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TECHNICAL REPORT NO. 461

SYSTEM ERROR BUDGETS, TARGET DISTRIBUTIONS AND HITTING PERFORMANCE ESTIMATES FOR GENERAL-PURPOSE RIFLES AND SNIPER RIFLES OF 7.62 X 51 MM AND LARGER CALIBERS

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U. S. ARMY MATERIEL SYSTEMS ANALYSIS ACTIVITY
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TR 461 expands work with error budgets and hitting performance of GP rifles begun in TR 440; makes aiming error estimates for riflemen in two different peacetime situations; discusses lack of combat stress in peacetime experiments; contains P_H estimates for two U.S. and two Soviet GP rifles; discusses inconsistencies caused with contemporary use of term maximum effective range; discusses use of MBC and optical sights, commenting on absence of any U.S. dim light target acquisition test data; provides the original ORO and a longer-range target distribution and discusses importance of selection of target distribution to analysis of small arms effectiveness; discusses hit/terminal effects trade-off that is needed if small, multiple projectiles (including fragments and flechettes) are used to increase hitting.

TR 461 contains the first systematic analysis of error budget and hitting performance estimates for the SWS through 12.7mm caliber; contains a considerable body of original test

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data for 7.62 and 12.7mm SWS; makes first AMSAA estimates of intrinsic RRD of weapons and aiming errors for troop snipers of several different qualities; discusses range measurement by eye, stadia and range finders; discusses unique requirement for AN/PVS-6 (MELIOS) and other active (laser) range finders (LRF) to hit correct target before range measurement is possible; develops error budget for MELIOS and estimates probability of hitting correct target; uses danger space for two SWS cartridges/targets as a solution space for evaluating LRF; discusses contemporary use of term accuracy, asserting that inconsistencies in the use of the term frequently hide problems a system has hitting a target; discusses importance of removing bias components of error budget; commenting on the importance time of flight in this regard.

TR 461 concludes (a) for GP rifle systems and ACR, it is difficult, if not impossible, to simulate combat stress in a peacetime experiment. If effectiveness is measured by single-shot hitting, U.S. M16A1, M16A2, and Soviet AK-47 and AK-74 rifles (and all GP rifles of any caliber) have the same effective range. The Army and Marine Corps should review those tactical instructions given to small rifle units that are based on an effective range of 550 meters for the M16A2 rifle. Wind and range errors have no practical effect on hitting performance of GP rifles since biases are smaller than aiming errors and engagement ranges tend to be short. A MBC such as the one used on the Soviet AK-74 or the one designed by the U.S. NAVWPNSUPPCEN, Crane, IN will control the very-close range burst fire pattern of the M16A1 and M16A2 rifles. An optical sight should increase the rifleman's ability to acquire targets under dim light. Firing multiple projectiles with a single trigger pull may increase hitting, but may also reduce terminal effects performance; wounds from bullets are relatively more lethal or incapacitating than those from small fragments; the type of body armor (titanium vs kevlar) selected to represent the threat may influence outcome of ACR evaluation and (b) for SWS, existing definition of "accuracy" hides potential problems with hitting. Wind and range errors are matters of great importance in a SWS error budget. Existing sniper materiel do not provide a true first-round hit capability; in the absence of effective fire control, the sniper will have to fire "will adjust" rounds that may alert his target and disclose his position (particularly if he is using a 12.7mm caliber SASR with a high efficiency muzzle brake). The sniper's aiming error is expected to increase at some level of recoil. The quality of military snipers, like GP riflemen, varies widely. By and large, user tests of SWS tend to overstate the performance of the system. The M3 telescope, used with the M24 sniper rifle does not have the correct ballistic reticle for the M18 cartridge. The AN/PVS-6 (MELIOS) does not have the capability to measure range to the nearest five meters as had been claimed; MELIOS must hit the "correct" target before range measurement commences; a MELIOS with performance like that seen in OT I is not a suitable range measuring device for SWS and other "long range" applications where a high order of accuracy is required.

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The U. S. Army Materiel Systems Analysis Activity (AMSAA) recognizes Dr. Frank H. Grubbs as Senior Reviewer of this report and commends him for his thoughtful critique.

The author thanks Dr. Grubbs for providing the intellectual foundation for this report and all other work done by the author in AMSAA. The author in particular, and all analysts, "Riflemen and Missile Engineers" owe Dr. Grubbs much.

DEDICATION

This report is dedicated to GEN Lewis W. Walt, USMC Retired. GEN Walt, who died recently, was a Marine Rifleman of great courage and distinction who graciously and patiently shared his knowledge of Riflemen, rifles and musketry with the author on several occasions at AMSAA. **Semper Fidelis Sir.**

GEN Walt would have said that this report should be dedicated to the USMC Riflemen for whom MG Rupertus originally wrote his Creed--and to the Riflemen of the Army and Marine Corps today.

My Rifle

The Creed of a United States Marine

by

MG W. H. Rupertus, USMC[1]

This is my rifle. There are many like it,
but this one is mine. My Rifle is my best friend.
It is my life. I must master it as I must master
my life. My rifle, without me is useless. Without
my rifle, I am useless. I must shoot straighter
than my enemy who is trying to kill me. I must
shoot him before he shoots me. My rifle and
myself know that what counts in this war is not
the rounds we fire, the noise of our burst, nor
the smoke we make. We know that it is the hits
that count. We will hit . . .

1 An incomplete excerpt from the inside front cover of the U.S. Marine Corps Operator's Manual for the Rifle, 5.56mm, M16A2 W/E. TM05538C-10/1, June 1983.

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SYSTEM ERROR BUDGETS, TARGET DISTRIBUTIONS AND HITTING PERFORMANCE ESTIMATES FOR GENERAL-PURPOSE RIFLES AND SNIPER RIFLES OF 7.62 X 51MM AND LARGER CALIBERS

1. INTRODUCTION

1.1 Purpose.

To outline the elements of a simple error budget for general purpose (GP) and sniper rifle systems and describe possible target/range distributions for both; to estimate the hitting effectiveness of both systems when used by typical users.

To call attention to the fact that all organizations do not define the terms accuracy and dispersion alike; further, that the basic operational concept of maximum effective range is unevenly and, in greater part, incorrectly applied to GP and sniper rifles. To identify several areas where engineers might increase small arms hitting performance.

1.2 Background.

Several years ago the U. S. Army Laboratory Command, a subordinate organization of the U. S. Army Materiel Command (AMC), began a technical assessment of small arms. Each section of the assessment was written by a panel of experts from different AMC organizations. AMSAA served as a consultant to each of the panels. Generally, AMSAA's contribution was blended into a single team-written document.

In the case of the Fire Control Panel, AMSAA's contribution was placed in an appendix apart from the body of the main report. This technique was adopted to facilitate an independent view by AMSAA of the situation unencumbered by the need for concensus that is implicit in a team-written product. AMSAA's contribution to the Fire Control Panel Report (FCPR) is Appendix A (Analysis of the Problem by AMSAA).

TR 461 and Appendix A are different in two respects: Section 5.2.3, TR 461 and Section 5.2.3, Appendix A, have inconsequential differences. Appendix A was written before AMSAA learned that the Army had re-activated a 1985 program to place an optical sight on some M16A2 rifles, and for the first time ever, on its squad automatic weapons (SAWs). Section 2.4.1 of TR 461 contains a more thorough analysis of the 1985 Operational Test (OT I) of the AN/PVS-6 laser range finder (LRF) than had been possible given the FCPR deadline, so is in substantially greater depth than Appendix A. TR 461 treats the LRF (for the first time probably) as a device whose beam must strike the "correct target"--the actual target to which the LRF operator requires range--before accurate range measurement can begin. Estimates of the probability of ranging on the correct target, together with appropriate error budgets are developed in Section 2.4.1.

1.3 Scope.

The GP and sniper systems were selected for analyis from a number of different small arms because each is designed to be used in a different tactical role. Conceptually, each is employed by a different type of user against targets of different character; the GP rifle engages targets at relatively close range, the sniper rifle at relatively long range. Each system presents a different problem for tacticians, trainers and armament engineers to solve.

The GP rifle error budget is altogether dominated by the shooter's aiming error; in the case of the sniper system, however, the shooter is usually considered to be a relatively small element of the error budget. Range and wind errors that affect the accuracy of the GP rifle by biasing (offsetting) the center of impact (COI) from the point of aim (POA) are inconsequential at close range because they are submerged in the rifleman's aiming error. On the other hand, wind and range errors will, if unaccounted for, devastate the hitting performance of a sniper system.

Note that when fire control technology has been successfully developed to solve the long-range bias problem for the sniper rifle, it can be transferred almost directly to other small arms that engage at long range. In similar fashion, technology developed to reduce or compensate for the rifleman's close-range aiming error, might be applied to other close-range small arms.

It will soon be obvious that the majority of this report deals with the sniper and sniper materiel. The author has dealt with the error budget of GP rifles at length in AMSAA TR 440, May 1987. AMSAA TR 461 contains the first systematic exploration of the sniper system error budget, including estimates of the magnitude of each element, that has been published. Such an examination was a necessary pre-condition to assessing the need for various components of a fire control system for the sniper system.

1.4 Organization of Report.

The report has three major sections: Section 2 deals with the error budgets for the GP and sniper rifle systems, listing and estimating the magnitude of the various elements. Section 3 lays out several possible range/target distributions that might apply to both systems. Section 4 provides basic hitting performance estimates and answers several "what if" questions. Section 5 contains an exposition of a problem perceived by the author with the contemporary definition of accuracy. Section 5 briefly explores some possible ways to improve small arms hitting performance.

A report of this sort is normally written by an analyst with an audience of other analysts in mind. This report has been slanted toward the interests and backgrounds of line and technical service military personnel who are not likely to be analysts. For this reason, analysts may feel that some of the marginal remarks, explanations and details are superfluous.

Tables have been constructed in considerable detail in order to provide a maximum of information concerning the circumstances under which the data were taken or for which the estimates are valid. This has been done because small arms hitting performance is in great measure situation dependent.

Two appendices accompany the report. Appendix A deals with matters concerning the use of optical sights. Appendix A provides a summary of the original experimental data of the response of the human eye pupil to varying ambient light conditions. As nearly as the author can tell, these data, taken in 1920, have been used unchanged in any way to this day. Appendix A also provides a collection of formulas obtained from several different sources. The formulas are provided to show the interdependence of the different optical characteristics. One cannot decide to make some desirable increase in one optical parameter without paying a penalty in one or more of the others.

