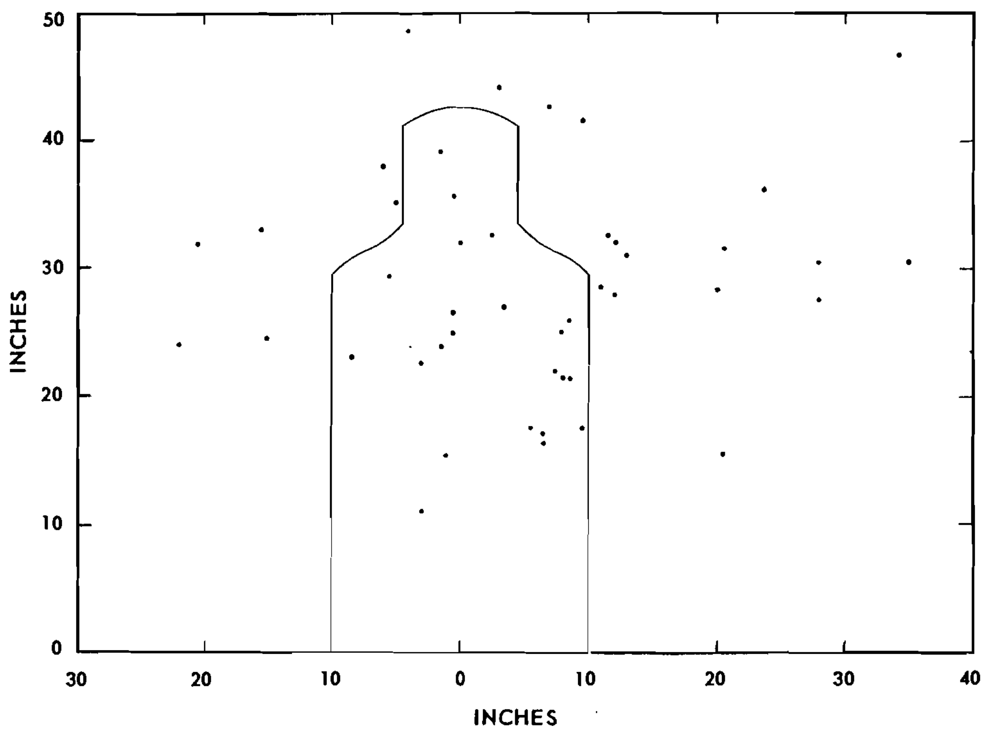


Fig. A18—205 yard range (Test No. 2), experts firing individually, 64 rounds fired (8 each by 8 men), 45 rounds hit target cloth, 22 rounds hit target

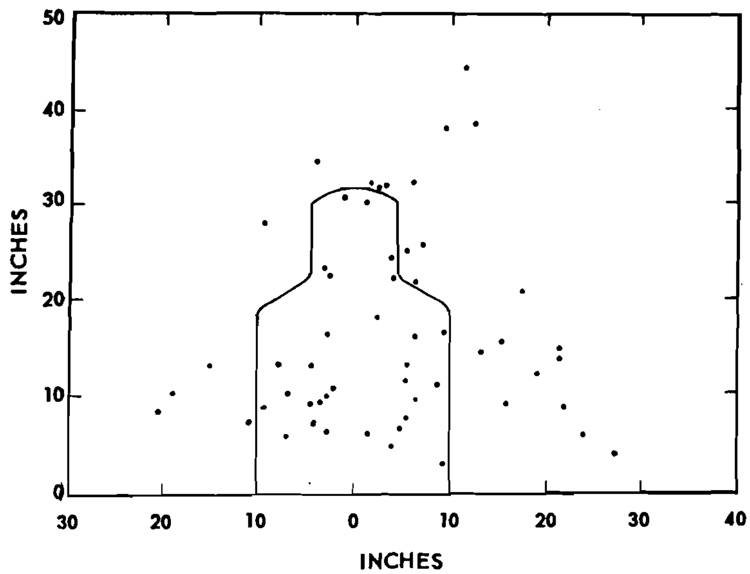


Fig. A19—265 yard range (Test No. 2), expert riflemen firing individually, 64 rounds fired (8 each by 8 men), 56 rounds on target cloth, 30 rounds on target

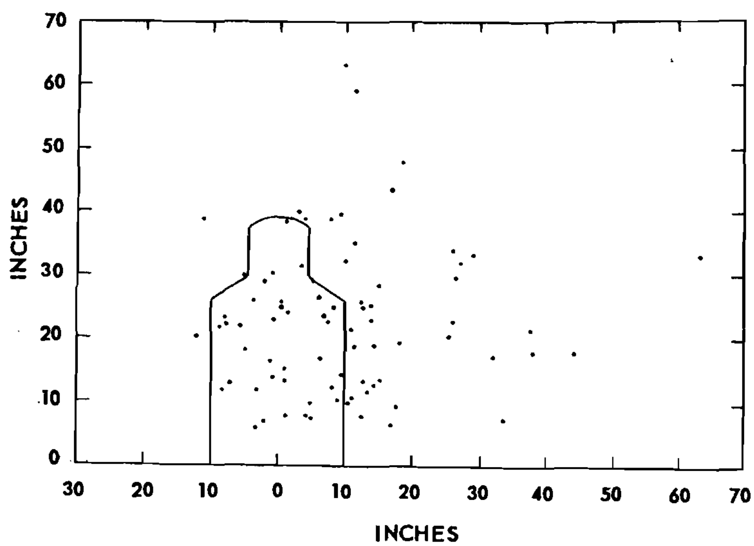


Fig. A20—310 yard range (Test No. 2), expert riflemen firing individually, 80 rounds fired (8 each by 10 men), 77 rounds hit target cloth, 35 rounds hit target

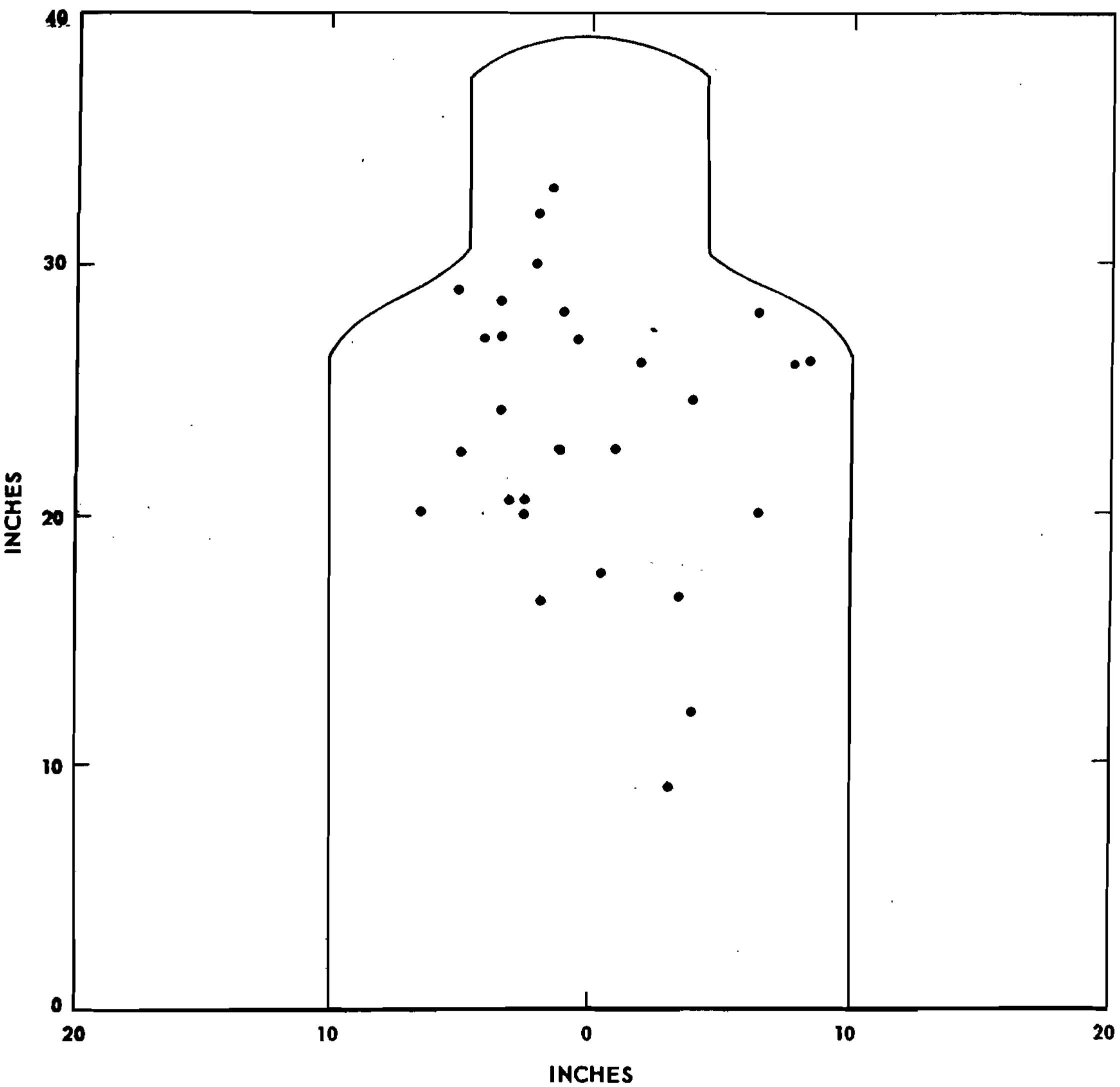


Fig. A21—110 yard range (Test No. 2), experts firing simultaneously, 32 rounds fired (4 each by 8 men), 28 rounds hit target cloth, 28 rounds hit target

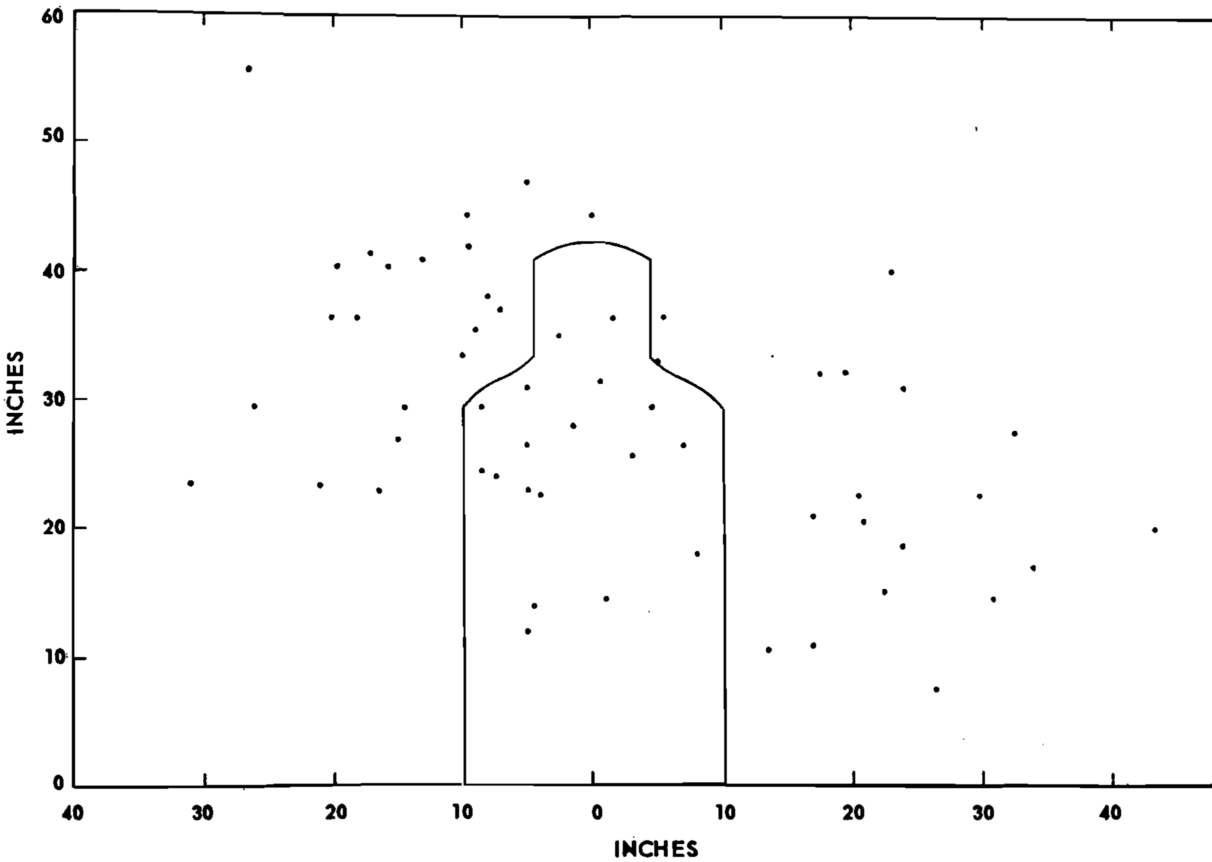


Fig. A22—205 yard range (Test No. 2), experts firing simultaneously, 64 rounds fired (4 each by 16 m
58 rounds hit target cloth, 19 rounds hit target

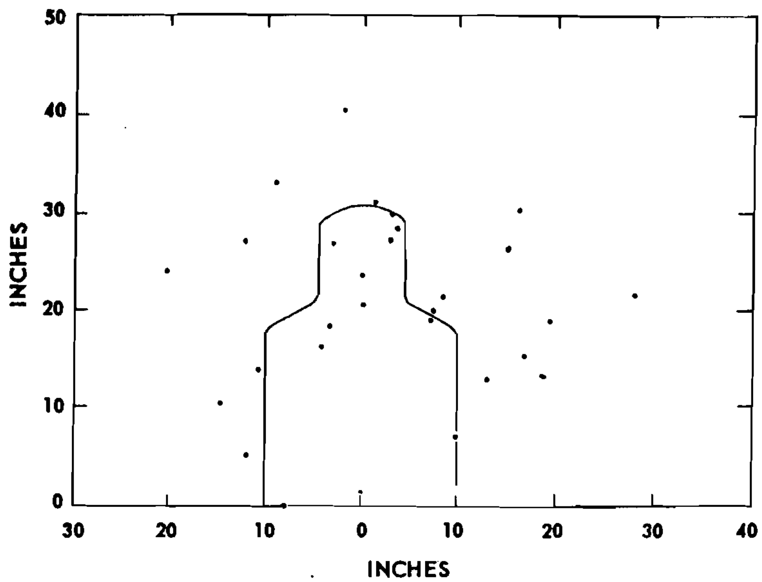


Fig. A23—265 yard range (Test No. 2), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 28 rounds on target cloth, 13 rounds on target