Appendix B contains a relatively large sample of test data for the 7.62 x 51mm, M118 Special Ball Cartridge--the standard round to be used with 7.62mm-caliber sniper rifles. The data are identified by lot number and with one exception, are all fired by the same test organization in a single test. The data are from an accuracy barrel/machine rest at ranges from 100 to 1,000 meters. Appendix B is provided since it is relatively rare to have such a comprehensive group of data taken under similar conditions.

1.5 Caution.

This report only deals with hitting. Targets might only seem to be abstractions of some size that are distributed in varying density and range in a zone of action. It is possible to be left with the impression that it is only necessary to hit the target in order to have a successful engagement. But a hit has no meaning unless the target receives some desirable or useful terminal effect (wounding, penetration) with the hit. All are cautioned that there is a nominal minimum quantity of chemical or kinetic energy needed to create a useful terminal effect on a given hard or soft (people) target; further (notwithstanding the importance of shape, material and velocity), there is a correspondence between the size (weight) of the projectile and the effect it produces.

The simplest way to increase the chance of a hit at close range is to shoot several projectiles with each trigger pull. This technique has been used by several of the Advanced Combat Rifle (ACR) prototypes now being tested. Muzzle climb and kick are related to the number, size and cyclic rate of the projectiles fired.

The trick is to make sure that the desire to increase the chance of a hit does not result in many projectiles whose size is too small to provide a useful terminal effect given a hit. This topic is covered in greater detail in Section 5.2.

2. SYSTEM ERROR BUDGET

2.1 Explanation of Terms.

2.1.1 Delivery Errors. A conventional direct-fire weapon error budget can be grouped into the three categories of errors seen below. Some of the errors may be inherent (fixed) in the design, some may vary from one occasion (fire mission) to another, some may vary within an occasion. The assignment of a particular error to one or more of the three groups may vary from one major weapon type to another.

The grouping of errors shown below is generally used for tanks and other direct-fire weapons fired from a more or less rigid ground mount. One important facility of this type of mount is that its design brings the muzzle of the weapon (the origin of the bullet) and sights back to the same reference planes after the shock of firing in a manner that is repeatable and predictable. The "burst-on-target" method of fire adjustment once (perhaps, still) used by tanks would not be successful without this facility. The rifleman (who, in a real sense, may be considered to be the GP rifle's mount) is the antithesis of such a mount.

With rigid mounts, it is generally possible to isolate, measure and assess the importance of each error separately. Over the years, a rather detailed list and protocol for its use has developed for measuring and applying the tank error budget. The error budget for a GP rifle fired in haste by a rifleman is at least as complex as the tank error budget, but the individual elements have not been broken apart and measured in any detail.

In many cases it is extremely difficult to isolate and measure individual errors such as cant when the weapon is fired from a non-rigid mount. A final caveat is needed here. Some elements of the error budget might not be applied equally among weapons and shooters. As an example, it is unlikely that a change in the ballistic characteristics of a new lot of ammunition would have any effect on a rifleman firing bursts with a GP rifle, thus it would not be included in its error budget. However, the same change could devastate the performance of a sniper or competition-quality shooter.

Sources of Delivery Error (Some of the errors operate in the vertical (Y) plane, others in the horizontal (X) plane):

a. Fixed Biases (treated as a mean X or mean Y offset):

(1) Inherent in the system design.

(2) Constant over all occasions.

(3) Include primarily:

Parallax
Bullet drift
Jump (may also be treated as a variable bias)
Incorrect design or construction of sights

b. Variable Biases (a standard deviation--SD):

(1) Constant within an occasion (fire mission).

(2) Vary from occasion to occasion.

(3) Include primarily:

Situation variables like:
Wind and other atmospheric phenomena

System variables like:
Range estimation, muzzle velocity variation, jump, fire control error

c. Random Errors (a SD):

(1) Vary from round to round within occasion.

(2) Include primarily: Cant and lay (aim) errors for tanks; aiming and remaining errors for GP rifles. Ballistic dispersion of ammunition and weapon.

The mathematical and statistical basis for the methodology used by the author in this and all of his other evaluations of small arms error budgets was developed by Dr. Frank E. Grubbs a number of years ago while he worked for the Ballistics Research Laboratory (BRL). In 1964 Dr. Grubbs, now a consultant for AMSAA, published privately, a small volume known familiarly around AMSAA and BRL as the Red Book. [see reference 25] The Red Book is a distillation of Dr. Grubbs' methodology focused on small arms.

Any who may need a more complete treatment of the methodology than is provided in the Red Book should obtain a copy of the Engineering Design Handbook, Army Weapon System Analysis, Part One, DARCOM-P 706-101, November 1977; a companion volume: Army Weapon System Analysis, Part Two, DARCOM-P 706-102, October 1979, also makes worthwhile study. Both of these documents, written by Dr. Grubbs, were published by the U.S. Army Materiel Development and Readiness Command (now the U.S. Army Materiel Command). [These and other titles in the series are available from Letterkenny Army Depot, ATTN: DRXLE-ATD, Chambersburg, PA 17201]

In general, it is not necessary for a small arms analyst to have a detailed error budget model to understand why a rifleman misses targets at close range--in the region where it is supposed the bulk of his targets will be found in any event. The rifleman's aiming and re-aiming error (a systematic random error) totally dominates the error budget in this region; errors caused by poor range estimation and wind are not important elements close in. The situation changes for the sniper system, especially at long range (say, 1,000 meters and beyond). It is impossible to account for important effects of a sniper's error budget without systematically considering each of the terms above.

Reference 43 is a technical report written by Mr. Arthur D. Groves and published in 1963 by the BRL. Mr. Groves' MR 1450 is a brief, yet comprehensive explanation of the direct-fire error budget showing how the various terms are collected and used in a single-shot hit probability model. MR 1450 deals with the 106mm recoilless rifle, so is concerned with the same phenomena as the sniper rifle at long range. Mr. Groves' work is also commended to all small arms analysts and fire control engineers who have more than a superficial interest in the topic.

2.1.2 Accuracy and Dispersion. Both of these terms have precise meanings, but as will be seen in Section 5.1, the application of these definitions is generally confused. Dispersion, usually treated as a SD, measures the size and shape of the round to round dispersion (RRD) of a number of shots fired under similar conditions at a common POA. Many systems analysts use the term precision interchangeably with dispersion. Accuracy measures the displacement of the COI of the shot group from the POA. (This effect is called an offset or bias.) Accuracy quantifies target hits. One major goal of a fire control engineer is to construct a reliable, robust, inexpensive device that insures that the center of the pattern of shot is centered in the target being shot at. This is a critical task in the case of a sniper system at long range. See also Section 5.1.

2.1.3 SIGMA. The term SIGMA used throughout this report is an estimate of a true, but unknown population SD made from a sample of some limited size. Probability of hit (P_H) estimates are usually thought to represent the entire group identified (the population). In order for the P_H to truly represent any population, SIGMA, the basic element of the various formulas used to calculate P_H, must be an estimate of the same population, not of some sample of limited size. SIGMA is usually tabled in mils as a matter of convenience; formula [1] gives somewhat greater precision to computations than is obtained using the usual military mil (1 unit at a range of 1,000 units):

$$\text{MILS} = \frac{\text{DISTANCE (units of range)} \times 1{,}018.59}{\text{RANGE}} \qquad [1]$$

SIGMA is a population SD; the SD squared is a variance. While it is not correct to add, subtract, multiply or divide a SD, it is ordinarily correct to do so with a variance. The author uses this technique extensively to combine, separate and average (pool) SIGMAs. For example, Table 2.2 gives the RRD SIGMA of the rifles and test ammunition as 0.20 mils for the semi-automatic and 0.15 mils for the bolt-action at 300 meters. Note d. says that RRD SIGMA from a MANN (accuracy) barrel of the M118 ammunition used in the APG test is 0.08 mils at 300 yards.

The RRD SIGMA attributed to the rifles alone, calculated using the technique just described, is 0.18 mils for the semi-automatic and 0.13 for the bolt action. This result for the semi-automatic rifle is arrived at as follows:

$$\sqrt{(0.20)^2 - (0.08)^2} = 0.18 \qquad [2]$$

The term pooled SD or pooled SIGMA is used throughout this report when a mean value for several SD is desired. A pooled SIGMA using the first three SIGMAs in Table 2.3 as an example is calculated as follows:

$$\text{TOTAL SIGMA} = \sqrt{\frac{(0.12)^2 + 0.24)^2 + 0.31)^2}{3}} \qquad [3]$$

2.2 General.

The bulk of this report deals with two basic classes of rifles: one class consists of the rifle used by the rifleman as his primary tool--and by other soldiers who occasionally contribute to the fire fight; the other class is made up of sniper rifles. In order to keep the two classes of rifles distinct in the analysis that follows, the rifle used by the rifleman will be called a GP rifle.

It is possible to separate the two classes by defining such things as targets, range, caliber, size, weight, velocity, and so forth. The type of fire control used by each is a major difference as far as this report is concerned. Perhaps the most important difference between the two classes is the skill, training and motivation of the soldier using each. This, together with the scale of issue of the two types makes certain solutions practical for one and not for the other. GP and Sniper rifles have fu[illegible]tally different error budgets.

GP Rifleman.

The GP rifle error budget is dominated by the [illegible]ing error; even when expressed in mils, his aiming error var[illegible]. The rifleman is concerned with targets at relatively close r[illegible] is little penalty for misestimated range and wind. Over the [illegible]so years, the basic approach to dealing with this aiming error at ve[illegible] range (less than, say 100 meters) has been to compensate for it by shooting a burst of multiple projectiles. A variety of sights have been designed to reduce the very close range aiming error, but none of them have been altogether satisfactory.

Sniper.

The sniper rifle is a weapon system that fire control engineers can sink their teeth into. There is variability in the RRD among the different sniper rifles. While this level of variability is of little consequence with a GP rifle because of the size of the rifleman's aiming error, differences in RRD matter in a sniper rifle.

There is something of a dichotomy here. The sniper and his weapon deliver consistently small RRD patterns about the POA selected--given there are not any other errors in the system at work. Any error, particularly in measuring and compensating for range (eye-ball estimation or range finder) and wind, has a disastrous affect on hitting. The sniper/weapon will, with great precision, miss the target with each shot fired.

Small-unit Specialized Rifleman.

The author has, in the past half-dozen years or so, come to believe that there needs to be a specialized weapon issued in limited quantities (perhaps one per squad in the infantry) to deal with targets at ranges beyond the capability of the typical rifleman. This weapon, a GP rifle with a telescope of 3 - 5 power, manned in the squad or platoon by a specially selected, trained, motivated/compensated marksman, could become a major element of force combat power. The weapon would, generally, seek targets out to the limit of danger space for rifles, SAWs and general-purpose machine guns (GPMGs); say, out to 600-700 meters. Such a weapon would add a different set of problems to be solved by the fire control engineer. See also Section 5.2.

2.3 Weapon and Ammunition Round-to-Round Dispersion.

2.3.1 GP Rifle. The rifle adds two errors to the system error budget. In one error, the RRD of the ammunition from the rifle is larger than the intrinsic dispersion of the same projectile from an ammunition test barrel. The difference in the two measured dispersions can be quantified; given similar test conditions, the difference can be attributed to the rifle. The first error is usually treated as a SD. The second error has the effect of offsetting (biasing) the COI of the shot group dispersion from the POA. In a simple small arms system, bias errors are usually attributed to the design or construction of the sights, particularly the rear sight. Errors made in zeroing the rifle and in estimating range and determining the effect of wind also create biases, but these errors are usually attributed to the rifleman.

Table 2.1 provides estimates of the intrinsic RRD of four GP rifles: the U.S. M16A1 and M16A2 and the Soviet AK-47 and AK-74. The population SD (SIGMA) from Table 2.1 will be used later to estimate P_Hs for the four rifles. Table 2.1 reflects the author's experience: the RRD test data for rifles taken from a bench rest using a "National Rifle Association (NRA) Master-Class" gunner are about the same as RRD data taken from a fixed (machine) rest. (This does not hold true for pistols.)

Some will probably note that all tables of RRD only show a single value for SIGMA. In doing this the author is saying that the horizontal (SIGMA X) and vertical (SIGMA Y) components of the dispersion are the same--the dispersion is circular. The value given in the tables may be taken to be a mean calculated using [3] in 2.1.3.

The RRD of small arms fired single shot is circular at relatively close range. The dispersion of a GP rifle is circular within the ranges that limit the user's interest in this weapon; this may not be the case at long-sniper ranges (greater than, say 1,000 meters). Considering the RRD to be circular provides an adequate basis for AMSAA to estimate hit probability for most targets; a fire control engineer probably requires values for both components of the dispersion, however.

Table 2.1. Intrinsic Round-to-Round Dispersion (RRD) of Several General Purpose Military Rifles with Ball Ammunition: [a] Proving Ground Aiming Error [b]

POPULATION SD (SIGMA - MILS)

	<-------- SOVIET ------->		<--------- U.S. -------->	
	5.45 X 39MM	7.62 X 39MM	<---- 5.56 X 45MM ---->	
RANGE	AK-74	AK-47	M16A1	M16A2
METERS	<-- TYPE PS BALL -->		M193 BALL	M855 BALL
50	0.33	0.45	0.25	0.25
100	0.33	0.45	0.25	0.25
150	0.33	0.45	0.25	0.25
200	0.33	0.45	0.26	0.26
250	0.33	0.45	0.27	0.26
300	0.33	0.45	0.28	0.27
350	0.34	0.46	0.29	0.27
400	0.35	0.46	0.30	0.28
450	0.36	0.46	0.31	0.29
500	0.37	0.47	0.33	0.30
550	0.38	0.47	0.34	0.31
600	0.40	0.48	0.36	0.32
700	0.43	0.50	0.40	0.36
800	0.50	0.54	0.46	0.43

a. TEST DATA FOR INTRINSIC RRD FROM MACHINE OR BENCH RESTS; DATA FOR RIFLES USING EITHER REST SEEN TO BE ABOUT THE SAME (WITH BENCH-REST USING NRA MASTER-CLASS GUNNER).

b. REFERENCE 9, TABLE 4.3.

2.3.2 Sniper Rifle.

2.3.2.1 User's Requirements. Before exploring the sniper system error budget, it is useful to have some idea of what the user requires of such a system.

The U.S. Army Institute for Military Assistance (USAIMA), Fort, Bragg, NC, issued a draft letter requirement (LR) for a Sniper Weapon System (SWS) in 1982. This document began a long and involved effort that only recently resulted in the type classification of the 7.62 x 51mm, M24 Sniper rifle--based on a Remington Model 700 bolt action. The first draft LR for the SWS specified the following performance requirement:

> The System will: (6) Have an accuracy of no more than 3/4 minute of angle [MOA] for a 5 shot group at 1,500 meters when fired from a supported, non-benchrest position. [Version of 17 February 1982]

The 1982 SWS requirement, when translated into parameters used to describe accuracy and dispersion in this report, says that the SWS must have a total system error (weapon, ammunition, fire control, sniper) of no more than 0.07 mils SIGMA--an impossible value! When the requirement first surfaced, AMSAA understood that the USAIMA was really specifying a 3/4 MOA rifle and ammunition RRD requirement, not a total system requirement. But even with this less severe interpretation, the requirement was thought to be unrealistic. It was dropped later.

The Army Concept Team in Vietnam (ACTIV) conducted a survey and reported on the conduct of sniper operations and the use of sniper materiel in Vietnam in a report dated 1968. Based on tests done by the Army Marksmanship Unit (AMU) at Ft Benning, ACTIV estimated the effective range of two 7.62 x 51mm competition-quality rifles. ACTIV said the accurized M14 (essentially the same as the present-day M21 sniper rifle) and the Winchester Model 70 both had an effective range of 600 meters for 100 percent hits and 700 meters for 90 percent hits. In this regard, ACTIV defined effective range as the range at which a sniper got a first round hit on a "man size" target. ACTIV also said that a rifle with an effective range of 600 meters would have been capable of engaging 95 percent of the enemy targets seen in Vietnam during the period of their survey. [20:p.13] [Note that Source reference is made using two numbers in brackets; references are grouped at the end of the report.]

What meaning does the ACTIV definition of effective have for designers and builders of sniper materiel? The total sniper system delivery error cannot be more than about 0.13 mils SIGMA in order to have about a 100 percent chance of a hit on a crouching man target at 600 meters (0.22 mils SIGMA to hit the same target 90 percent of the time at 700 meters). These are extremely small error budgets (solution spaces) for engineers to work with.

The most difficult aspect is the requirement for a first round hit. Any requirement for a first round hit coupled with a requirement for hits at long range means that a full-solution fire control system is required. If the user does not require a first round hit, the sniper can use one or more "will adjust" rounds to dope the wind, fix the range and get an empirical solution for any non-standard atmospheric conditions.

As a practical matter the sniper can only reasonably expect to get off one shot since his chance of surviving the engagement is diminished with each round he fires. Further, near misses will send human targets to ground quickly. The blast and debris kicked up by the muzzle brakes required for caliber .50 sniper rifles is particularly bad; consequently, position disclosure should be a matter of major concern with these weapons.

One of our allies in NATO also says that a sniper must be able to hit a man with the first shot out to 600 meters. The author does not know if the other country read the ACTIV report, since their requirement is no more than a paraphrase of the definition of effective used by ACTIV. In any event, it creates the same engineering burden.

Like it or not, serious long-range sniping requires a sophisticated full-solution fire control apparatus.

2.3.2.2 Need for Sniper Materiel Greater Than 7.62mm. There has been considerable interest in large-bore (larger than 7.62 x 51mm) sniper rifles for several years. The user apparently feels a need to engage targets at ranges beyond what they consider to be the limit of the present sniper rifles and ammunition; he may also want to hit targets with a bigger, more lethal, bullet at any range encountered.

The Naval Weapons Support Center (NAVWPNSUPPCEN), Crane, IN, has purchased bolt-action sniper rifles in 12.7 x 99mm caliber (U.S. .50 caliber) from DAISY and McMILLAN. The Navy calls these weapons Special Application Sniper Rifles (SASR). The Army is holding open options to "rebore" the M24 to 7.62 x 62 mm (.300 Winchester MAGNUM). The Army may have equipped some units with .50 caliber rifles for all the author knows.

Some idea can be had of the required hitting performance of the SASR from a draft USMC required operational capability (ROC) document, ca. 1985. First, an idea of the targets and ranges for a .50 caliber SASR visualized by the USMC helps to give perspective to the accuracy-related requirements. The author was never directly involved with the program, so does not know if the document was ever changed or approved.

The draft ROC says that the SASR would not replace the 7.62mm, M40A1 rifle, but would be employed against targets of opportunity at, " . . . extended ranges from 1,000 to 2,000 meters." Note that the USMC Technical Manual (TM) for the M40A1 gives its "maximum effective range" as 1,000 yards [p. 1-1]

The SASR would use armor piercing ammunition (AP) against material targets when appropriate. Several other particulars of the draft ROC are interesting: The rifle would have a capability to fire 2,000 meters with a dispersion no greater than one MOA or approximately 22 inches or less (at 2,000 meters). If the rifle requirement is, like the ammunition requirement, based on a 5-round shot group, it is specifying that the intrinsic RRD of the rifle and ammunition must be no more than 0.10 mils SIGMA at 2,000 meters. The ROC has the effect of requiring that the ammunition have a RRD at 300 meters for 5 rounds of no more than 0.05 mil SIGMA.

The rifle is also required to, " . . . provide the sniper with at least a 0.5 probability of hit for the first shot fired at a target 1 meter by 1 meter at 2,000 meters of range with a cross wind of eight to ten miles per hour [mph]." If a perfect range and wind solution can be assumed, the requirement allows an error for the ammunition, rifle and sniper of 0.24 mils SIGMA. Actually, this would be more reasonable as a system requirement.

Two final aspects of the requirement need to be mentioned: The system is to be capable of firing three ammunition types that have relatively different velocities. This probably means that the sniper might be required to carry several firing tables. A handheld LRF with an error not to exceed 2 percent of range is required. The ROC does not specify a need for materiel to solve the wind problem. This is unfortunate, since the author believes the most formidable problem facing the sniper is a firing solution that accounts for the effects of wind.

2.3.2.3 RRD of 7.62 x 51mm Sniper Rifles. Table 2.2 provides estimates of the intrinsic RRD of two classes of sniper rifles firing 7.62 x 51mm, M118 Special Ball. The M118 projectile has a nominal weight of 11.3 grams (175 grains) and is launched at a nominal velocity of 818 meters per second (mps), equal to 2683 feet per second (fps). Table 2.2 summarizes data from a test of sniper materiel done at APG, in 1978. [Reference 28]

Appendix B contains a relatively large sample of RRD data for several lots of the M118 cartridge from an accuracy barrel at ranges of 100, 200, 300, 600, 700, 800 and 1,000 yards. Most of the data were taken at the Armament Research, Development and Engineering Center Test Unit, Fort Dix, ca. June 1987. [Reference 48] These data were received too late to completely evaluate in the main body of this report. A quick analysis of the these data indicates that it is unlikely that there will be any inconsistencies with the existing data base. The data are provided since it is relatively rare to have data identified to specific ammunition lots and to have so many different ranges fired by the same organization under identical test conditions.