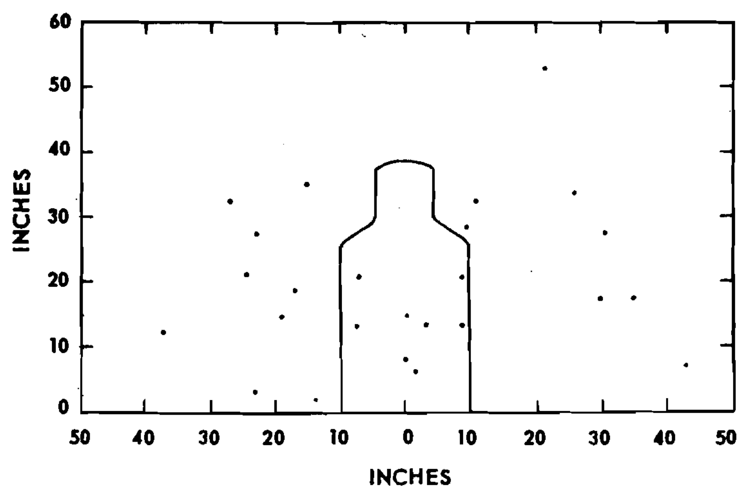


Fig. A24—310 yard range (Test No. 2), expert riflemen firing simultaneously, 32 rounds fired (4 each by 8 men), 25 rounds hit target cloth, 8 rounds hit target

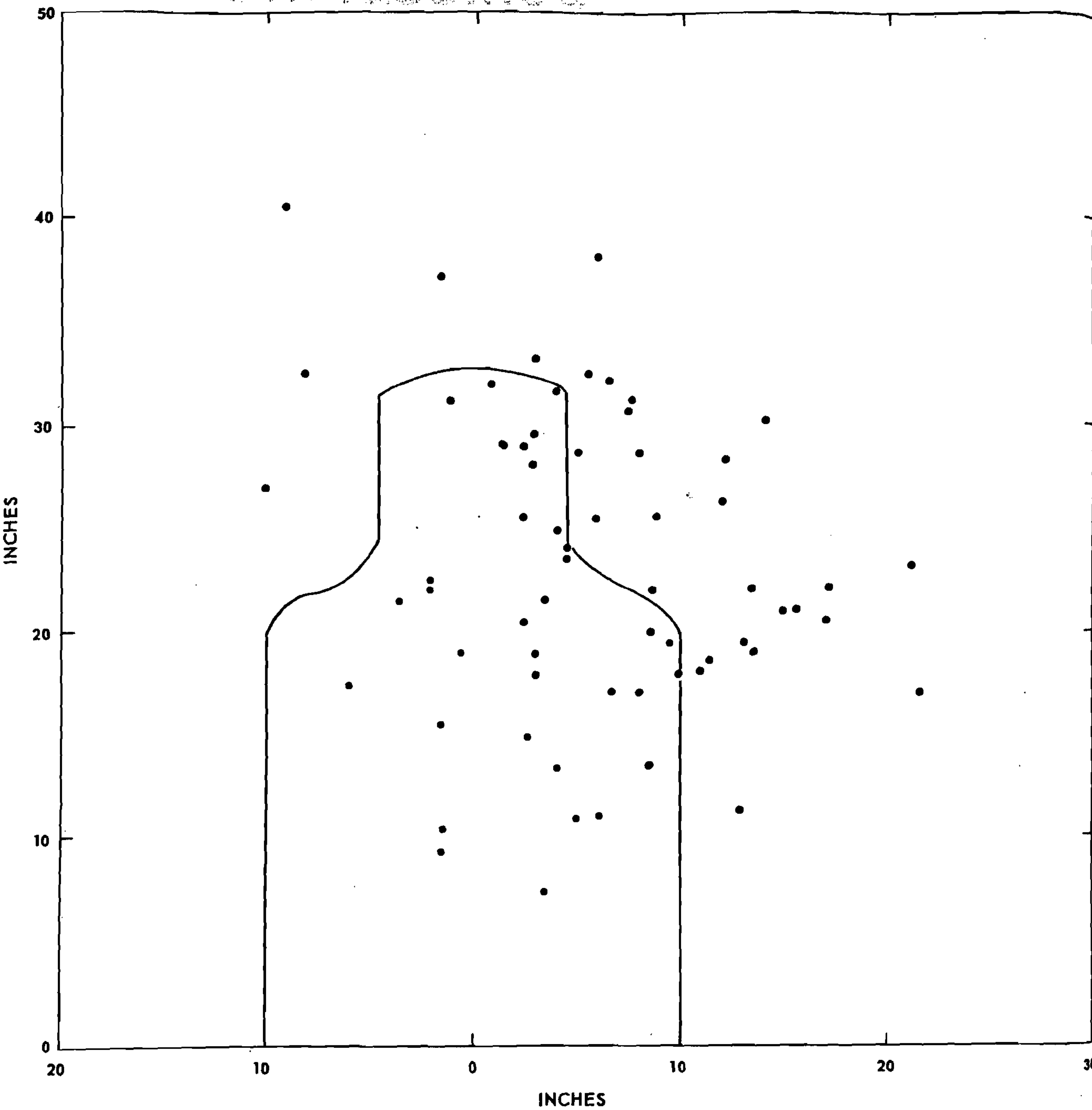


Fig. A25—110 yard range (Test No. 2), marksmen firing individually, 64 shots fired (8 each by 8 men), 64 rounds hit target cloth, 34 rounds hit target

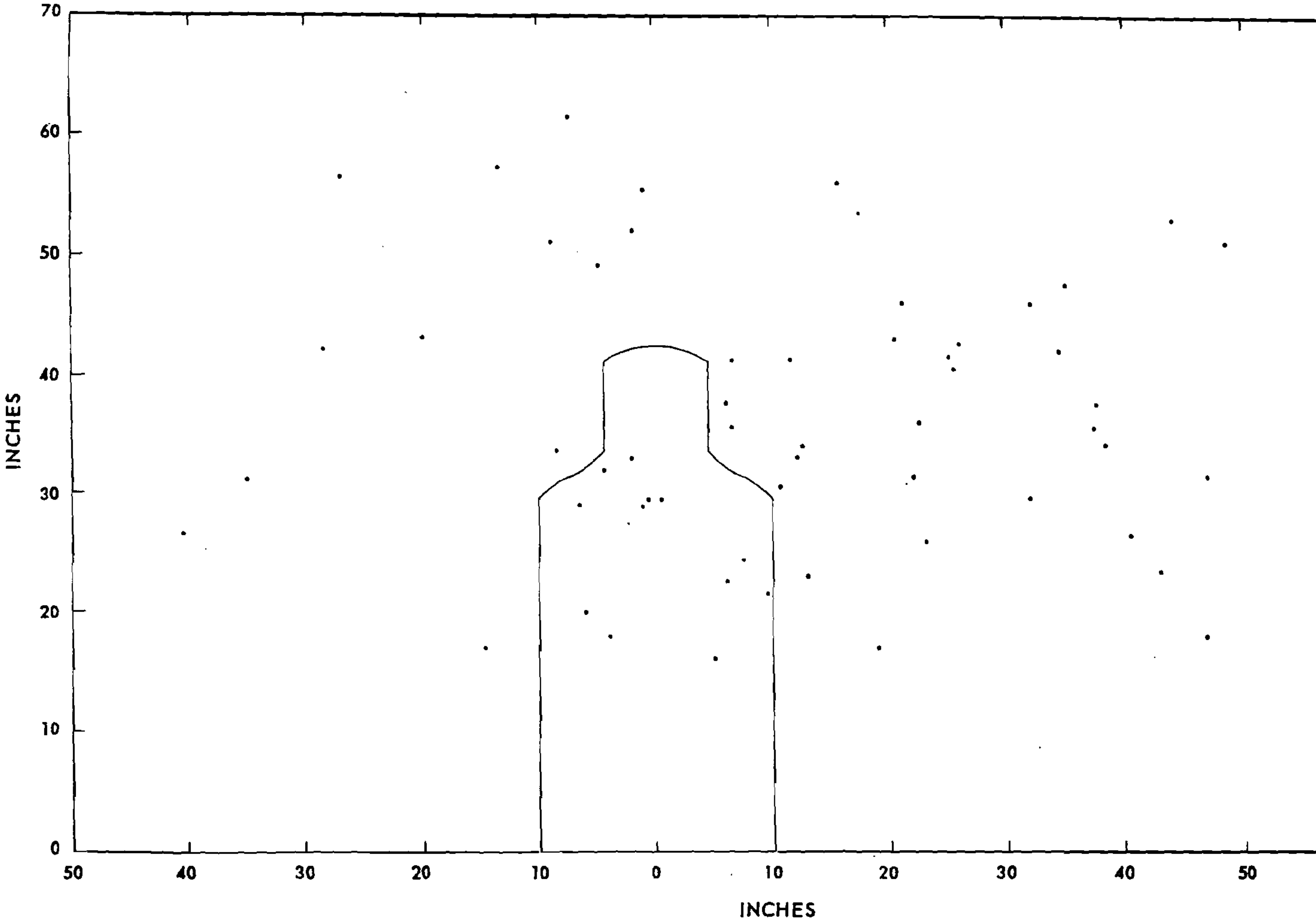


Fig. A26—205 yard range (Test No. 2), marksmen firing at target individually, 72 rounds fired (8 each by 9men), 59 rounds hit target cloth, 12 rounds hit target

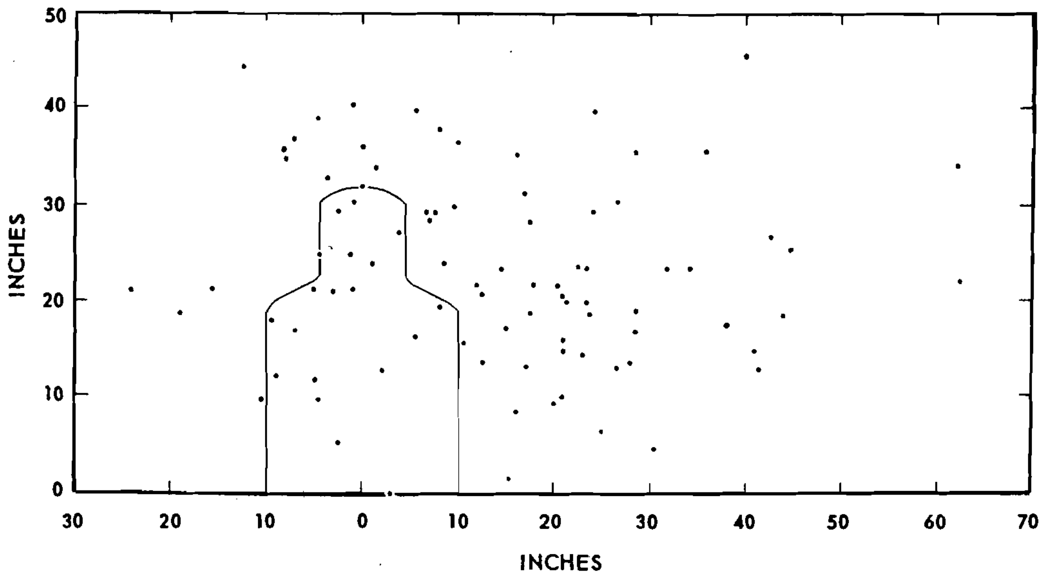


Fig. A27—265 yard range (Test No. 2), marksmen firing individually, 96 rounds fired (8 each by 12 men), 88 rounds on target cloth, 19 rounds on target

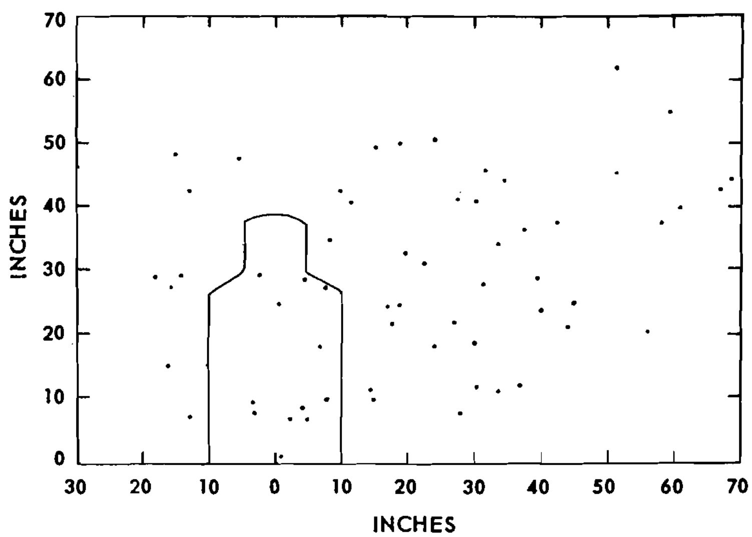


Fig. A28—310 yard range (Test No. 2), marksmen firing individually, 80 rounds fired (8 each by 10 men), 61 rounds hit target cloth, 12 rounds hit target

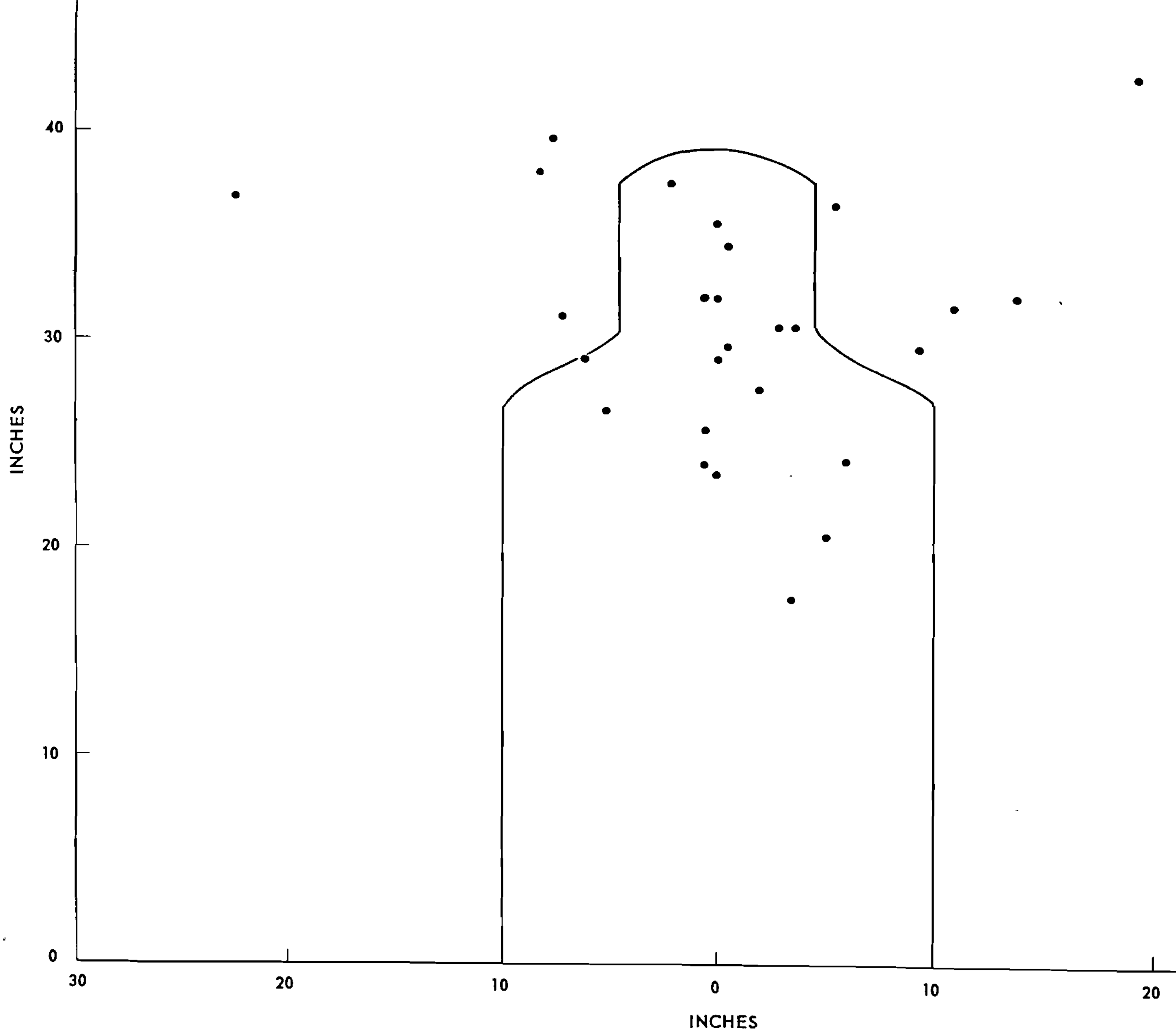


Fig. A29—110 yard range (Test No. 2), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 29 rounds hit target cloth, 18 rounds hit target