Table 2.2 represents data for the M21 sniper and the modified M14 National Match semi-automatic rifles and three bolt-action sniper-quality rifles including the USMC M40A1. A sample of three rifles was used from a bench rest at 200 yards; then, using standard testing procedures at APG, the weapons with the largest and smallest mean radius at 200 yards were tested in a machine rest at 300, 600, 800 and 1,000 yards. The author modified the test data (inches and yards), to mils and meters in order to follow AMSAA convention. The estimates are the result of a simple least squares regression using a polynomial model.

Many of the tables that follow (in particular those dealing with the sniper system error budget) are being published for the first time with this report. The notes that accompany each table provide the source of the data and explain the circumstances and conditions under which the data were obtained. The author made a decision to structure the notes in greater detail than one usually expects to find in a report of this sort; this was done in order to allow each table to stand alone with the information that is essential to make a reasoned judgment.

The Army has adopted the 7.62 x 51mm, M24 bolt-action sniper rifle to replace the M21 sniper rifle. RRD estimates for the M24 are based on test data contained in Reference 30. Reference 47 contains additional RRD data for the M24 from a recent test; however, it has not been possible to complete more than a superficial examination of the data. The data from Reference 30 have been appended to the body of estimates in Table 2.2. Even though the RRD of the test ammunition is different, the SIGMAs calculated from the two sets of data are reasonably similar. Until the new M24 RRD data have been evaluated, the author will use the data in Table 2.2 to represent the RRD of the M24 as well as the M21 and USMC M40A1.

A statistical test to discover if the RRD of the two classes were the same was not performed. Given a sufficiently large sample size, the apparent differences seen in Table 2.2 will be found to be real (in a statistical sense). As is the case with the GP rifle, the differences in the RRD of semiautomatic rifles like the M21 and bolt-action rifles like the M24 are probably large enough to be a matter of concern to a competition shooter.

Whether cr not the differences are large enough to be of concern to an operational sniper depends on assumptions made about the composition and magnitude of the remaining elements of the error budget.

Table 2.2. Intrinsic Round-to-Round Dispersion (RRD) of two Classes of 7.62 X 51mm Sniper Rifles [a] Firing M118 Special Ball Ammunition [d]

PART A. POLYNOMIIAL (POWER CURVE) FIT OF TEST DATA: [e]

ESTIMATED INTRINSIC RRD SIGMA (MILS) [f]

	SEMI-AUTO CLASS [b]	BOLT-ACTION CLASS [c]		SEMI-AUTO CLASS [b]	BOLT-ACTION CLASS [c]
RANGE METERS	SIGMA MIL	SIGMA MIL	RANGE METERS	SIGMA MIL	SIGMA MIL
100	0.19	0.12	700	0.20	0.19
D 200	0.19	0.14	D 800	0.20	0.19
D 300 [d]	0.20	0.15	900	0.21	0.20
400	0.20	0.16	D 1,000	0.21	0.20
500	0.20	0.17	1,100	0.21	0.21
D 600	0.20	0.18	1,200	0.21	0.21

PART B. TEST DATA FROM REFERENCE 30 FOR M14 NM AND M24 USING M118 NM AMMUNITION (RD SIGMA = 0.14 MILS AT 300 YARDS).

200 YARDS	0.27	0.15
300 YARDS	0.24	0.14

D = DATA AT THESE RANGES ONLY; TEST DATA IN INCHES/YARDS.
a. PREVIOUSLY UNPUBLISHED WORK BY AUTHOR; DATA FROM REFERENCE 28, TABLES 2-1, 2-4.
b. FOR EXAMPLE: U.S. ARMY M21, M14 NATIONAL MATCH.
c. FOR EXAMPLE: U.S. ARMY M24, USMC M40A1.
d. RRD OF M118 USED IN THIS TEST (LOT LC 60-1) FROM A MANN (ACCURACY) BARREL HAD A 0.08 MIL SIGMA AT 300 YARDS.[28:P.128]
e. MEAN RADIUS AT EACH RANGE BASED ON LEAST SQUARES REGRESSION (POWER CURVE MODEL).
f. SIGMA (POPULATION SD) BASED ON GRUBBS' MEAN RADIUS WITH n = 10. [REFERENCE 25, TABLE 5]

One final, but very important, thought concerning the apparent differences in the intrinsic RRD of different models of GP and sniper rifles needs to be mentioned. Within the same class of rifle, whatever difference there may be in the intrinsic RRD will collapse to zero at some range because the two weapons are using the same ammunition. Variation in the velocity and drag of the bullet, not the design or care taken in the manufacture of a rifle, finally determine size of the RRD at long range. The author uses as the range where the bullet dominates the error budget, the range where the velocity of the bullet is about equal to the speed of sound (approximately 341 mps or 1,120 fps). The M118 Special Ball drops to a velocity of 341 mps between 900 and 1,000 meters from the muzzle. (see Table 2.9)

2.3.2.4 RRD of 12.7 x 99mm SASR. Table 2.3 contains test data with which to estimate the intrinsic RRD of the McMILLAN 12.7mm SASR. Note that except for groups 4 and 9, the SIGMA calculated for the SASR with M8 API (Incendiary) ammunition is less than 0.25 mils. Note f indicates that the user requires a SASR with a RRD not greater than 0.27 mils SIGMA at 600 yards. It appears that this requirement has been met with the McMILLAN.

If the intrinsic RRD of M8 API is really 0.25 as it is given in Table 2.3, Mr. McMillan is shooting groups with his SASR whose size is less than the intrinsic RRD of the test ammunition he used--a remarkable feat, to say the least. For years the author has resisted the notion that this sort of thing can happen but, has finally come to accept that it is possible on a single occasion for very skilled marksmen to shoot groups where the system (ammunition, rifle, shooter) RRD is less than the long-term nominal ammunition RRD. Mr. Earl Chronister's performance with a benchrest rifle (Table 2.6 and Figure 2.2) is an example of this phenomenon. Note e, Table 2.3, says that Mr. McMillan is given, effectively, zero aiming error. This statement is not exactly correct, but close enough to the mark to be useful later in the evaluation.

Note that Mr. McMillan fired sight-in rounds before recording test data. Doing this compensates for the effects of many non-standard atmospheric conditions, effectively removing them from the error budget. As nearly as the author can tell, this situation is true for all of the sniper rifle RRD data that follow. It is with this situation in mind, and knowing that tests were conducted at known range and limited wind, that it is possible to say that with the ammunition RRD removed, the main residual effect is the shooter's aiming error.

A sniper's survivability is likely to be directly linked to the number of "sighters" [illegible]t shoot in order to dope the conditions for a particular fire missi[illegible], [illegible]nus a properly designed fire control system for a first-round-hit sniper system must eliminate the need for "sighters."

Up until now, the author estimated the single-shot RRD of all .50 caliber ammunition from an accuracy barrel to be about 0.25 mils SIGMA at 600 yards/meters. Note c of Table 2.3 shows estimates of 0.23 and 0.18 mils SIGMA for two different types of caliber .50 ammunition. Estimates based on test data recently received from the U.S. Army Combat Systems Test Activity (CSTA), formerly the Materiel Test Directorate (MTD) gives the .50 caliber, M33 ball (steel core) a RRD of 0.36 mils SIGMA from an accuracy barrel at 600 yards, so there is obvious variability in the RRD of different models of caliber .50 ammunition.

Until additional data have been seen, the author, provisionally, takes the intrinsic RRD of the McMILLAN SASR with M8 API to be 0.25 mils sigma. Hitting performance estimates for sniper materiel will show that in the case of a sniper system, the weapon and ammunition RRD is likely to be the least important element of the system error budget.

Table 2.3. 12.7 X 99mm (.50 Caliber) Special Application Sniper Rifle (SASR): [a]
RRD of McMillan SASR in First Article Test Shot in Arizona for NAVWPNSUPPCEN, Crane, IN, January 1988

AMMUNITION: M8 API (5 ROUND SHOT GROUPS) [b]
SHOT BY MR. McMILLAN (DESIGNER/MFG) FROM PRONE POSITION
LEUPOLD 16 X TELESCOPE AND BIPOD

KNOWN RANGE = 600 YARDS AND BENIGN PG CONDITIONS)

	TEST DATA: McMILLAN RIFLE AND AMMUNITION			
GROUP NR	MEAN RADIUS INCH	[b] SIGMA MILS	[c] RRD OF M8 API SIGMA (MILS)	CALCULATED RRD ATTRIBUTED TO McMILLAN RIFLE SIGMA (MILS)
1	2.94	0.12	0.25	NC [d]
3	5.75	0.24	"	NC
4	7.38	L 0.31	"	0.18
5	5.55	0.23	"	NC
6	3.52	0.15	"	NC
7	5.82	0.24	"	NC
8	5.43	0.23	"	NC
9	6.42	0.27	"	0.10
10	5.67	0.24	"	NC
11	5.38	0.23	"	NC
12	2.90	S 0.12	"	NC
13	3.72	0.16	"	NC
14	4.92	0.21	"	NC
15	6.02	0.25	"	NC
MEAN	5.10	0.21	0.25	NC
SD	1.34			

a. REFERENCE 31: NAVWPNSUPPCEN IS NAVAL WEAPONS SUPPORT CENTER.

b. SIGMA CALCULATED USING GRUBBS' MEAN RADIUS WITH n = 5.

c. DATA FROM NAVWPNSUPPCEN GIVE 0.25 MIL SIGMA AS RRD FOR M8 API AND MK 211 FROM MACHINE REST AT 600 YARDS; LAKE CITY ARSENAL REPORTED RRD OF M8 API = 0.23 MIL; RAUFOSS REPORTED RRD OF EX 211 = 0.18 MIL SIGMA. [27:p.15 - 18]

d. L = LARGEST, S = SMALLEST 5-ROUND GROUP.

e. NC = NOT CALCULATED: RRD SIGMA OF SASR (INCLUDING AMMUNITION, RIFLE AND McMILLAN'S AIMING ERROR) IS LESS THAN ESTIMATED RRD SIGMA OF M8 API AMMUNITION FROM ACCURACY BARREL AT 600 YARDS; McMILLAN, GIVEN, EFFECTIVELY, ZERO AIMING ERROR.

f. SASR SPEC REQUIRES SASR TO HAVE 5 ROUND GROUP MR NO GREATER THAN 6.5 INCH AT 600 YARDS (SIGMA = 0.27 MIL).

2.3.2.5 Brophy's 1954 Test of Sniper Materiel. Table 2.4 is provided to give historic perspective to the .50 caliber SASR program, showing that the idea of sniping with a .50 caliber weapon is not new by any means. The M1D sniper rifle was the then-standard caliber .30 sniper rifle; it used AP ammunition in this test. Note how the SIGMAs for caliber .50 are about double those for .30 caliber rifles, and how the RRD SIGMA increases with range. The .50 caliber rifle tested did not have a muzzle brake, and MAJ Brophy reported the recoil of the weapon to be "objectionable" in 1955. [21:p.18] About 30 years would pass before the .50 caliber sniper weapon would be tried again.

Table 2.4. Round-to-Round Dispersion of Sniper Materiel: [a]
Tested at APG, MD, December 1953 to June 1954

KNOWN RANGE + BENIGN CONDITIONS + BULLS-EYE TARGET
THOUGHT TO BE NRA MASTER-CLASS SHOOTERS
CAL .30 RIFLES FROM BENCH REST, CAL .50 RIFLES FROM PRONE

		300 YARDS (274 METERS) 4 X 10-RD GP		600 YARDS (548 METERS) 1 X 10-RD GP/ DAY FOR 5 DAYS		1,000 YARDS (914 METERS)	
NR	WEAPON	MEAN RADIUS INCH	SIGMA MILS	MEAN RADIUS INCH	SIGMA MILS	MEAN RADIUS INCH	SIGMA MILS
1	CAL .30 MATCH GRADE RIFLE	2.2	0.17	5.3	0.21	11.2	0.27
2	CAL .30, M1D SNIPER RIFLE	4.0	0.32	11.4	0.45	18.3 [f]	0.44
3	CAL .50 RIFLE [b] [e] (LT BARREL)	4.9	0.39	8.6	0.34	18.5	0.44
4	CAL .50 RIFLE (HV BARREL)	3.0	0.24	NOT TESTED		NOT TESTED	

RANGE = 1,400 YARDS (1,280 METERS)

NR	WEAPON	MEAN RADIUS (INCH)	SIGMA (MILS)
5	CAL .30 MATCH RIFLE:		
	PALMA MATCH 18 GRAIN	20.7	0.35
	HAND LOAD 180 GRAIN	25.8	0.44

a. REF 21: 37TH REPORT OF PROJECT TS2-2015 (BROPHY REPORT).
b. SOVIET 14.5 MM, PTRS-41 ANTITANK RIFLE RECVR: U.S. LMG BIPOD AND 57MM RECOILLESS RIFLE MONOPOD; TRIGGER PULL = 11.0 LB.
c. INTRINSIC RRD FROM ACCY BARREL: .30 CAL PALMA MATCH = 0.17 MIL SIGMA AT 100 YARDS; RRD M2 AP NOT RECORDED; 12.7MM, M2 BALL (MILD STEEL CORE) AT 600 YARDS = 0.27 MIL SIGMA. [APP C]
d. TELESCOPES USED: M1D RIFLE: M84 (2 X 18MM); .30 CAL MATCH GRADE RIFLE: 12 X 35MM; .50 CAL RIFLE: 20 X 57MM. [P. 7]
e. WEIGHT .50 CAL RIFLE: WITH M3 ACFT LT BARREL = 27.65 LB; WITH M2MG HB = 42.80 LB. [p.7]
f. 1 ROUND OF 1 10-RD GROUP MISSED 12 FT X 12 FT TARGET PANEL; OTHER GROUPS = 11.5, 21.6, 19.6 AND 20.4 INCH.

2.3.2.6 Predicted Dispersions and Test of Methodology. Shortly after the first SWS LR was put out, Mr. Bob McCoy of BRL constructed a model that considers the exterior ballistics characteristics of rifle projectiles, and predicts the RRD of the projectile at any range. About 1985, he used the model to predict the RRD of a top-of-the-scale MAGNUM .30 caliber benchrest rifle when fired by competition-quality shooters under benign conditions.

Table 2.5 displays predictions of the intrinsic RRD of two sniper-quality rifles by Mr. McCoy, expressed as an extreme spread (ES) and as a SIGMA for a 10-round shot group. The ES is the distance between the two shots in the group separated by the greatest distance.

Table 2.5. Predicted Intrinsic Round to Round Dispersion: Two Benchrest (Sniper-Quality) Rifles

EXPERIENCED SHOOTER (EFFECTIVELY NO AIMING ERROR) [a]
BENIGN CONDITIONS + KNOWN RANGE

	MAGNUM.30 CALIBER BENCHREST RIFLE [b] [REF. 23, TABLE 2]		.35/50 (.50 NECKED TO .35 CALIBER) [REF. 24, TABLE IV]	
	(10-ROUND SHOT GROUPS)			
RANGE METERS	EXTREME SPREAD METERS	POPULATION SD MILS	EXTREME SPREAD METERS	POPULATION SD MILS
200	0.03	0.04	NC	----
400	0.07	0.05	NC	----
500	NC	----	0.08	0.04
600	0.12	0.05	NC	----
800	0.19	0.06	NC	----
1,000	0.30	0.08	0.22	0.06
1,200	0.46	0.10	NC	----
1,400	0.70	0.13	NC	----
1,500	NC	----	0.51	0.09
1,600	1.07	0.18	NC	----
1,800	1.55	0.23	NC	----
2,000	2.10	0.28	1.11	0.15

a. PRACTICALLY NO WIND, RANGE OR AIMING ERROR; THUS, APPROXIMATES THE INTRINSIC ROUND TO ROUND DISPERSION OF BOTH RIFLES.

b. FOR EXAMPLE: .300 MAGNUM, .30-378, .308 SUPER; APPROXIMATES THE M24 SNIPER RIFLE IF RE-CONFIGURED TO .300 MAGNUM CALIBER.

NC = NOT CALCULATED IN THIS REFERENCE.

The left portion of Table 2.5 provides Mr. McCoy's 1985 estimates for the .300 MAGNUM caliber sniper/competition rifle. The author has calculated a SIGMA from Mr. McCoy's ES using Dr. Frank Grubbs' methodology outlined in Reference 25 and explained in detail in DARCOM-P 706-101.

The dispersions in the right portion of Table 2.5 were produced some time later for a .35 caliber rifle conceptualized by Mr. McCoy to a later SWS requirement. Note that this concept uses a 12.7 x 99mm (.50 caliber) cartridge case necked down to 8.89mm (.35-inch). The .35/50 projectile weighs 22.7 grams (350 grains); it is the same projectile whose conceptual exterior ballistics characteristics are shown in Table 2.9.

For the moment, disregard the predictions for the .35/50 in Table 2.5. Mr. McCoy needed experimental data to validate the predictions made in his model, so he decided to conduct a field experiment. This is the genesis of the <u>One Mile Shoot</u>, done at Fort Indiantown Gap, PA, on 21 October 1984. The shoot was conducted at a measured range of 1,780 meters using members of the Original Williamsport [Pa.] 1,000 Yard Bench Rest Club as test subjects (using their own weapons, scopes and ammunition). All shooting was from a benchrest at a target with a 24-inch bullseye. Shooters had 15 minutes to fire 10 shots. The performance of this civilian shooting club is provided since there is little data dealing with the performance of sniper-quality rifles at ranges visualized in the 1982 SWS LR.

Table 2.6 summarizes the results of the Indiantown Gap shoot. Keep in mind that the goal of the benchrest shooters in this exercise (and in their shooting at home) is to group 10 rounds as close together as possible. By the definition used in this report, they are not interested in accuracy--that is to say, that they are not concerned with the location of the COI, only the size of the pattern. This statement, however, is not altogether true, since the benchrest shooter must shoot each round under identical conditions if he is to have any chance of winning. Accordingly, the benchrest shooter must deal with wind, light, mirage and other atmospheric conditions, in order to decide when to pull the trigger.

In general, the performance seen at 1,780 meters at Indiantown Gap validated Mr. McCoy's model. Note, at the same time, that Mr. Chronister, whose performance was commented on earlier, fired a 41.5-inch extreme spread group--much less than the 61-inch extreme spread that had been predicted.

Look again at Table 2.5 and note how much smaller the RRD of the .35/50 is compared to the .30 caliber class of benchrest rifles and cartridges beyond about 1,500 meters. The difference is only important beyond this range, since both cartridges would, intrinsically, deliver a P_H of 1.00 against a crouching target at 1,000 meters.

Table 2.6. Round to Round Dispersion of
Sniper-Quality Rifles and Shooters:
Very Long Range (1,780 mers) [a] Ft Indiantown Gap, PA, 21 October 1984

ONE 10-ROUND SHOT GROUP AT KNOWN RANGE + BENCH REST

SHOOTER [b]	RIFLE [c]	SHOTS ON TARGET	EXTREME SPREAD INCH	SIGMA (MILS)
RELAY 1: WIND = 1/2 MPH, OSCILLATING FROM 3:00 TO 9:00 O'CLOCK				
GREG AMAND	308 SUPER	10	51.1	0.20
BRUCE BAER	308 BAER	8	----	----
KEN RIDENOUR	276-8MM MAG	5	----	----
CLIFF HOCKER	30-378 WOLFE	1	----	----
RELAY 2: WIND = 2 1/2 MPH, OSCILLATING FROM 3:00 TO 9:00 O'CLOCK				
EARL CHRONISTER	30-378	10	41.5	0.16
LOWELL AMAND	308 SUPER	10	76.3	0.29
KEN RIDENOUR	276 SUPER	10	66.5	0.25

a. REFERENCE 23, TABLE 1.
b. SHOOTERS FROM ORIGINAL WILLIAMSPORT (PA.) 1,000 YARD BENCHREST CLUB.
c. A VARIETY OF FIXED AND FLOATING-MOUNT SCOPES (16 TO 24 POWER).