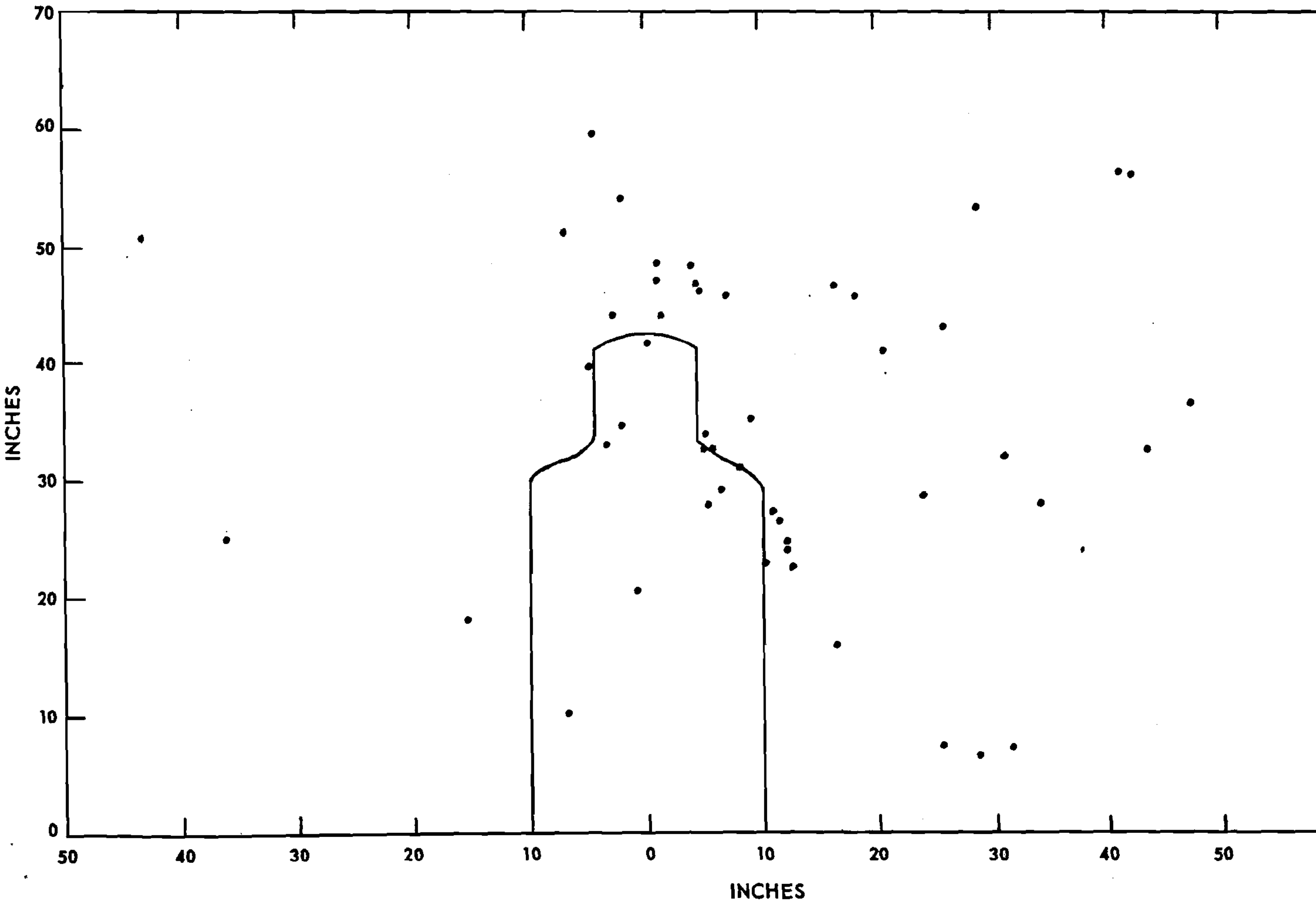


Fig. A30—205 yard range (Test No. 2), marksmen firing simultaneously, 65 rounds fired (4 each by 16 men) – 1 man fired 5 rounds – 49 rounds hit target cloth, 10 rounds hit target

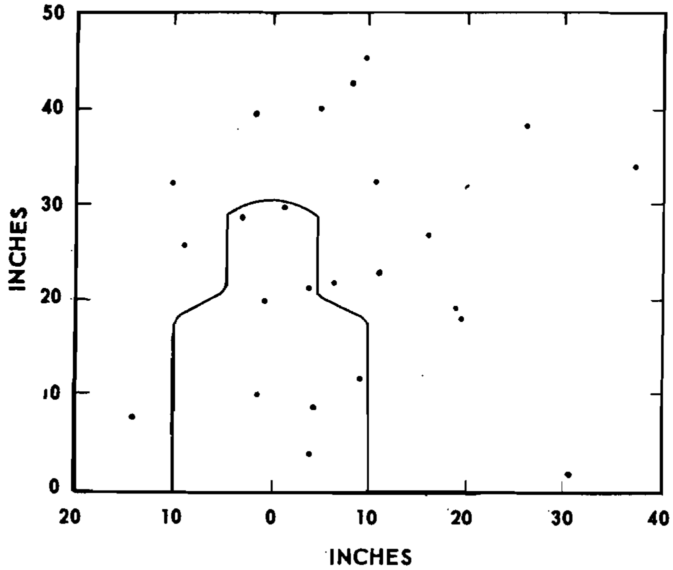


Fig. A31—265 yard range (Test No. 2), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 24 rounds hit target cloth, 8 rounds hit target.

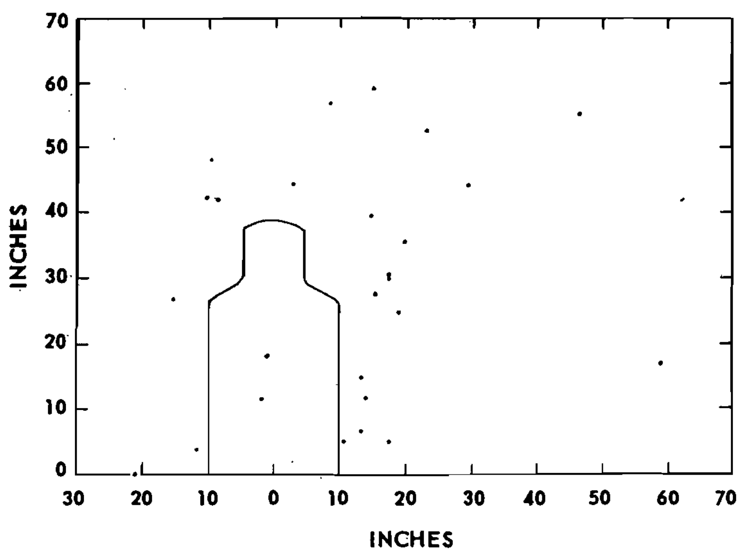


Fig. A32—310 yard range (Test No. 2), marksmen firing simultaneously, 32 rounds fired (4 each by 8 men), 26 rounds hit target cloth, 2 rounds hit target

Determination of Means (mpi)
and Dispersion (Standard Deviation)

As already indicated, the location of those rounds which did not hit the target or screen, is, of course, unknown. How then can the mean (mpi) and dispersion (standard deviation) be determined when these depend on the actual location of all shots? This problem is most conveniently solved by using probability paper as illustrated in Fig. A33.

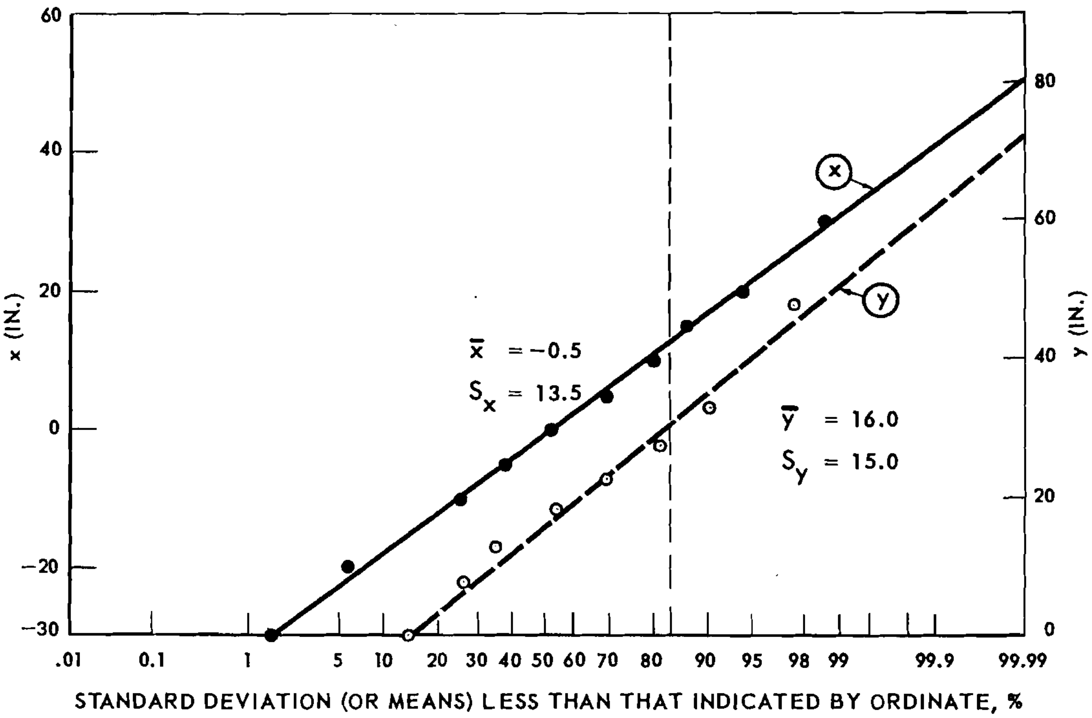


Fig. A33—Example illustrating use of probability paper to determine standard deviations and means, whether or not distribution is truncated. Data are from Test 1, experts firing individually at 205 yd.

Suppose x is a variable normally distributed about mean $\bar{x}$, and suppose from a sample of n x's F_1 is determined, where F_1 is the fraction of all the x's in the sample which have values less than x_1, and F_2 the fraction containing all values of x less than x_2 ($x_2 > x_1$) and so on to F_n. Then for a normal distribution of the x's, the scale of F (abscissa scale of Fig. A33) is so designed that when values of F are plotted against the corresponding x, the points determine a straight line. The ordinate, on this line, corresponding to abscissa F = 50 (i.e., 50 percent) determines the mean of the sample. If this mean is subtracted from the ordinate corresponding to abscissa F = 0.841, the difference is the estimated standard deviation of individual values about the mean of the sample.

Thus, the upper line in Fig. A33 indicates mean: $\bar{x}$ = - 0.5 inch and standard deviation: S_x = 13.5 in. These apply to the x coordinates of the points of Fig. A2. Similarly from the lower line in Fig. A33: $\bar{y}$ = 16.0 inches (y measured from bottom of screen in Fig. A2) and S_y = 15.0 inches. The percentages (i. e., abscissae) for the points along the lower line of Fig. A33 were computed using as base (i. e., 100 percent) the total number of shots fired (i. e., 80 from Fig. A2), although of these (11/80) 14 percent were off the screen at the bottom. Thus, even though the distribution of y's is truncated at y = o (bottom of screen), it is relatively simple to estimate the mean and the standard deviation through the use of probability paper which incidently facilities the calculation even for the nontruncated case.

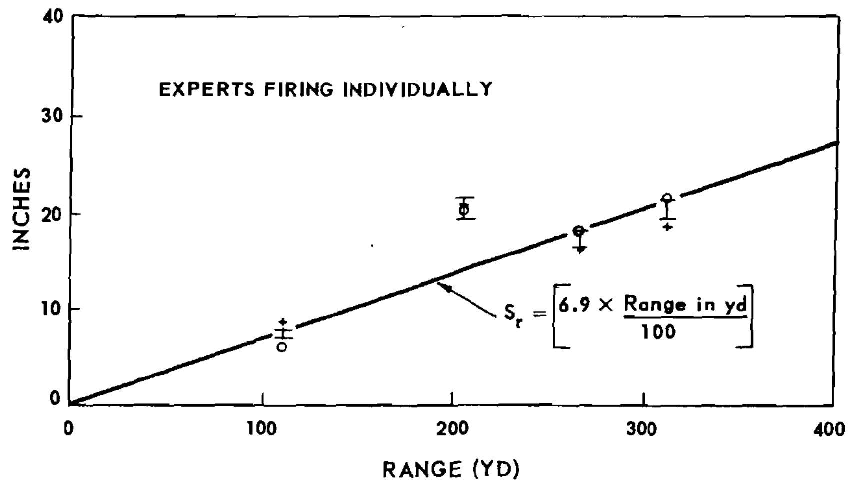
On the other hand, if the distributions of x and y are statistically independent (as was the case of Fig. A1 for which the correlation between x and y did not significantly differ from zero) then, referring to Fig. A2, the mean and standard deviation of x will be independent of y. Hence, in computing the percentages (ordinates) for the upper set of points in Fig. A33, it was essential to use a base (i. e., 100 percent) equal to the number of shots on the screen (i. e., 69 from Fig. A2). That is to say, the distribution of the x's of Fig. A2 is not truncated, as was that of the y's; only the sample size for x is diminished as a consequence of some 11 shots having gone off the screen.

Summary of Means and Standard Deviation

Proceeding as described in the preceding paragraph, the means of x and y and their standard deviations were determined for each of the test results shown in Figs. A1 to A32. For Tests 1 and 2, the results are given respectively in Tables A1 and A2. Inspection of S_x and S_y (i. e., the standard deviations of x and y) in Tables A1 and A2 indicates on the whole no very great difference between S_x and S_y. More elaborate tests indicate the same conclusion. For example, in Test 1, Table 1, if S_x and S_y in the first four rows are each normalized to range 100 yd (on the assumption of constant mil error), and then the variance of x and y are separately pooled (from the results at the four ranges), the resulting S_x = 4.9 inches and S_y = 5.8 inches, a difference of only 18 percent. In other cases, for example, in Test 1 for marksmen firing individually, (M_1, Table A1) S_x exceeds S_y. Hence, on the whole no serious consequences are likely to arise from assuming $\sigma_x = \sigma_y$ for all the results (σ_x, and σ_y are standard deviations for the whole population).