It is important to bear in mind that the Williamsport benchrest materiel are not suited to military sniping. Typical rifle weight is about 45 pounds; the only way to disassemble the rifle is to heat the bedding sleeve until the bedding softens. Most of the telescopes used by the Williamsport shooters range from 16 to 24 power, although a few shooters used higher and lower magnification. Most of the telescopes float in the mount and are returned to battery by a spring--presumably to mitigate the recoil of magnum loads. A few shooters use mounts fixed to the weapon's receiver. [23:p.10] As might be imagined, the telescopic sights and mounts are not likely to stand up to hard field use.

A final table will complete the section dealing with the RRD of various weapons and cartridges. The test data available to the author are incomplete, so the RRD estimates must be considered tentative. The table is provided to draw attention to a new class of small arms cartridges for which a fire control solution must be provided if they are ever employed by snipers.

2.3.2.7 RRD of 7.62 and 12.7mm SLAP. The ARDEC has had an on-again off-again effort for the past ten or so years to field a small caliber, high-performance, antiarmor cartridge. Apparently with money provided by the USMC, two SLAP (Saboted, Light Armor Penetrator) cartridges, each with a companion tracer round, were to be fielded sometime in FY89. The Army has run hot and cold on this one, so the author is not sure where they stand on the matter today. As of September 1988, all have XM designations.

It is almost certain that both calibers are being developed, principally for use in machineguns, not in sniper rifles. Table 2.6A provides an initial estimate of the intrinsic RRD of both. The use of either as an "effective" sniper munition depends on having satisfactory terminal effects against a class of materiel targets of interest to the user, and on a small round to round dispersion. It is true, unfortunately, that the class of small caliber projectiles developed to enhance terminal effects against materiel targets tend to have a rather large round to round dispersion--this is particularly true of projectiles filled with incendiary and explosive mixes.

Table 2.6A. RRD of Two Small Caliber Antimateriel Cartridges

PART A. CHARACTERISTICS: [a]

CALIBER	7.62 X 51MM	12.7 X 99MM
DESIGNATION OF SLAP [b]	XM 948	XM 903
DESIGNATION OF TRACER	XM 959	XM 962
WEIGHT OF SLAP PENETRATOR	3.37 GRAM	29.16 GRAM
APPROXIMATE MUZZLE VEL	1220 MPS	1220 MPS
POSSIBLE APPLICATION	M21, M24, M40A1	USN/USMC SASR

PART B. ESTIMATE OF INTRINSIC RRD:

RANGE (METER)	200	550 (600 YARDS)
SIGMA (MILS)	0.22	0.27

a. WEIGHT, XM NUMBERS, VELOCITY, RRD OF XM 948 FROM CONVERSATION OF AUTHOR AND MR. RHODES, ARDEC; RRD XM903 FROM ADVANCE COPY OF CSTA FIRING RECORD.
b. SLAP = SABOTED, LIGHT ARMOR PENETRATOR.

2.4 Biases (Offsets) of the COI From the Intended POA.

The author has already said that bias errors are the least important errors to the GP rifleman at the shorter ranges; they are, without question, the most important errors in the long-range target error budget. To be effective, the sniper needs to be grouping his rounds where the densest portion of his RRD is coincident with the center of the target--firing with zero biases. The need for a firing solution that accounts for wind and range increases as the RRD of the rifle and ammunition gets smaller, since the smallest bias caused by an incorrect estimate of either will cause a tight pattern to miss more often than not. The sniper is not likely to benefit from the occasional, accidental hit that statistical theory says is to be expected with a large RRD.

The author has no data from any Service for tests conducted at unknown range where the sniper had to measure range by some means--all tests were done on known distance (KD) ranges. Several years ago, one of the reasons given for testing the Army's new sniper rifle with troops on a KD range was that the snipers, equipped with a handheld LRF, would always know the range to the nearest 5 meters.

Ultimately, the using Services must face up to the costs of obtaining a sniper system with a "satisfactory" first-round hit capability under the unknowns, vagaries and stresses of a reasonable operational scenario. The .50 caliber SASR uses a high-efficiency muzzle brake in order to keep recoil at tolerable levels. The dust, debris and smoke created with each shot has the potential of allowing the sniper's position to be pinpointed quickly. If for no other reason, the sniper's survivability is a sufficient basis to work toward a true first-round system.

A first-round sniper system against a target such as a man at long-range cannot tolerate any errors that will offset the COI from the POA. Range and wind errors must be effectively eliminated from the error budget of such a system.

2.4.1 Range (Y) Bias Caused by Range Measurement Error. Range measurement has always been a formidable obstacle to the production of effective fires at longer ranges. This error is usually treated in various models that estimate effectiveness as a population SD (SIGMA). The 21 percent value most often encountered almost certainly, as will be seen later, understates the true magnitude of the range measurement error.

It is likely that a major source for the 21 percent value are two experiments conducted by the Human Engineering Laboratory (HEL) about twenty years ago. The earlier experiment evaluated the performance of mortar forward observers (FOs); the other, done in 1970--the first of the Human Engineering Laboratory Battalion Artillery Test series (called HELBAT I)-looked to see how well artillery FOs performed certain basic tasks. Table 2.7 summarizes selected results for artillery FOs from the HELBAT I test report.

The SD are the values to focus on in Table 2.7. Over many observations, the mean azimuth and mean range would approach zero unless there were something in the system biasing the measurements. Thus far, no data have been seen to suggest that there is such a bias in either eyeball or machine range measurement.

The sample size seen in the HELBAT I report is sufficiently large that the SD shown in Table 2.7 may be taken to be approximately equal to the population SIGMA.

Note in Table 2.7 that the 22 percent SD is for a sample of 58 observations; if the 4 data points HEL considered to be "outliers" are replaced, the value is increased to 26 percent SD. The values and sample sizes in this table will have to be reconciled with the much larger values seen in Table 2.8.

Table 2.7. Performance of Artillery Forward Observers, HELBAT I, 1970. [a]

ERRORS IN MEASUREMENT OF AZIMUTH AND RANGE

RANGE MEASURED BY	SAMPLE SIZE [c]	AZIMUTH (MILS) [b]		PERCENT OF RANGE (METERS)	
		MEAN	SD [c]	MEAN	SD [c]
EYE-BALL RANGE EST	62	9	249	10	26
(REMOVE 4 "OUTLIERS"	58	-11	78	8	22
TRIPOD MOUNTED LASER RANGE FINDER	20			-0.1	4

a. REFERENCE 12, TABLE 9.
b. USING AN M2 COMPASS.
c. SD APPROXIMATES SIGMA AT THESE SAMPLE SIZES.

Compass Error.

Compass error has been inserted into this discussion of range estimation because a compass is an essential fire control instrument used in locating targets. The M2 Compass, presently the standard compass for FO, is thought by many to be a very "accurate" compass; however, if accuracy means (as it must) that the FO has the true azimuth in his mind at the end of the measurement process, the M2 compass is not very accurate.

The M2 compass probably can measure azimuth with great precision, given that it is pointed at the same point each time. In this context, precision in exactly analogous to the round to round dispersion of a rifle; and, like the GP rifle-shooter system, it is the smallest element of the error budget. Anyone that has used the M2 will understand that the FO can never point at the same spot each time, so another error is created. This error is the exact analog of the rifleman's aiming error. Even if the compass were pointed at the true target, the FO must catch the swing of the undampened needle at the index and read the dial through a mirror--a process requiring time and steady nerves.

More recently, about 450 basic trainees were tested in their ability to use a lensatic compass in an end-of-cycle proficiency test at Ft. Benning in 1984. The difference between the correct azimuth and the azimuth announced by each trainee amounted to a mean of 0.02 degrees and a SD of 3.0 degrees (about 54 mils).

It is expected that a rigorous test would show that the standard lensatic compass, in the hands of troops, provides a more accurate azimuth measurement in less time than the M2.

2.4.1.1 Estimate of Rifleman's Range Estimation Error in the Small Arms Firing Manual, 1913. The earliest estimate of range measurement error seen by the author is contained the 1913 version of the Army's Small Arms Firing Manual; it says:

> With soldiers who have had some instruction the average error in the estimation of ranges by the eye, for distance between 600 and 1,200 yards, is approximately 15 per cent. The average error of a well instructed class is about 12 1/2 percent. The best instrumental range finders [split image types used on the infantry firing line] will give results with an error not exceeding 5 per cent of the range. [13:p.135] [underline by AMSAA]

The word average has been underlined to make the point that the term was being used then in the sense of a probable error (PE), something that can be recalculated as a SIGMA. (The PE equals 0.6745 SIGMA.) The text of a lecture prepared by the Musketry School, Ft Sill, OK in 1916 refers to the same experiment, and adds the label probable error:

> Experiments conducted in the 5th Brigade at Galveston, with four regiments of infantry involving hundreds of estimates by trained estimators confirm previous experiments here and abroad, that the "probable error" in estimating the range to battle targets over unknown ground and at infantry ranges is 12.5 percent. [quotation marks in the original] [Reference 14]

Probable errors of 5, 12.5 and 15 percent are equal to SIGMAs of about 7, 19 and 22 percent. As a matter of interest, the 15 percent error was still quoted as late as the 1943 version of the .30 caliber, M1 Rifle field manual. [p.242]

The results reported in the 1913 Small Arms Firing Manual tend to support the values contained in the 1970 HELBAT I report, but the error-estimates of the soldier's range estimation by eye (aided with a map, compass and binoculars) seen in Table 2.8 are about double the HELBAT I values. The author offers no explanation for this situation, but is more comfortable with the data with the larger sample size.

2.4.1.2 Errors Using a Hand-Held Laser Range Finder. It might be imagined that a LRF would solve the sniper's range measurement problem; unfortunately, test data do not support such a supposition. It will be shown in a moment that a class of LRF that may be small and light (portable) enough to be carried readily and used unobtrusively by a sniper almost certainly has the intrinsic (device alone, without operator error) ability to measure range with great accuracy, but only when pointed exactly at the target to which the operator intends to measure range--and therein lies the problem.

General Utility and Employment of Portable LRFs.

In the author's judgment, there is an exact analogy between the intrinsic round to round dispersion of a GP rifle and the "dispersion"--the scatter--of the beam of a LRF. The intrinsic dispersion of the beam will, even with zero aiming error, lead on occasion to a missed target and consequent incorrect range. The magnitude of the range error is sensitive to the shape of the terrain and the number, location, size and reflectance of false targets (any other target that the LRF may get a response from) in the scene; such sensitivity is a hallmark of active range measuring devices like the LRF. Passive range measurement systems (eyeball range estimation, stadia and optical range finders) do not have to hit their target before they can measure range.