Dispersion as a Function of Range

In the preceding paragraph, it was indicated that when the standard deviation in x (or y) at each of the four ranges was divided by the range, the results were essentially independent of range. It was also indicated that x and y were independent



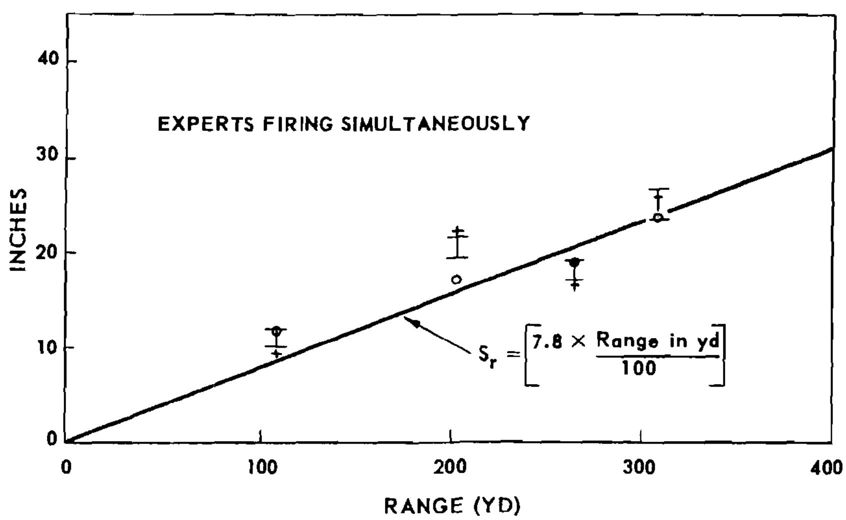


Fig. A34—Observed standard deviation, S_r, of distance of individual shots from mpi as function of target range, for experts. o, Test 1; +, Test 2; Ī, centered at S_r from combined results of Tests 1 and 2. Total vertical extent of Ī indicates range within which 50 percent of results from similar samples should fall.

(i. e., correlation zero) and that their standard deviations could be assumed equal. This suggests the standard deviation of r ($r^2 = x^2 + y^2$) as a convenient measure of dispersion since it combines S_x and S_y (actually $S_r^2 = S_y^2 + S_x^2$).

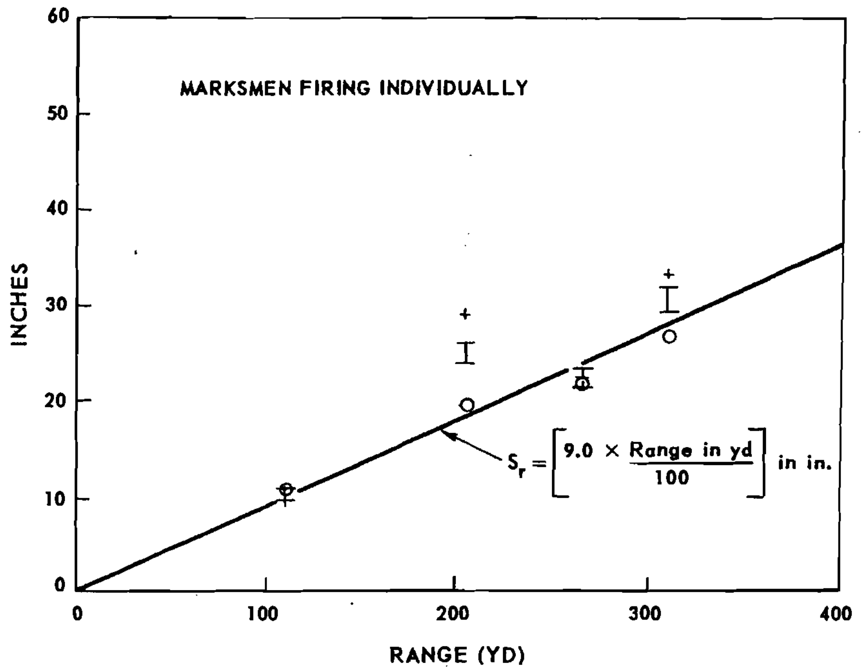
For Tests 1 and 2 respectively, values of S_r are listed in column 7 of Tables A1 and A2. In Figs. A34 and A35, these values of S_r are plotted as a function of range to target. It is evident in Figs. A34 and A35 that the "observed" values of S_r for the different ranges are, within the indicated statistical uncertainties, reasonably approximated by the indicated straight lines. This implies that the dispersion (standard deviation) in inches at the target increases linearly with the target range, according to the equations indicated. The constants show that, in accuracy, the riflemen rank in the following order: (1) experts firing individually, (2) experts firing simultaneously, (3) marksmen firing individually, and (4) marksmen firing simultaneously.

Systematic Errors in the mpi

Figure A36 indicates the vertical distance of the mpi from the top of the target, at the four ranges, for experts and marksmen in Tests 1 and 2. Even if all men aimed at the center of the target, vertical systematic deviations of the mpi from the aiming point would be expected as a consequence of the parabolic nature of the bullet trajectory. How the vertical coordinate of the mpi varies with range would depend on the range for which the sights are set. Figures A37 and A38 indicate for Tests 1 and 2, respectively, the x - coordinate of the mpi at different ranges. It is evident that in Test 1 the bias is quite small and in most cases probably not statistically significant. On the contrary, the bias in Test 2 is generally larger than in Test 1, particularly for marksmen, and is in many cases statistically significant. Results of tests for the significance of this bias are given in the last row of Tables A4, A5, A6, and A7, on which further comment will follow.

Comparison of Observed and Theoretical Distributions of Deviations from mpi

If x and y are deviations from a mean, and are independently and normally distributed with equal standard deviations, $\sigma_x = \sigma_y$, then it is convenient to consider the distribution of radial deviations, r, (r = x + y), which have standard deviation, $\sigma_r = (\sigma_x^2 + \sigma_y^2)^{1/2}$. It can be shown that, of all the radial deviations



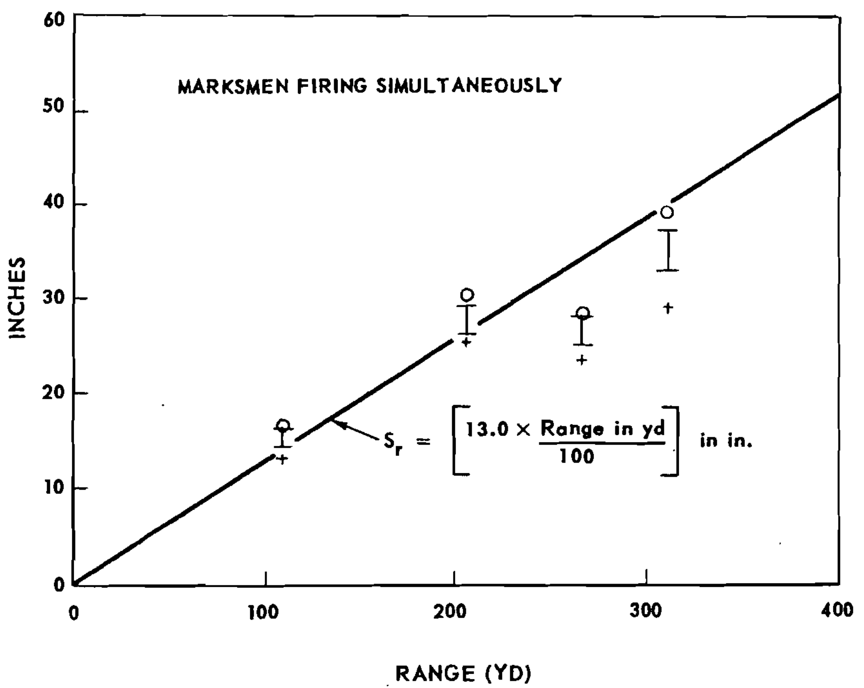


Fig. A35—Observed standard deviation, S_r, of distance of individual shots from mpi as function of target range for marksmen. For meaning of symbols see Fig. A34.

from the mean, the fraction having deviations greater than or equal to $k\sigma_r$ is, on the average, given by:

$$W(k) = e^{-k^2} \quad (1)$$

or looked at in another way W(k) is the probability that a shot falls outside the circle of radius $r = k\sigma_r$. The following table indicates values of W(k) for a few selected values of k:

k	0.000	0.536	0.833	1.179	∞
W (k)	1.000	0.750	0.500	0.750	0.000

In particular, the circle of radius 0.833 σ_r, with W(k) = 0.500, is usually called the circular probable error (cpe). Thus circles of radii, o, 0.536 σ_r, 0.833 σ_r, 1.179 σ_r, and ∞, with centers at the mpi, divide the plane into four zones, such that the probability of a shot hitting within any one of the zones is 25 percent. These circles were drawn in each of the originals of Figs. A1 to A32, (but they are not reproduced here), and the radii of the circles bounding each zone are listed in Tables A4, A5, A6, and A7. These tables also indicate the expected and observed numbers of shots falling in each zone.

In several cases, such as illustrated in Fig. A4, parts of some or of all zones are off the screen. For these cases it is obviously impossible to indicate how those shots which did not hit the screen were distributed among the zones. In such instances only those shots observed to hit the screen can be properly allocated among the partial zones which are on the screen. The expected number of hits within the parts of zones which are on the screen is, however, computed from the total number of shots fired (72 in the case of Fig. A4). This was done using circular probability paper to facilitate the numerical integration to determine the probability of hits falling within the partial zones. Multiplying these probabilities by the total number of shots fired gave the expected number of hits in each partial zone.

Corresponding to each of Figs. A1 to A32, the discrepancy between the observed and expected number of hits in each of the four zones (or partial zones) was measured by χ^2. P (χ^2) in Tables A4, A5, A6, and A7 indicates the probability of obtaining, in similar samples, as bad or a worse fit between observation and expectation than that indicated in the Tables. For Test 1, the values of P (χ^2) in Tables A4 and A5 are, in general, large enough so that the fit of the observed distribution to the theoretical one is acceptable. Thus, for subsequent calculations, the more convenient theoretical distribution can with confidence be used in place of the observed distribution. The discrepancy between the observed and theoretical distributions in Test 2 are on the whole greater than for Test 1.

Undoubtedly, this arises either from a large bias in the mpi for shots fired by some of the riflemen, or from nonhomogeneity in the dispersion for all the riflemen. However, as Figs. A34 and A35 indicate, the radial dispersions, s_r, are not very different in the two tests so that subsequent conclusions based on dispersion indicated by the straight lines (or equations) of Figs. A34 and A35, will not be much in error.

Remarks on the Homogeneity of Results for Individual Riflemen

Attempts were made to identify each bullet hole according to the man firing in the case of those tests in which men fired individually. In many cases, it turned out that holes were obviously improperly marked. Because of the small number of shots fired by each man, the results of individuals could be compared reliably only if the location of all shots fired was known. Thus, the comparison of individuals is limited to the situation of Figs. A1 and A9. The test for homogeneity consisted, in the case of Fig. A1, in counting the number of shots each individual fired inside and the number outside the probable error circle, and testing this against the expected number based on the results for all riflemen. The following table indicates the results for Fig. A1:

Man No.	1	2	3	4	5	6	7	8	9	10	11	12	Total
No. inside[a] p.e. circle	0	4	4	5	2	5	7	7	5	6	1	2	48
No. outside[a] p.e. circle	8	4	4	3	6	3	1	1	3	2	7	6	48

[a]The expected number throughout is 4.

Applying the χ^2 test, P = 0.003, for the hypothesis that there is no difference (in the long run) among the several individuals, the value of P indicates a likelihood of some difference among the individuals, which for subsequent purposes is not serious, mainly because some individuals (Nos. 1 and 11) appear worse than the average, while others (Nos. 7 and 8) appear better. This somewhat compensates, so that the distribution of all shots does not deviate seriously from the expected distribution (see P (χ^2) Tables A4, A5, A6, and A7). Similar tests for the results in Fig. A9 are given in the following table:

Man No.	1	2	3	4	5	6	7	Total
No. inside[a] p.e. circle	1	4	5	4	7	2	4	27
No. outside[a] p.e. circle	7	4	3	4	1	6	4	29

[a]The expected number throughout is 4.

Here P (χ^2) = 0.08, indicating no statistically significant departure from homogeneity of results for the seven individuals.

Remarks on Deviations of mpi from Aiming Point

In connection with Fig. A36, it is reasonable to expect some systematic vertical deviations in mpi with range; because of this, tests of the vertical deviation of the mpi from an aiming point were not made. However, deviations of the mpi to the right or left (x coordinate) from the vertical line through the center of the target were tested to determine whether they were large enough to be statistically significant. The results are shown in Tables A4, A5, A6, and A7 in which P ($\bar{x}$) indicates the probability of obtaining (in further samples under similar circumstances) deviations of the mpi as great or greater than those actually observed. It is evident in Tables A4 and A5 that, in most cases, the deviations are not statistically significant. For Test 2 as shown in Tables A6 and A7 several small values of P were obtained. This indicates that many of the deviations are statistically significant, particularly since Table A2 and Fig. A37 show that all the mpi, in Test 2, deviated to the right ($\bar{x}$, positive). It should be mentioned, however, that if the mpi for some of the individual riflemen deviate significantly from the mpi averaged for all, then the deviations of single shots from the latter mpi are not statistically independent. Taking account of this would increase the values of P ($\bar{x}$) in the Tables. In any case, the deviations of the mpi ($\bar{x}$ in Tables A4 and A5) in Test 1 were not, in general, significant so that subsequent calculations will apply reasonably well to conditions of Test 1.

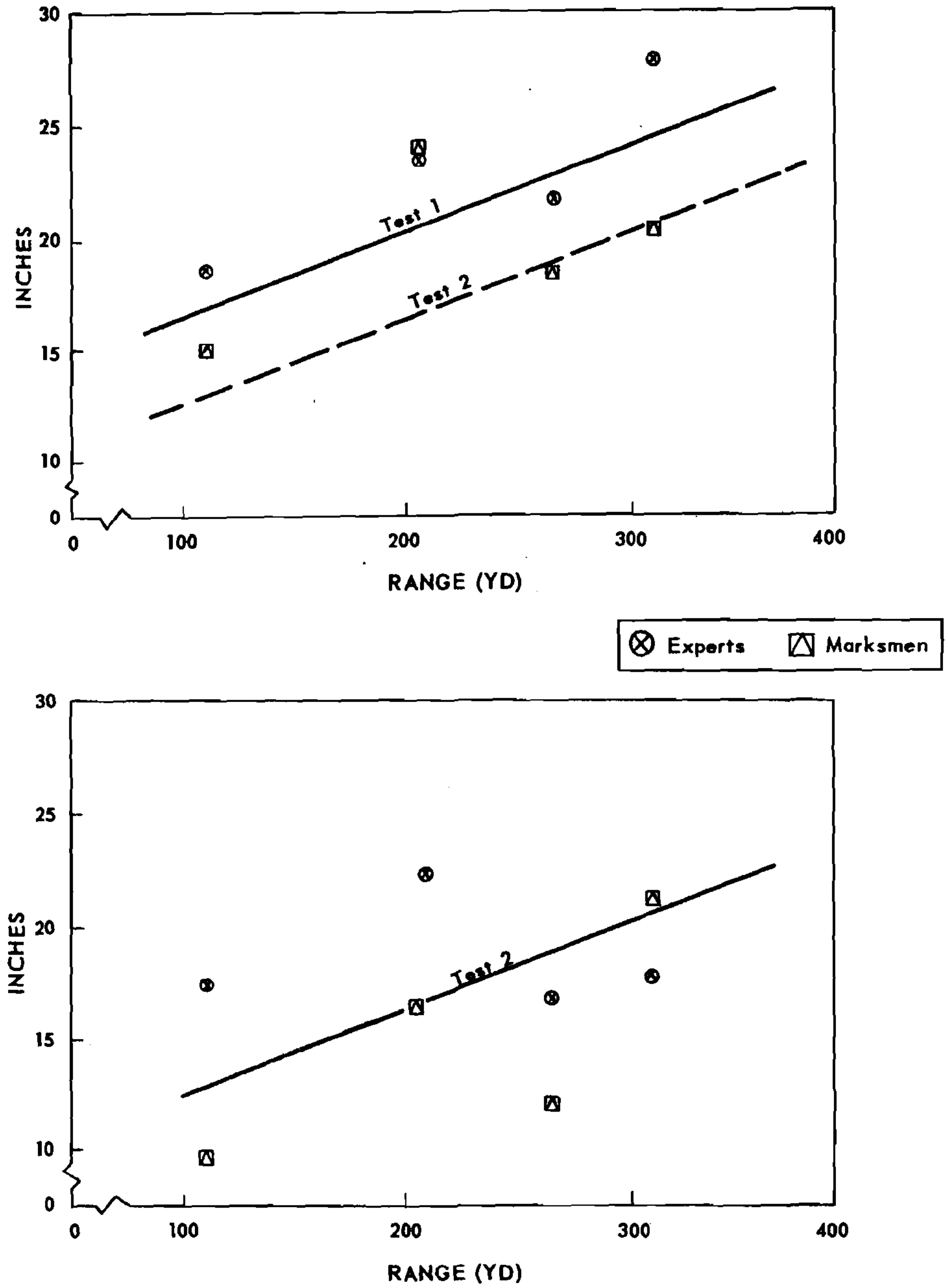
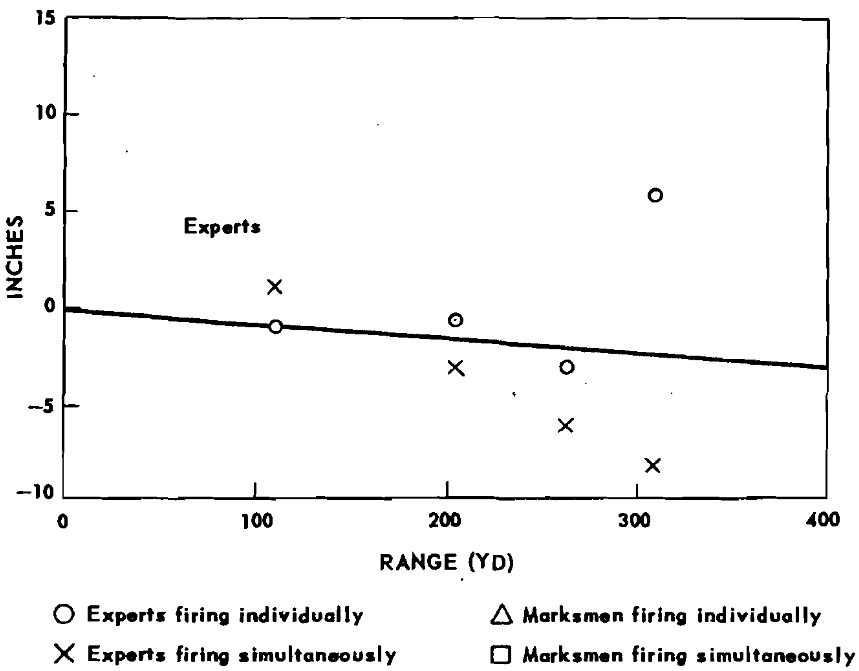


Fig. A36—Distance of mpi from top of target as function of range; combined individual and simultaneous firings of experts and marksmen; Tests 1 and 2.



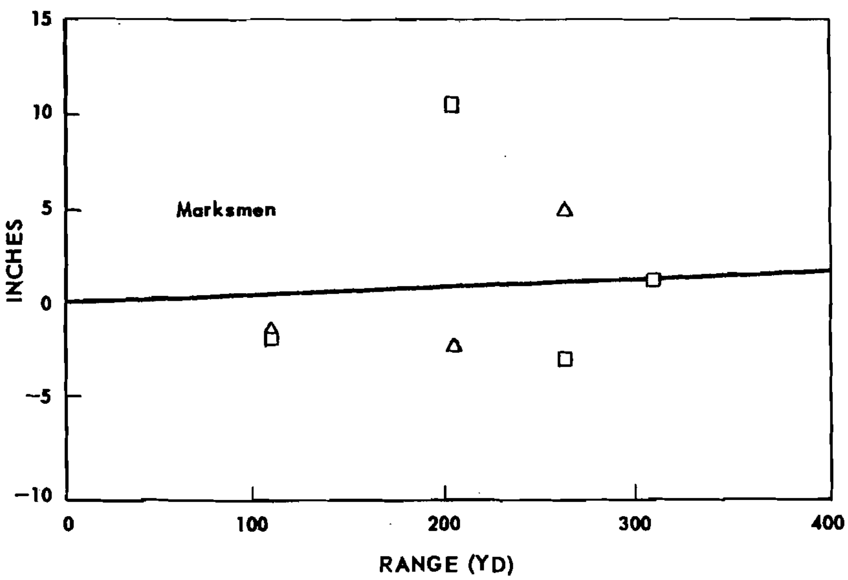


Fig. A37—Distance of mpi from vertical line through target center as function of range; marksmen and experts firing individually and simultaneously, Test 1.

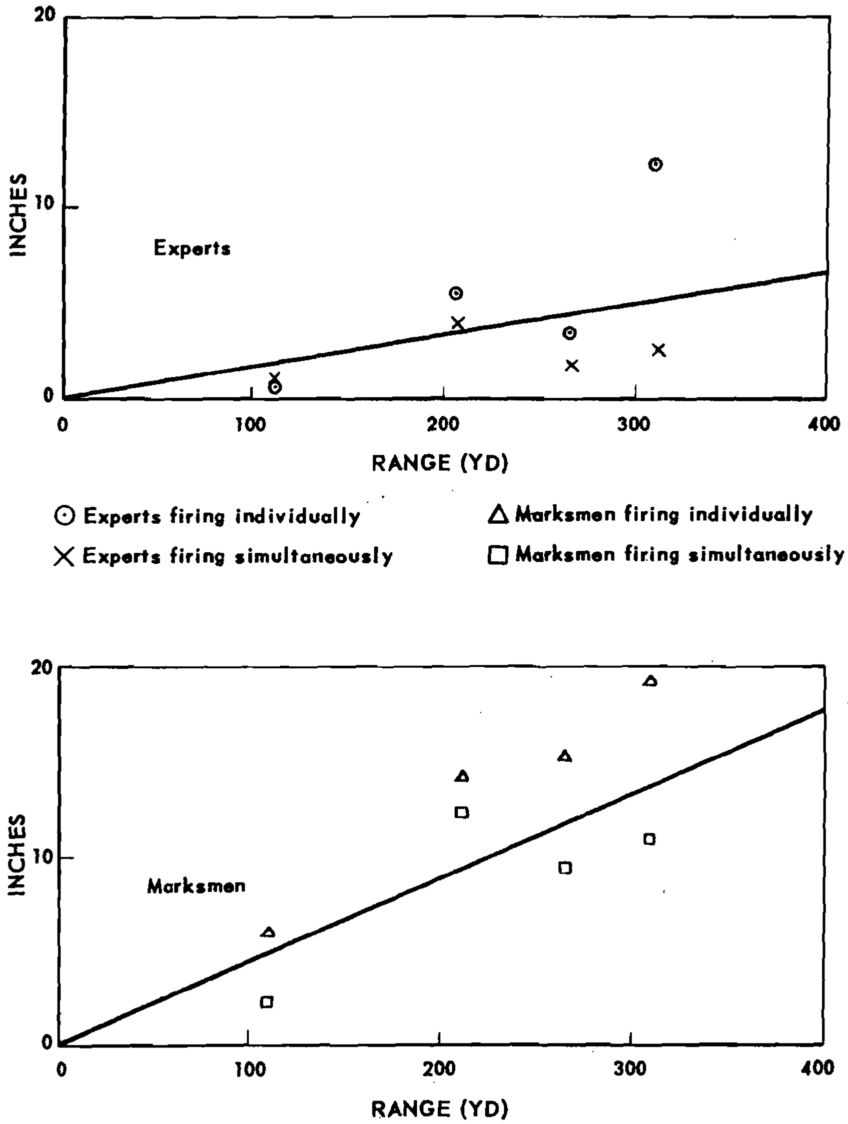
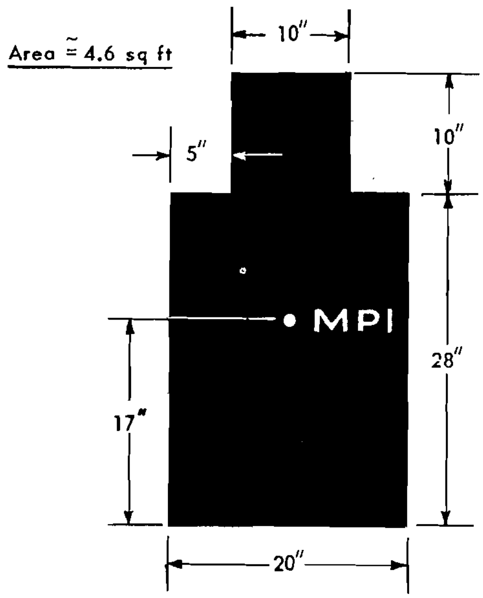


Fig. A38—Distance of mpi from vertical line through target center as function of range; marksmen and experts firing individually and simultaneously, Test 2.

Comparison of Observed and Theoretical
Probabilities of Hitting Target at Various Ranges

Figures A39 and A40 compare the observed and theoretical probabilities of hitting the target at different ranges under the several conditions involved in Tests 1 and 2. The observed probabilities are, of course, just the percentage hits on the target, from Fig. A1 to A32. The theoretical probabilities, shown by the curves of Figs. A39 and A40 were computed on the basis of the following model: (a) The target was assumed to have the shape and dimensions shown in the accompanying sketch:



The location of the assumed mpi for all ranges is shown; it is on the vertical center line through the target. (b) The standard deviation of radial deviations, for any particular range, was assumed to be that given by the lines (or equations) in Figs. A34 and A35.

Tests show that the deviations of some of the "observed points" from the curves, in Figs. A39 and A40, are statistically significant. These deviations are generally below the curve. In Fig. A40, for example, all the crosses in the upper figure fall below the curve. Examination of Table A2 indicates that the mpi (the $\bar{x}$'s in the Table) were all to the right of the vertical center line through the target; moreover, the small values of P ($\bar{x}$) in Table A7 indicate that these deviations of the

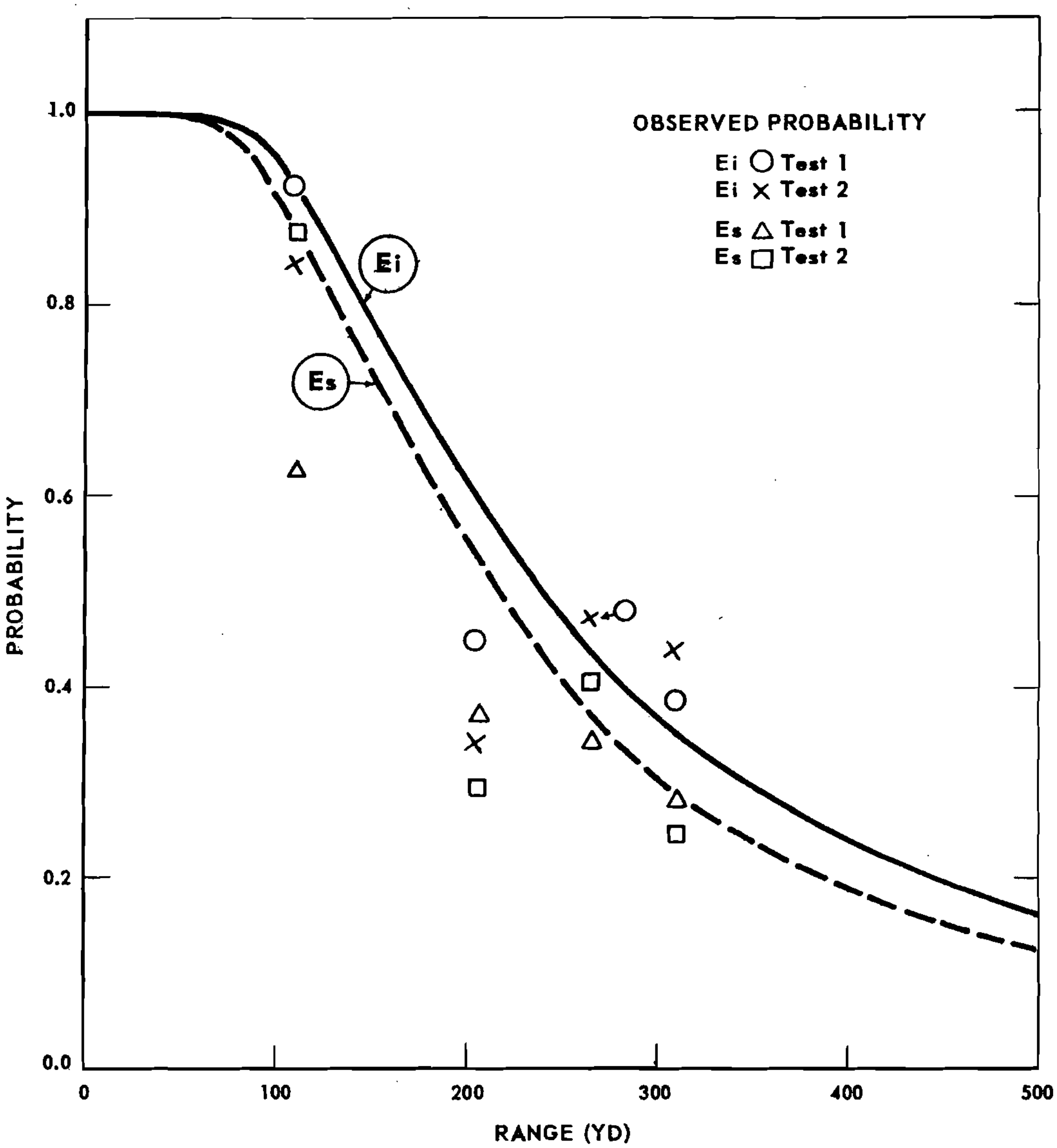


Fig. A39—Probability of expert riflemen hitting Type E silhouette of range. Ei: firing individually; Es: firing simultaneously.