As an active device, the LRF beam can be detected with suitable equipment. The actual chance of detection and consequent discovery of the location from which the device is being used is very sensitive to the assumptions built into a scenario. Accordingly, it seems reasonable to expect that the user's willingness to risk detection by using his LRF decreases with some correspondence to his knowledge of how much error there is likely to be in the range he measures. The assurance of measuring range to the correct target, having risked detection by this and other means, will be used as a strawman later in this analysis to analyze the performance of LRF.

The LRF is like other weapons and devices that must be aimed (GP or sniper rifle, compass, target designator or tracker, to mention a few). None of them are ever pointed exactly at their target, and an error is created when they are "fired." Although this error consists of many parts, one of its largest elements is the soldier-operator/firer's aiming error. The relative importance of aiming error in the GP rifleman's and sniper's error budgets will be discussed in detail in Section 2.5.

Description of AN/PVS-6 (MELIOS), 1985.

The basis for the assertions just made can be seen with a brief inspection of Table 2.8, which shows the results of the OT I of the Mini Eyesafe Laser Infrared Observation Set (MELIOS), AN/PVS-6, done in 1985 at the U.S. Army Infantry Board (USAIB), Ft Benning, GA. Table 2.8 is also notable because Part B contains AMSAA's first estimate of the MELIOS system error budget.

Figure 1 is a photograph of one of the two types of MELIOS tested. A type MELIOS is generally described below:

Both types are about the size of a pair of 7 x 50 binoculars and weigh about 4 pounds stripped; a carrying case, batteries and a small tripod (that looks like the type used by amateur photographers) adds about another pound. (The user had asked for a LRF weighing no more than 4 pounds.) Both devices have 7 power monoculars with 7 degree fields of view; both have a reticle that provides an aiming mark, a ready light, a multiple-target light and range (to the nearest 5 meters); both devices have switches that allow the operator to select first or last-pulse ranging logic, and both manufacturers recommend that their device be routinely used set at last pulse.

Figure 1. Soldier operating AN/PVS-6 (Laser Range Finder) during 1985 Operational Test I at USAIB.
(Soldier is wearing chemical protective mask, gloves and parka.)

Both types use a cross hair for course target alignment, and a small circle at the intersection of the hairs for precise aiming. A draft training publication for the Type A MELIOS said that the target, " . . . must be centered in the small circle." [15: D-21] The size of the aiming circle was not specified for the Type A MELIOS, but the draft training publication for the Type B MELIOS told prospective readers to, " . . . center the 1 mil aiming circle on [the] object." [15: E11] The author spoke with a MELIOS project engineer, who said that the aiming circle has a 1 mil diameter, and that the diameter of the MELIOS laser beam is less than 1 mil, so is contained within the aiming circle so long as the optics and laser paths remain bore-sighted. By way of comparison, the LRF used on the M1A1 Main Battle Tank (MBT) has a beam about 1/4 mil diameter. This is an important difference whose effect on performance will be discussed later.

The size of a laser beam increases with range. This is a matter of major importance since the beam will spill over the edges of a target beyond some range, even in the unlikely event that the center of the beam is pointed exactly at the target. A 1 mil diameter aiming circle, projected at range, over-fills the width of a crouching-type target (0.50 meters wide) at any range greater than about 500 meters; a 1 mil circle is, however, small enough to be contained by a M113 armored personnel carrier (APC), bow-on (2.7 meters) and side-on (4.9 meters) at ranges less than about 2,750 and 4,950 meters, respectively. In abstract, beam spread could cause incorrect ranging, but the effect of this error is probably small compared to the operator's aiming error.

USAIB OT I of AN/PVS-6 (MELIOS): Design and Conduct.

The 1985 USAIB MELIOS OT I range measurement subtest design was based on this one critical issue: "Does use of the MELIOS improve the range estimation ability of user troops?"

The critical issue was evaluated by comparing the performance of the MELIOS with the system currently in use (designated the control). The control was defined by the USAIB as a soldier's estimate of range by eye aided by a pair of binoculars, a lensatic compass and a 1:50,000 scale map of the test area. [15: p. 1-2, B-3]] Soldiers made 1,309 estimates using the control; data for these are shown in Part A, Table 2.8, in column <1>: "Soldier Range Estimate."

The OT I tested both types of MELIOS from a variety of positions: handheld from a kneeling-dismounted position from a building and from the commander's hatch of a M113 APC or a M2 fighting vehicle; both were also tested with a small tripod with the soldier standing in a foxhole and from the prone. A total of 2,466 observations were made by the two types; the results shown in column <2>, Table 2.8, were averaged over all positions.

The test subjects (54 soldiers with infantry and cavalry occupations) estimated range using the control procedure, then with each type of MELIOS. The soldier had one minute per target to measure range to silhouette targets representing personnel, to tank and APC hulls, wheeled vehicles, building facades and bunkers.

The test was done in benign atmospheric conditions using test subjects who were not under stress. All targets were in clear line of sight and had a highly visible, low-reflective point at which to aim. Target contrast and reflectance were artifacts of the test that would not be seen in the real world, thus the results seen are likely to overstate the ability of an operational sniper to measure range.

USAIB OT I of MELIOS: Outcome and Discussion.

Part A, Table 2.8, summarizes the USAIB test data, which includes: the number (n) of test observations and the mean error (expressed as an absolute (unsigned) value and as a percent error (of the correct target range). Part A also shows a count of the number of times that range was measured to a target with an error not exceeding 5 meters (the smallest increment of range change displayed in the MELIOS reticle). This count is designated Y in the USAIB test data and in Part A. The number Y serves as a useful rough approximation of the number of times that a MELIOS beam hit the target at which it was being aimed. A fraction, labeled FRAC Y, is given for each range band later in Table 2.8A. The FRAC Y is calculated by dividing Y by n, both taken from Table 2.8; for example, in the 0 - 1,000 meter range band, 284 divided by 415 results in a FRAC Y of 0.68. Note a identifies the specific tables from which the test data seen in Part A were taken.

The 9.2 percent range error for the MELIOS seen in Part A in the 1,001 - 2,000 meter range band seems unaccountably large when it is compared to the other three range bands. The soldier range estimation error (35.6 percent in the same range band), while quite large, is about the same over all range bands. This seems to suggest that whatever caused the spike in the MELIOS error did not have a similar effect on troop range estimation. The author has no explanation that he will defend rigorously, but thinks that the relatively small size of the personnel target used in this range band might have had a bearing.

The distribution of troop range estimation errors seen in <1> and <4>, Table 2.8, is not symmetrical; it indicates that troops tended to estimate range over (greater than the true range) more often than they did under (the true range). For the moment, it is not known if this is a real characteristic of troop performance or an outcome that can be explained by the test design and the configuration of the ground used in the test.

If experience can be used as a guide, the USAIB used E (crouching-man) type targets (0.50 meters wide x 0.87 meters high) during the MELIOS OT I; they were located at 30, 630, 780, 1,025, 1,300 and 1,520 meters--none farther. [15: p. 2-13] If one recalls that the laser beam overfills an E target at relatively close range, target type becomes a plausible, if not compelling, explanation for the large MELIOS error.

There may be another explanation for the large MELIOS range error in the 1,001 - 2,000 meter range band. This explanation is interesting since it points out that the LRF range error depends to some considerable degree on the configuration of the terrain and on the relative locations of the LRF and target. It is useful to reemphasize here that the LRF range error is much more sensitive to such vagaries than is the error estimated using the unaided

Table 2.8. Range Measurement Performance of Troops with AN/PVS-6 (MELIOS) and Troop Error in Estimating Range: MELIOS OT I, USAIB, Ft Benning, GA, 1985; with AMSAA Population (SIGMA) Estimates of System Errors

54 INFANTRY & CAVALRY SOLDIERS IN PEACETIME (NO STRESS)
MELIOS TESTED IN BENIGN ATMOSPHERIC CONDITIONS
ERRORS FOR HIGHLY VISIBLE TARGETS, AVERAGED OVER ALL POSITIONS

PART A - USAIB TEST DATA: [a]

RANGE BAND (METERS)	SOLDIER [b] <1> RANGE ESTIMATE: MEAN ABSOLUTE ERROR			AN/PVS-6 (MELIOS) ERROR SOUCE: <2> USED BY TROOPS: MEAN ABS ERROR			[c] Y = NR ERRORS	<3> WITHOUT TROOPS INTRINSIC PERF ABSOLUTE ERROR		
	n	METER	%	n	METER	%	=< 5 M	MEAN METER	SD METER	SD %
0-1000	246	207	38.9	415	12	4.1	284	0.7	4.3	0.9
1001-2000	410	527	35.6	801	121	9.2	355	4.8	6.0	0.5
2001-3000	246	872	37.6	467	109	5.1	213	1.0	4.1	0.2
3001-4000	407	941	28.3	783	136	4.1	302	4.2	3.4	0.1

PART B - AMSAA POPULATION (SIGMA) ESTIMATES OF SYSTEM ERRORS:

RANGE BAND (METERS)	<4> RANGE MEASUREMENT ERROR SIGMA (% TRUE RANGE) [d] SOLDIER RANGE ESTIMATION	<5> [e] MELIOS INTRINSIC RANGE ERROR	<6> DISPERSION & AIMING ERRORS SIGMA (MILS) [f] MELIOS INTRINSIC DISPERSION	<7> [g] OPERATOR AIMING ERROR
0-1000	48.8	0.9	0.18 - 0.26	0.92
1001-2000	44.7	0.5		
2001-3000	47.2	0.2	(SAME VALUES USED FOR ALL RANGES)	
3001-4000	35.5	0.1		

a. REF 15: PARAS. 2.3.3.5, 2.3.4.2; TABLES 2.3-13, 2.3-18.
b. CONTROL SYSTEM: RANGE ESTIMATED BY SOLDIER (AIDED BY BINOCULARS, LENSATIC COMPASS AND 1:50,000 SCALE MAP).
c. Y = NUMBER OF TIMES RANGE WAS MEASURED WITH ERROR EQUAL TO OR LESS THAN 5 METERS (APPROXIMATES A TARGET HIT BY LRF BEAM).
d. SIGMA FROM <1>; ESTIMATE IS FOR 1 SD (AS A % OF TRUE RANGE); FROM RELATIONSHIP OF THE MEAN DEVIATION TO SIGMA. [25: TABLE 3]
e. SIGMA FROM <3>; IF NORMAL DISTRIBUTION, SAMPLE SD IS ABOUT EQUAL TO SIGMA BECAUSE OF LARGE (n = 130) SAMPLE SIZE.
f. IF IMPACT OF ALL LASER PULSES CONTAINED IN 1 MIL DIAM CIRCLE, SIGMA = 0.18 MILS (n = 100), 0.26 MILS (n = 10). [25: TABLE 7]
g. BASED ON LASER TRACKER ON TRIPOD; FROM 1985 AMSAA DAZER STUDY.

eye, or measured using stadia devices and optical range finders; further, unlike optical devices, the LRF operator must hit his target for the device to measure range correctly.