Unclassified

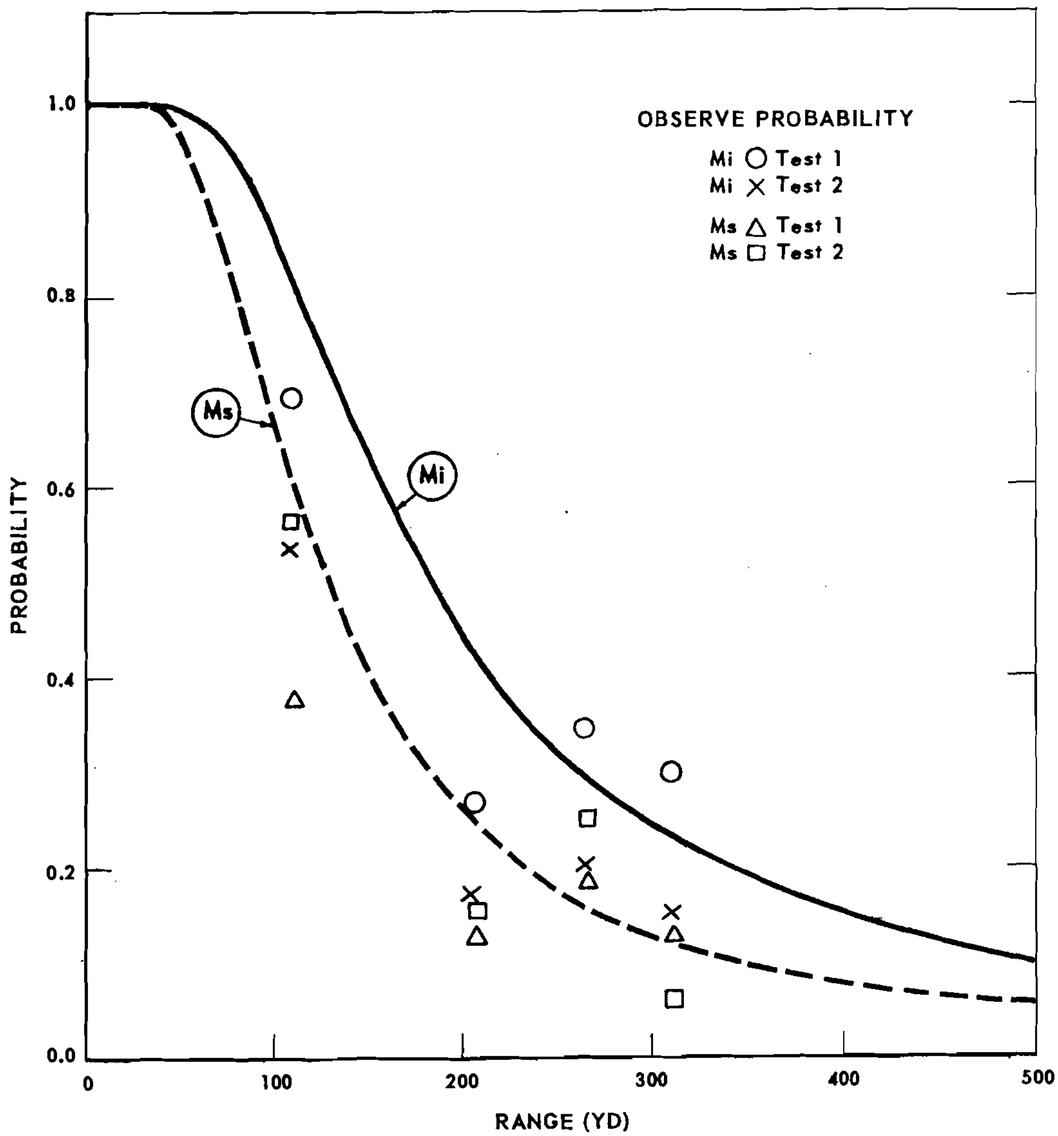


Fig. A40—Probability of marksmen hitting Type E silhouette target as a function of range. Mi: firing individually; Ms: firing simultaneously.

mpi from the center line were statistically significant. Nevertheless, the curves give a fair approximation to observed results, at least for Test 1. In fact, the differences between the theoretical probabilities of hit and those observed in Test 1 are, in general, comparable with the differences between the observed probabilities in Test 1 and those observed in Test 2. At the range of 205 yd, all the observed points fall below the curves. In Figs. A34 and A35 it may also be seen that the observed standard deviations obtained for range 205 yd, appear to be consistently high. Observers at the firing range indicated that the target appeared to be as far away as that at 265 yd. This may have been an illusion due to some bushes close to the line of sight. If sufficient data were available to determine from a large number of samples the nature of the distribution of mpi, this could be used in the determination of theoretical probabilities. In any case, the theoretical curves and the hypotheses on which they were derived provide a convenient and sufficiently good basis on which to compare probabilities of hitting targets with a single-shot weapon and a hypothetical one which fires several shots simultaneously in a pattern.

Remarks on Results of Firing on Targets Appearing Randomly at Either of Two Ranges

Table A3 indicates the results obtained when the target (type E silhouettes) appeared randomly, and for 1 sec., at either of two ranges (110 yd or 265 yd) as described in the introduction. Due to the small number of rounds fired and especially to the very small number of hits on the target, inspection of Table A3 indicates that for any particular range the differences between the percentage hits on the target are not statistically significant for experts firing individually (E_i) compared to experts firing simultaneously. For Test 3 the same conclusion obtains for marksmen. Thus, from Table A3 the results E_i and E_s were combined for each of the two ranges; results for M_i and M_s were similarly combined. When the combined results for experts in Test3 at range 110 yd were compared with the results of experts firing simultaneously from Tests 1 and 2, at 110 yd, the percentage hits on the target were definitely less in Test 3, and the difference was found to be statistically significant. Similarly, the combined results for experts in Test 3 at 265 yd indicated a significantly lower percentage hits than that obtained from the combined results, in Tests 1 and 2, of experts firing simultaneously at range 265 yd. That is, as would be anticipated, the accuracy of expert riflemen for the same range was much less under the conditions of Test 3 than under the conditions of Tests 1 and 2. For the marksmen, the results from Test 3 were not statistically different from those of Tests 1 and 2 at the same ranges.

APPLICATION

Theoretical Probability of Hitting Type E Silhouette Target With a Salvo Pattern

In the same way that the results of the present analysis were used to compute the curves of Figs. A39 and A40, they may also be used to obtain the variation, with range, of the probability of hitting the target with a salvo pattern. In Fig. A41, the curves $M_s(1)$ and $E_i(1)$ are respectively the curves M_s of Fig. A40, and E_i of Fig. A39. The curves $M_s(1)$ and $E_i(1)$ were obtained for the target, sketched previously, in the following way: The right half of the target can be considered made up of two rectangles: one 5 in. x 38 in., and the other 5 in. x 28 in.; with A as mean, the independent probabilities of x and y falling inside each of the rectangles are readily found from tables of the probability integral since the standard deviations of x and y are known for any range; for each rectangle the product of the two probabilities gives, of course, the probability of both x and y being in the rectangle; summing over both rectangles and multiplying by 2 gives the probability of hitting the target.

In Fig. A41, the curves $E_i(2)$ and $M_s(2)$ were computed for the five-shot pattern drawn as it would hit a screen at 300 yd range. It was assumed that there was no statistical dispersion in the position (at the target) of any one of the individual missiles relative to the others. It was also assumed that the "spread" of the pattern was proportional to range. The dispersion of the center missile (the others in the pattern remain fixed relative to the center missile) at the target was assumed to be the same as that used in computing the curves $E_i(1)$ and $M_s(1)$, i.e., that derived from the analysis of the aiming errors obtained in the tests. For each range a "virtual target" was drawn such that if the aimed round of the pattern (i.e., the central one) fell inside the boundary of the virtual target then at least one missile hit the target. Except for the fact that the "virtual target" was somewhat more complex in shape, the procedure used to obtain

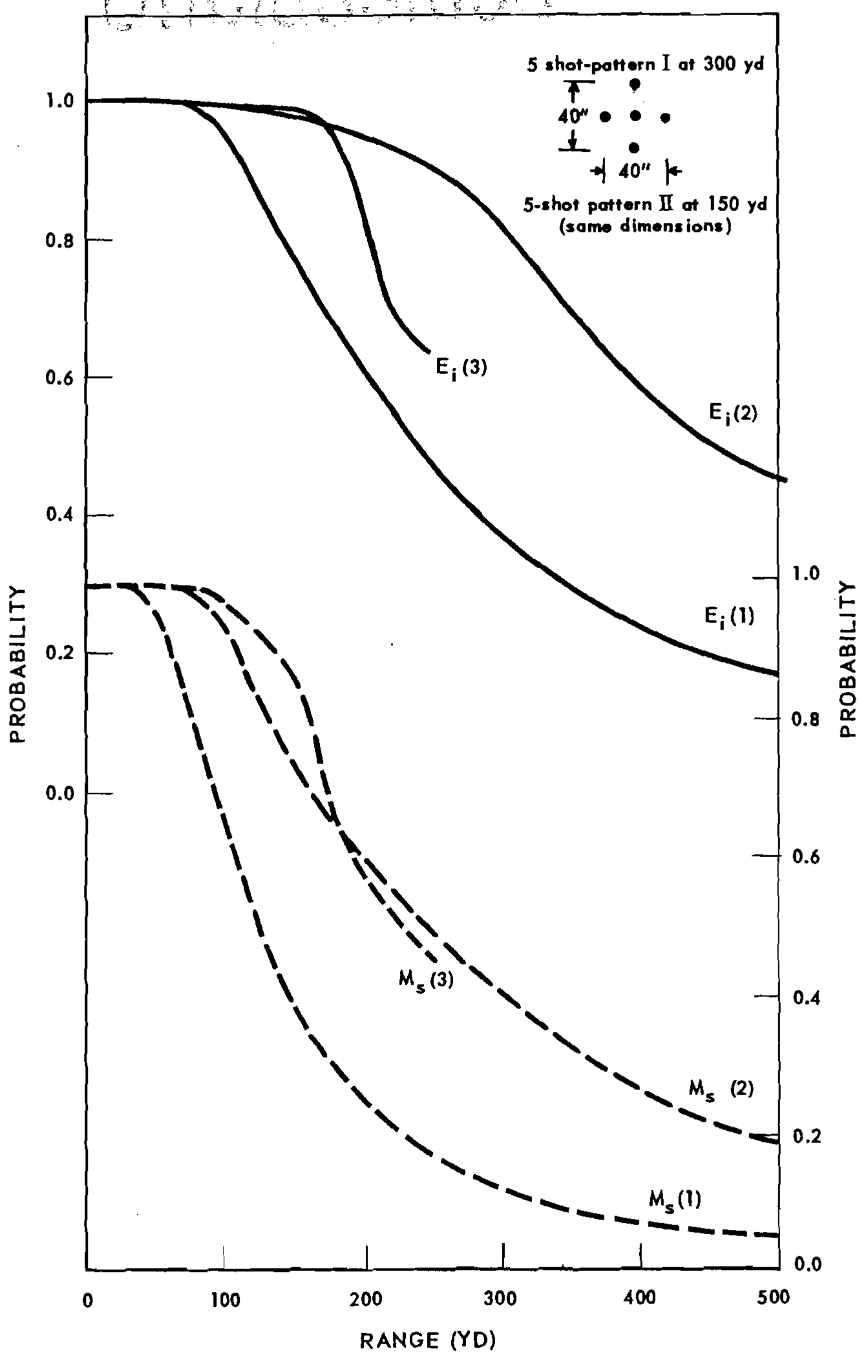


Fig. A41—Probability of hitting E type silhouette target with single shot compared with probability of at least one hit with a five-shot pattern salvo; curves based on aiming errors. E_i: experts firing individually; M_s: marksmen firing simultaneously; (1) with single shot; (2) at least one hit with five-shot pattern I; (3) at least one hit with five-shot pattern II.

the probability of obtaining at least one hit was the same as that described above for single shots (i.e., no pattern).

The curves $E_i(3)$ and $M_s(3)$ were similarly computed for the same shape of salvo pattern, but for a pattern with half the spread (at any given distance) as that used for $E_i(2)$ and $M_s(2)$. From Fig. A41 it is evident that, of the two shot patterns, the one with the greater spread has the over-all advantage over ranges up to 300 yd. Incidentally, the probability of at least one hit, on type E silhouette, indicated by curves $E_i(2)$ and $M_s(2)$, Fig. A41, for ranges up to 225 yd applies also to the four-shot pattern resulting from removal of the center shot from pattern I. Curves $E_i(3)$ and $M_s(3)$ apply also to the four-shot pattern resulting from the removal of the central bullet of pattern II.

Probabilities for 1, 2, 3, 4, and 5 Hits on Man-Size Target With Five-Shot Pattern Salvo

The probabilities of 1, 2, 3, 4, and 5 bullets hitting a target are given in Tables A8 and A9 for marksmen and for experts individually firing a five-shot pattern salvo. The target, type E silhouette, is that sketched previously. The shot pattern used in the calculations is pattern I as sketched in Fig. A41. It should be noted that, in the case of multiple hits, the individual hits are not located at random relative to each other. This follows from the assumptions stated previously to the effect that on arrival at the target the relative positions of all missiles in the pattern are fixed, with the dimensions of the pattern proportional to range.

Comparison of Theoretical Probabilities of Hitting "Average Target" with Single-Shot and Five-Shot Pattern Salvo

At the eye of a rifleman, the solid angle subtended by the average human target in combat is less than that subtended by the type E silhouette.[1] For the approximation to the average target a rectangle (for convenience in calculation) 20 in. x 12 in. was chosen and designated target A (see Fig. A42). The probability of hitting target A as a function of range was computed giving the results shown by the curves in Fig. A42. These curves indicate that the probability of at least one hit with the five-shot pattern salvo is decidedly greater, for the same range, than the probability of hitting with a single shot. If the central bullet is removed from

[1]ORO-R-5

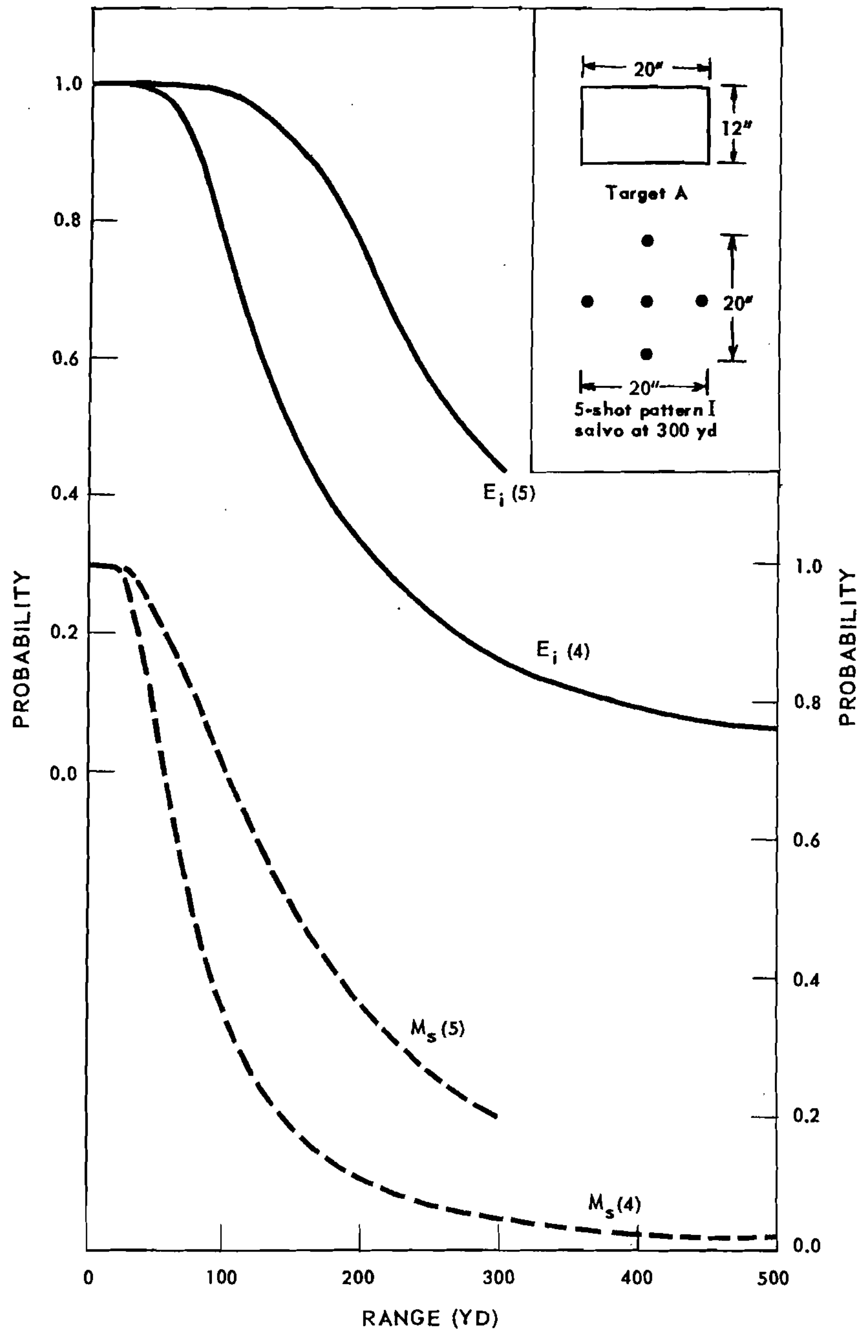


Fig. A42—Probability of hitting "average" target, A, (sketched in box) with single shot compared with probability of at least one hit on target with five-shot pattern salvos. E_i: experts firing individually; M_s: marksmen firing simultaneously; (4) with single shot; (5) at least one hit on target with five-shot pattern I.

the five-shot pattern the probability of at least one hit on target A is unaffected at ranges less than 150 yd.

Remarks on Significance of Probabilities of Hitting a Target with a Single-Shot and with Five-Shot, Four-Shot Pattern Salvos

Although the probability of at least one hit on the target is, at the same range, greater for one five-shot pattern salvo than for a single shot, it is less then the probability of at least one hit on the target for five separately aimed single shots. Consider, for example, the comparison at 200 yd range for the upper curves in Fig. A42. For the five-shot pattern, curve $E_i(5)$ indicates at 200 yd a probability of about 0.74 for at least one hit. For one single shot, curve $E_i(4)$ indicates about 0.32 for the hit probability. The probability of at least one hit in five single-shot trials is then: $(1 - 0.68^5) \doteq 0.85$ which is somewhat greater than the probability of 0.74 for at least one hit for the five-shot pattern.

Consider also the case for range 150 yd for target A. The curve $E_i(4)$ of Fig. A42 shows for range 150 yd a probability of 0.49 for hitting target A. Curve $E_i(5)$ indicates 0.90 for the probability of at least one hit using the five-shot pattern. As indicated in the preceding section, the probability of at least one hit for the four-shot pattern (central one of the five-shot pattern removed) is, for ranges less than 150 yd, the same as for the five-shot pattern. Thus, the probability of at least one hit, in this case, from five single shots is $(1 - 0.51^5) = 0.97$ which is slightly greater than that for at least one hit from a single five-shot pattern salvo. However, if we use a four-shot pattern we find $(1 - 0.51^4) = 0.93$ for the probability of at least one hit from four single shots compared to 0.90 for the probability of at least one hit from the four-shot pattern. Thus, for targets which may remain in the rifleman's view only long enough for him to aim once, the advantages of the five-shot pattern salvo are evident.

Effect of Weapon Dispersion on Probability of Hitting Target

In order to determine the effect of weapon dispersion (the dispersion at the target when the rifle is rigidly fixed) on the probability of hitting the target, it is necessary to determine the standard deviation due only to aiming. From the firing test data the total standard deviation, σ_r, at the target was found to be proportional to the range, that is

$$\sigma_r = cr \text{ in.} \qquad (1)$$

with r the range in units of 100 yd.

Let σ_w represent the standard deviation due to weapon dispersion (i. e., standard deviation of shot distances from mpi). Now the standard deviation at the target, due only to weapon dispersion, will also be proportional to the range r, then:

$$\sigma_w = \alpha r \text{ in.} \qquad (2)$$

Also the standard deviation, σ_A, due to aiming errors only (i.e., no weapon-ammunition dispersion) will be proportional to the range, thus:

$$\sigma_A = Ar \text{ in.} \qquad (3)$$

Since deviations from the mpi due to aiming errors and to weapon-ammunition errors are independent, than at a particular range:

$$\sigma_r^2 = \sigma_A^2 + \sigma_w^2 \qquad (4)$$

or for any range r:

$$c^2 r^2 = A^2 r^2 + \alpha k^2 r^2 \qquad (5)$$

Tests on the M-1 rifle indicate that $\alpha = 2.3$ in.; that is, the standard deviation of shot distances from the mpi, for a rigidly held rifle, is 2.3 in. at 100 yd. (i.e., r = 1), including dispersion due to ammunition. This determines A in Equation 5 when c is known. From Table A5 the value of c is 9.0 in. for marksmen firing individually. For this case, and using $\alpha = 2.3$ in., Equation 5 determines A = 76. Thus for other weapon dispersions, k x 2.3, the variance σ_r^2 of the combined errors due to weapon-ammunition and aiming is given by:

$$\sigma_r^2 = r^2 (76 + 5k^2) \qquad (6)$$

Consider target A which, as previously described, is a rectangle 20 in. x 12 in. The probability of hitting this target (mpi at center) is, to a degree of approximation sufficient for present purposes, the probability of hitting a circular target with the same area. Thus, for convenience in estimating the effect of weapon dispersion on probability of hitting, consider the circular target with radius a such that $\pi a^2 = 240$ in.², (12 in. x 20 in.) from which $a^2 = 76.5$ (a = 8.75 in.). For the mpi at the center of the circle, the probability, P_m, of missing the target (i. e., of shots falling outside the circle of radius a) is:

$$P_m = e^{-a^2/\sigma_r^2} = e^{-76.5/r^2(76 + 5k^2)} \qquad (7)$$

for marksmen firing individually. The three lines designated M_i in Fig. A43 are the curves of Equation (7) for each of three values

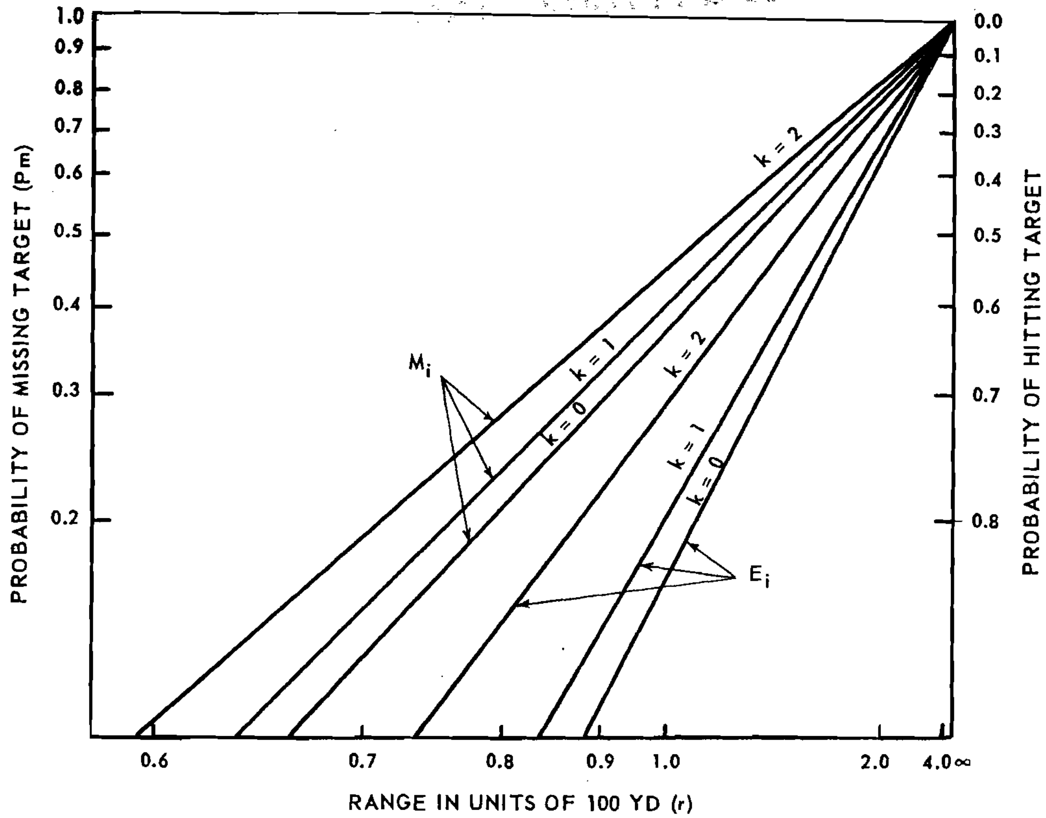


Fig. A43—Probability of hitting a circular target of area = 240 sq in. (radius = 8.75 in.) as a function of range for several weapon-ammunition errors. Plotted for marksmen firing individually, M_i; and experts firing individually, E_i. k is a selected multiple of the standard deviation of the strike from the mpi, as caused by weapon and ammunition alone. Thus k = 1 represents actual performance with issue rifle and ammunition, k = 0 shows performance with perfect weapons and ammunition, and k = 2 indicates performance with weapons and ammunitions giving double the actual standard deviation.

of k. From these curves (M_i) it will be seen that the probability of hitting for K = 0 (i.e., no weapon-ammunition dispersion) is only slightly less than k = 1 (i.e., for the actual dispersion of the M-1 rifle and ammunition). Also, the curves for k = 2 indicate probabilities of hitting which are still not significantly less than those for a dispersionless rifle and ammunition (k = 0). The four lower curves (E_i) in Fig. A43 apply to experts firing individually, for which the equation is:

$$P_m = e^{-a^2/\sigma_r^2} = e^{-76.5/r^2 (42.5 + 5k^2)} \quad (8)$$

Equation 8 is obtained in the same manner as Equation 7 starting with the value of 6.9 in. for c, obtained from Table A4 for experts firing individually.

TABLE A1

RIFLE RANGE TEST 1

Men	Range, yd	$\bar{x}$, in.	$\bar{y}$, in.	Std. Deviation, in.			No. Men Firing	Rounds per man	Total Rounds	No. Rounds	
				x	y	r				Target	Screen
E_i [a]	110	− 0.9	13.5	4.1	5.2	6.4	12	8	96	88	96
	205	− 0.5	16.0	13.5	15.0	20.2	10	8	80	36	69
	265	− 3.0	19.5	13.0	13.0	18.4	9	8	72	34	62
	310	+ 6.0	7.0	12.6	17.8	21.8	9	8	72	28	47
E_s [b]	110	+ 1.2	8.7	4.1	11.2	11.9	8	4	32	20	24
	205	− 2.8	15.6	11.0	12.8	16.9	8	4	32	12	26
	265	− 5.9	11.0	8.4	17.2	19.1	8	4	32	11	21
	310	− 8.2	10.0	15.0	18.3	23.7	8	4	32	9	19
M_i [c]	110	− 1.7	16.4	8.7	6.4	10.8	7	8	56	39	56
	205	− 2.0	15.2	13.0	14.5	19.5	9	8	72	19	58
	265	+ 4.8	18.3	17.2	14.0	22.2	9	8	72	25	65
	310	− 1.0	14.8	24.0	12.2	26.9	10	8	80	24	61
M_s [d]	110	− 1.8	14.2	14.2	9.0	16.8	8	4	32	12	30
	205	+ 10.5	11.8	23.0	20.2	30.6	8	4	32	4	19
	265	− 2.5	31.5	25.1	13.9	28.7	8	4	32	6	32
	310	+ 1.0	17.2	36.0	15.8	39.3	8	4	32	4	25

[a] E_i - Expert Riflemen Individually Firing at Target.
[b] E_s - Expert Riflemen Simultaneously Firing at Target.
[c] M_i - Marksmen Individually Firing at Targ
[d] M_s - Marksmen Simultaneously Firing at T

TABLE A2

RIFLE RANGE TEST 2

Men	Range, yd	$\bar{x}$, in.	$\bar{y}$, in.	Std. Deviation, in.			No. Men Firing	Rounds per man	Total Rounds	No. Rounds	
				x	y	r				Target	Screen
E_i[a]	110	+ 0.6	15.4	5.2	6.9	8.6	12	8	96	81	91
	205	+ 5.7	18.0	14.8	14.5	20.7	8	8	64	22	45
	265	+ 3.4	14.1	9.4	13.1	16.1	8	8	64	30	56
	310	+ 12.5	23.5	13.5	13.1	18.8	10	8	80	35	77
E_s[b]	110	+ 0.8	20.5	2.8	9.3	9.7	8	4	32	28	28
	205	+ 3.9	23.0	17.1	14.3	22.3	16	4	64	19	58
	265	+ 1.7	17.0	10.1	12.8	16.3	8	4	32	13	28
	310	+ 2.5	13.9	21.5	14.1	25.7	8	4	32	8	25
M_i[c]	110	+ 5.8	23.4	6.8	7.1	9.8	8	8	64	34	64
	205	+ 14.1	26.6	23.1	17.9	29.2	9	8	72	12	59
	265	+ 15.2	20.2	19.5	11.4	22.6	12	8	96	19	88
	310	+ 19.1	17.0	24.1	23.3	33.5	10	8	80	12	61
M_s[d]	110	+ 2.2	26.7	10.5	8.1	13.3	8	4	32	18	29
	205	+ 12.1	24.5	18.5	18.0	25.8	16	4	65[e]	10	49
	265	+ 9.2	14.4	12.7	20.1	23.8	8	4	32	8	24
	310	+ 10.8	21.3	17.2	23.7	29.3	8	4	32	2	26

[a] E_i - Expert Riflemen Individually Firing at Target.
[b] E_s - Expert Riflemen Simultaneously Firing at Target.
[c] M_i - Marksmen Individually Firing at Target.
[d] M_s - Marksmen Simultaneously Firing at Targ
[e] One Man Fired Five Rounds.

TABLE A3

RIFLE RANGE TEST 3
FIRING AT TARGETS NO. 1 AND NO. 3 ALTERNATELY ON RANDOM SCHEDULE

Men	Range, yd	$\bar{x}$, in.	$\bar{y}$, in.	Std. Deviation, in.			No. Men Firing	Rounds per man	Total Rounds	Number Roun…	
				x	y	r				Not Expend.	On Target
E_i[a]	110	- 4.4	16.8	20.2	21.4	29.4	4	4	15	1	4
	265	0.0	23.0	20.0	15.9	25.6	4	4	16	0	1
E_s[b]	110	+ 4.0	7.9	18.0	11.3	21.3	4	4	11	5	2
	265	+ 4.0	- 8.0	21.0	24.8	32.5	4	4	16	0	0
M_i[c]	110	- 1.8	16.7	13.4	8.7	16.0	4	4	14	2	7
	265	- 1.4	6.9	41.1	23.5	47.3	4	4	15	1	1
M_s[d]	110	- 10.8	13.0	11.6	15.4	19.3	4	4	13	3	4
	265	- 2.7	- 7.0	15.4	19.5	24.8	4	4	16	0	3

[a] E_i - Expert Riflemen Individually Firing at Target.
[b] E_s - Expert Riflemen Simultaneously Firing at Target.
[c] M_i - Marksmen Individually Firing at Target.
[d] M_s - Marksmen Simultaneously Firing at Targ…

TABLE A4

COMPARISON OF OBSERVED NUMBER OF SHOTS INSIDE ZONES BOUNDED BY CIRCLES OF RADII r_1, AND r_2, IN., WITH NUMBER EXPECTED FROM BIVARIATE DISTRIBUTION WITH RADIAL STANDARD DEVIATION σ_r; AT FOUR RANGES, R, IN YD: TEST 1

(A) Experts Individually σ_r = 6.9 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 4.87 R/100, in.)

R (yd)	110				205				265				310			
σ_r	7.6				14.1				18.3				21.4			
	Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
	0	4.1	25	24	0	7.6	15	20	0	9.8	23	18	0	11.5	20[d]	16[d]
	4.1	6.3	28	24	7.6	11.7	14	20	9.8	15.2	19	18	11.5	17.8	12[d]	12[d]
	6.3	9.0	23	24	11.7	16.6	18	20	15.2	21.6	12	18	17.8	25.2	8[d]	11[d]
	9.0	∞	20	24	16.6	∞	33	20	21.6	∞	18	18	(25.2	B)[b]	7[d]	11[d]
On Screen			96				69				62				47	50
Off Screen			0				11[a]				10[a]				25[c]	22[c]
Total			96	96			80	80			72	72			72	72
$P(\chi^2)$			0.75				0.01				0.25				0.5	
$P(\bar{x})$			0.10				0.66				0.05				10^{-4}	

(B) Experts Simultaneously σ_r = 7.8 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 5.51 R/100, in.)

R (yd)	110				205				265				310			
σ_r	8.6				16.0				20.7				24.2			
	Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
	0	4.6	9	8	0	8.6	8	8	0	11.1	7	8	0	13.0	5[d]	8[d]
	4.6	7.1	5	8	8.6	13.3	7	8	11.1	17.2	7[d]	6[d]	13.0	20.1	7[d]	6[d]
	7.1	10.1	4	8	13.3	18.9	5	8	17.2	24.4	5[d]	5[d]	20.1	28.5	3[d]	5[d]
	10.1	∞	14	8	18.9	∞	12	8	(24.4	B)[b]	2[d]	5[d]	(28.5	B)[b]	4[d]	5[d]
On Screen			24				26				21	24			19	24
Off Screen			8[a]				6[a]				11[c]	7[c]			13[c]	8[c]
Total			32	32			32	32			32	32			32	32
$P(\chi^2)$			0.05				0.75				0.4				0.25	
$P(\bar{x})$			0.27				0.17				0.02				0.01	

[a]Off screen in outermost zone.
[b]Outside r_1 but on screen.
[c]Off screen; zone unknown.
[d]Within zone and on screen.
$P(\chi^2)$ probability of obtaining as bad or worse fit between observed and expected numbers.
$P(\bar{x})$ probability of obtaining mpi as far or farther from vertical center line of target.

TABLE A5

COMPARISON OF OBSERVED NUMBER OF SHOTS INSIDE ZONES BOUNDED BY CIRCLES OF RADII r_1, AND r_2, IN., WITH NUMBER EXPECTED FROM BIVARIATE DISTRIBUTION WITH RADIAL STANDARD DEVIATION σ_r; AT FOUR RANGES, R, IN YD: TEST 1

(A) Marksmen Individually σ_r = 9.0 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 6.36 R/100, in.)

R (yd)	110			205				265				310			
σ_r	9.9			18.4				23.9				27.9			
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	5.3	18	14	0	9.9	11	18	0	12.8	15	18	0	15.0	22	20
5.3	8.2	10	14	9.9	15.4	10	18	12.8	19.9	18[d]	18[d]	15.0	23.2	14[d]	16[d]
8.2	11.7	11	14	15.4	21.8	13[d]	15[d]	19.9	28.0	20[d]	14[d]	23.2	32.9	15[d]	16[d]
11.7	∞	17	14	(21.8	B)[b]	24[d]	13[d]	(28.0	B)[b]	12[d]	12[d]	(32.9	B)[b]	10[d]	12[d]
On Screen		56				58	64			65	62			61	64
Off Screen		0				14[a]	8[a]			7[a]	10[a]			19[a]	16[a]
Total		56	56			72	72			72	72			80	80
$P(\chi^2)$		0.25				10^{-5}				0.3				0.9	
$P(\bar{x})$		0.07				0.07				0.02				0.7	

(B) Marksmen Simultaneously σ_r = 13.0 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 9.2 R/100, in.)

R (yd)	110			205				265				310			
σ_r	14.3			26.6				34.5				40.3			
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	7.7	5	8	0	14.3	4[d]	8[d]	0	18.4	11	8	0	21.6	11[d]	8[d]
7.7	11.9	7	8	14.3	22.2	2[d]	6[d]	18.4	28.7	13[d]	8[d]	21.6	33.6	4[d]	6[d]
11.9	16.9	9[d]	8[d]	22.2	31.4	8[d]	5[d]	28.7	40.6	3[d]	5[d]	33.6	47.5	4[d]	4[d]
(16.9	B)[b]	9[d]	6[d]	(31.4	B)[b]	5[d]	4[d]	(40.6	B)[b]	5[d]	3[d]	(47.5	B)[b]	6[d]	2[d]
On Screen		30	30			19	23			32	24			25	20
Off Screen		2[a]	2[a]			13[a]	9[a]			0[a]	8[a]			7[a]	12[a]
Total		32				32	32			32	32			32	32
$P(\chi^2)$		0.5				0.1				0.01				0.2	
$P(\bar{x})$		0.3				2×10^{-5}				0.6				0.8	

[a] Off screen, zone unknown.
[b] Outside r_1 but on screen.
[d] Within zone and on screen.
$P(\chi^2)$ probability of obtaining as bad or worse fit between observed and expected numbers.
$P(\bar{x})$ probability of obtaining mpi as far or farther from vertical center line of target.

TABLE A6

COMPARISON OF OBSERVED NUMBER OF SHOTS INSIDE ZONES BOUNDED BY CIRCLES OF RADII r_1, AND r_2, IN., WITH NUMBER EXPECTED FROM BIVARIATE DISTRIBUTION WITH RADIAL STANDARD DEVIATION σ_r AT FOUR RANGES, R, IN YD: TEST 2

(A) Experts Individually $\sigma_r = 6.9$ R/100 (σ_r in in.)
($\sigma_x = \sigma_y = 4.87$ R/100, in.)

R (yd)	110			205				265				310			
σ_r	7.6			14.1				18.3				21.4			
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	4.1	15	24	0	7.6	9	16	0	9.8	20	16	0	11.5	21	20
4.1	6.3	23	24	7.6	11.7	8	16	9.8	15.2	14	16	11.5	17.8	31	20
6.3	9.0	22	24	11.7	16.6	9	16	15.2	21.6	14[d]	13[d]	17.8	25.2	18	20
9.0	∞	36	24	16.6	∞	38	16	21.6	B)[c]	8[d]	11[d]	25.2	B)[c]	7[d]	16[d]
On Screen		91				45				56	56			77	76
Off Screen		5[a]				19[a]				8[b]	8[b]			3[b]	4[b]
Total		96	96			64	64			64	64			80	80
$P(\chi^2)$		0.02				<0.001				0.71				0.02	
$P(\bar{x})$		0.25				3×10^{-6}				0.04				2×10^{-9}	

(B) Experts Simultaneously $\sigma_r = 7.8$ R/100 (σ_r in in.)
($\sigma_x = \sigma_y = 5.51$ R/100, in.)

R (yd)	110			205				265				310			
σ_r	8.6			16.0				20.7				24.2			
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	4.6	6	8	0	8.6	6	16	0	11.1	10	8	0	13.0	8	8
4.6	7.1	8	8	8.6	13.3	10	16	11.1	17.2	9	8	13.0	20.1	2[d]	7[d]
7.1	10.1	11	8	13.3	18.9	15	16	17.2	24.2	8[d]	7[d]	20.1	28.5	7[d]	6[d]
10.1	∞	7	8	18.9	∞	33	16	24.4	B)[c]	1[d]	6[d]	28.5	B)[c]	8[d]	5[d]
On Screen		28				58				29	29			25	26
Off Screen		4[a]				6[a]				4[b]	3[b]			7[b]	6[b]
Total		32	32			64	64			32	32			32	32
$P(\chi^2)$		0.63				<0.001				0.26				0.23	
$P(\bar{x})$		0.49				0.01				0.52				0.42	

[a]Off screen in outermost zone.
[b]Off screen, zone unknown.
[c]Outside r_1 but on screen.
[d]Within zone and on screen.
$P(\chi^2)$ probability of obtaining as bad or worse fit between observed and expected numbers.
$P(\bar{x})$ probability of obtaining mpi as far or farther from vertical center line of target.

TABLE A7

COMPARISON OF OBSERVED NUMBER OF SHOTS INSIDE ZONES BOUNDED BY CIRCLES OF RADII r_1, AND r_2, IN., WITH NUMBER EXPECTED FROM BIVARIATE DISTRIBUTION WITH RADIAL STANDARD DEVIATION σ_r AT FOUR RANGES, R, IN YD: TEST 2

(A) Marksmen Individually σ_r = 9.0 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 6.36 R/100, in.)

R(yd)	110				205				265				310		
σ_r	9.9				18.4				23.9				27.9		
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	5.3	13	16	0	9.9	9	18	0	12.8	32	24	0	15.0	13	20
5.3	8.2	21	16	9.9	15.4	9	18	12.8	19.9	20	24	15.0	23.2	13[d]	18[d]
8.2	11.7	16	16	15.4	21.8	12	18	19.9	28.1	27[d]	20[d]	23.2	32.9	17[d]	14[d]
11.7	∞	14	16	21.8	∞	42	18	28.1	B)[c]	9[d]	17[d]	32.9	B)[c]	18[d]	13[d]
On Screen		64				59				88	85			61	65
Off Screen		0				13[a]				8[b]	11[b]			19[b]	15[b]
Total		64	64			72	72			96	96			80	80
$P(\chi^2)$		0.50				<0.001				0.04				0.12	
$P(\bar{x})$		$<2\times10^{-9}$				$<2\times10^{-9}$				$<2\times10^{-9}$				$<2\times10^{-9}$	

(B) Marksmen Simultaneously σ_r = 13.0 R/100 (σ_r in in.)
($\sigma_x = \sigma_y$ = 9.2 R/100, in.)

R(yd)	110				205				265				310		
σ_r	14.3				26.6				34.5				40.3		
Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone		Zone		No. in Zone	
r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd	r_1	r_2	Obsd	Exptd
0	7.7	13	8	0	14.3	16	16	0	18.5	13	8	0	21.6	13	8
7.7	11.9	9	8	14.3	22.2	10	16	18.5	28.7	8[d]	6[d]	21.6	33.6	8[d]	6[d]
11.9	16.9	3	8	22.2	31.4	13[d]	15[d]	28.7	40.6	3[d]	5[d]	33.6	47.5	3[d]	5[d]
16.9	∞	7	8	31.4	B)[c]	10[d]	12[d]	40.6	B)[c]	0[d]	5[d]	47.5	B)[c]	2[d]	5[d]
On Screen		29				49	59			24	24			26	24
Off Screen		3[a]				16[b]	6[b]			8[b]	8[b]			6[b]	8[b]
Total		32	32			65	65			32	32			32	32
$P(\chi^2)$		0.09				<0.001				0.05				0.15	
$P(\bar{x})$		0.23				$<2\times10^{-9}$				0.04				0.03	

[a]Off screen in outermost zone.
[b]Off screen, zone unknown.
[c]Outside r_1, but on screen.
[d]Within zone and on screen.
$P(\chi^2)$ probability of obtaining as bad or worse fit between observed and expected numbers.
$P(\bar{x})$ probability of obtaining mpi as far or farther from vertical center line of target.

TABLE A8

PROBABILITIES, FOR EXPERTS FIRING INDIVIDUALLY, OF OBTAINING EXACTLY 1, 2, 3, 4, AND 5 HITS ON TYPE E SILHOUETTE WITH FIVE-SHOT PATTERN SALVO FOR INDICATED TARGET RANGES

Range, yd	Exact No. of Hits					At least 1 hit
	1	2	3	4	5	
100	0.040	0.002	0.049	0.420	0.489	1.000
150	0.174	0.041	0.269	0.506	0.000	0.990
200	0.325	0.145	0.398	0.091	0.000	0.959
250	0.423	0.353	0.125	0.000	0.000	0.901
300	0.546	0.280	0.000	0.000	0.000	0.826
350	0.524	0.165	0.000	0.000	0.000	0.689
400	0.499	0.087	0.000	0.000	0.000	0.586

TABLE A9

PROBABILITIES, FOR MARKSMEN FIRING INDIVIDUALLY, OF OBTAINING EXACTLY 1, 2, 3, 4, AND 5 HITS ON TYPE E SILHOUETTE WITH FIVE-SHOT PATTERN SALVO FOR INDICATED TARGET RANGES

Range, yd	Exact No. of Hits					At least 1 hit
	1	2	3	4	5	
100	0.111	0.011	0.093	0.415	0.360	0.990
150	0.271	0.066	0.250	0.350	0.000	0.937
200	0.388	0.122	0.284	0.058	0.000	0.852
250	0.434	0.240	0.085	0.000	0.000	0.759
300	0.482	0.186	0.000	0.000	0.000	0.668
350	0.436	0.108	0.000	0.000	0.000	0.544
400	0.398	0.057	0.000	0.000	0.000	0.455