A MELIOS project engineer who had been on the round during OT I thought that certain test conditions, coupled with the method used by the USAIB to calculate mean error, caused the large absolute error reported for the 1,001 - 2,000 meter range band seen in Table 2.8. He believes that a number of the targets were near the skyline, and when the LRF was on ground lower than the target, a miss, high, would result in a laser beam out in space. When this happened, the value of the miss distance recorded for the test event would be the maximum range the MELIOS was designed to measure (6,000 meters for Type A and 9,000 meters for Type B). In abstract, such a procedure would tend to increase the size of the mean absolute error calculated, but it is by no means certain that it was the major contributor to this unusually large error.

The error SIGMAs seen in Table 2.8 are expressed as a percent of true range; they represent the Ft. Benning area only and probably can only be generalized to other terrain with a general form like the Ft. Benning area. It would be a mistake to use these values to represent LRF performance in a desert.

The user had hoped that the MELIOS would measure range with no more than a 5 meter error. Examination of the mean absolute error in <3>, Table 2.8, shows that the MELIOS probably does have such intrinsic accuracy; however, a look at <2> shows that it does not have this accuracy in the hands of troops. When the MELIOS was aimed properly on the correct target, it performed far better than troop eyeball range estimation, thus the critical issue was met. A simple inspection of Part A shows that the MELIOS with a 105 meter mean absolute error measures range with less error than troops estimating range by eye (660 meter mean absolute error). The user's critical issue was met, but unless something extraordinary happens--an unlikely event--the simple analysis that follows will show that this MELIOS does not measure range with a level of accuracy required by any user that must have a nearly exact range solution.

Population Estimates of Range Measurement Errors.

Note in particular before proceeding that an error estimate for a LRF is only valid for atmospheric conditions similar to those that existed at the test location when and where the data were taken. This is a very important statement since it is almost certain that the class of LRF represented by MELIOS will be found to behave more or less like other LRF and optical devices; that is to say, they will be seriously affected by phenomena like atmospheric scattering and optical path bending, to mention several. All of this is meant to say two things: one, more than one error budget is needed to describe the performance of a LRF world-wide; two, the LRF is likely to be seriously degraded at certain times and seasons at least in some critical geographic areas such as the desert.

Part B of Table 2.8 shows population (1 SIGMA) estimates. Range measurement errors are expressed as a percent of true range; laser beam dispersion and operator aiming errors are expressed in mils. Bear in mind that plus or minus 3 SIGMAs (a total of 6 SIGMAs) contain 99.7 percent (virtually all) of a normal distribution. Consider the range measurement errors first. An estimate of the performance of troops estimating range by eye is in column <4>. The intrinsic (device only) range measurement error for the MELIOS and similar LRF under benign atmospheric conditions in an unstressed peacetime OT is in column <5>.

Note that the SIGMA (percent of true range) for the soldier's eyeball range estimation in <4> is almost double the values reported by HEL in HELBAT I (See Table 2.7). The author cannot offer any explanation for this situation, but is inclined to give greater credibility to the MELIOS test outcome simply because of its sample size (1,309 vs 58).

Look at the 1 SIGMA values at ranges of 1,000, 1,500 and 2,000 meters. These are ranges of considerable interest to a sniper. A cartridge with a flat trajectory would tend to compensate for range errors at ranges less than about 1,000 meters, and 2,000 meters or so probably marks the outer limit of usable terminal effects for a projectile fired from a weapon whose recoil can be tolerated.

In abstract, the values at <5> provide no clue to whether the MELIOS, unencumbered by an operator, has the intrinsic capability to measure range with the accuracy needed by a user like the sniper; some sort of effectiveness or performance or engineering model is needed to make that sort of assessment. Section 2.4.1.4 has such a model--in this case, a simple model that estimates the required range measurement accuracy needed by a sniper in order to employ two different sniper weapons against targets of two sizes. For the moment, though, a different kind of error budget will be developed.

Percent of true range is the correct unit of measure to use for SIGMAs that quantify range estimation errors and errors caused when range is measured using stadia and optical range finders; it is the correct unit of measure for SIGMAs used to quantify the <u>intrinsic</u> performance of a LRF. Percent of true range should not be used generally to quantify the total system error of a LRF nor the aiming error attributed to its operator. SIGMAs (percent of true range) representing the intrinsic performance of the LRF can only come into consideration on those occasions when the operator has successfully ranged on ("hit") his target. An altogether different error budget must be developed to predict the chance of this event. Active range measuring devices are unique in these regards.

<u>A Tentative Error Budget Used to Estimate the Probability of a LRF Ranging on the Correct Target</u>.

It was said earlier that a LRF like the MELIOS is an active device whose beam must "strike" the correct target (the one its operator wants to range on) in order to measure range correctly. A LRF is unlike passive devices such as eye-ball estimation and optical range finders in this regard. To estimate the chance of obtaining the correct range or, if you will, the probability of ranging on the correct target (PRCT), one must have estimates of the MELIOS "intrinsic round to round dispersion" and of the aiming error of its operator. The author's first estimates for these errors are at <6> and <7>, Part B, Table 2.8. The logic for the estimates is shown below:

The intrinsic dispersion of the MELIOS seen in <6> is an estimate because there are no test data with which to calculate the population parameter SIGMA. Test data are required; they should be measured by "firing" a sample of MELIOS laser pulses (shots) from a rigid mount on a suitable range under suitable atmospheric conditions. Instrumentation appropriate to the task is needed to record the x and y coordinates of each pulse. Small arms test procedures, sampling plans and measures used to quantify dispersion (mean radius, extreme spread, range, figure of merit, to mention a few) would probably apply almost exactly. The population dispersion estimates seen at <6> were calculated using a substitute measure taken from Dr. Grubbs' Red Book that is explained now. [Reference 15]

Assume that the size of the MELIOS laser beam with a nominal, but small, bore-sight error is about 1 mil in diameter. (A 1 mil diameter probably understates the size of the beam for many occasions of field use.) The Red Book shows that a SIGMA that estimates the MELIOS intrinsic dispersion can be calculated by treating the 1 mil diameter as a circle that contains the "shot holes" of all of the laser pulses fired in a sample of some size. In this regard, the dispersion SIGMA that is calculated depends, critically, on the number of laser pulses observed. If, for example, the 1 mil diameter contained all shots fired of samples of 10, 20 or 100, SIGMA would be calculated as 0.26, 0.22 and 0.18 mils respectively. Earlier, the beam of the LRF used on the MBT was said to be 1/4 mil diameter. If the 1/4 mil diameter contained all shots of the same sample just used, SIGMA would be calculated as: 0.06 mils (n = 10), 0.05 mils (n = 20) and 0.04 mils (n = 100). [25: Table 7] SIGMAs of 0.18 and 0.26 mils seen in <6>, will be used to represent plausible limits of the MELIOS intrinsic dispersion. The estimates are probably off a bit, but are needed now in order to estimate PRCT.

There are no test data with which to calculate the aiming error of an LRF operator explicitly. AMSAA, in a 1985 study of the DAZER, estimated that the operator of an infrared tracker employed from a tripod had an aiming error of 0.92 mils SIGMA. The infrared tracker seems to be similar enough to the MELIOS to make a useful surrogate for these early PRCT estimates, so the LRF operator is given an aiming error of 0.92 mils SIGMA in <7>, Part B.

PRCT and Assessment.

Table 2.8A contains estimates of PRCT against a small target (PERS), represented by a crouching man (0.50 meters wide x 0.87 meters high), and a large target (TANK) (4.6 meters wide x 2.3 meters high). The PRCTs shown in Table 2.8A are calculated using the same hit probability model used to calculate P_Hs for GP and sniper rifles seen in other tables of this report (Tables 4.3, 4.4, 4.6, to mention several examples). PRCT calculations assume that the laser is aimed at the center of the target, the laser beam is circular and all of the target is exposed; similar assumptions are normally used in GP and sniper rifle P_H calculations.

Table 2.8A is in two parts: Part A shows PRCTs calculated using the intrinsic dispersion of a LRF whose beam is contained in a 1 mil diameter circle (the MELIOS); the two values for dispersions used in these calculations were taken from <6>, Table 2.8. Part B shows PRCTs calculated using an intrinsic dispersion based on a 1/4 mil beam diameter like the LRF used on the M1A1 MBT. Parts A and B use the same aiming error taken from <7>, Table

Table 2.8A. Probability of Ranging on Correct Target (PRCT): AN/PVS-6 (MELIOS) and Similar Small, Portable Laser Range Finders (LRF)

AS A FUNCTION OF SEVERAL LASER RANGE FINDER SYSTEM ERRORS FOR A LARGE (TANK) AND A SMALL (PERS) TARGET [a]

PART A - PRCT IF MELIOS INTRINSIC ERROR BASED ON 1 MIL DIAM BEAM:

	INTRINSIC ERROR (LRF ONLY) [b] <1>				LRF ERROR = 0.18 MIL PLUS AIMING ERROR = [c] <2>				<3>
	0.18 MILS		0.26 MILS		0.92 MILS		0.46 MILS		FRAC Y
RANGE METERS	PERS	TANK	PERS	TANK	PERS	TANK	PERS	TANK	[d]
1,000	0.84	1.00	0.62	1.00	0.08	0.79	0.25	0.99	0.68
2,000	0.41	1.00	0.23	0.98	0.02	0.37	0.07	0.76	0.44
3,000	0.21	0.98	0.11	0.87	0.00	0.19	0.03	0.51	0.46
4,000	0.13	0.90	0.06	0.73	0.00	0.12	0.02	0.34	0.39

PART B - PRCT IF MELIOS INTRINSIC ERROR BASED ON 1/4 MIL DIAM BEAM:

	INTRINSIC ERROR (LRF ONLY) [e] <4>		LRF INTRINSIC ERROR = 0.04 MIL PLUS AIMING ERROR = [c] <5>			
	= 0.04 MILS		0.92 MILS		0.46 MILS	
RANGE METERS	PERS	TANK	PERS	TANK	PERS	TANK
1,000	1.00	1.00	0.08	0.80	0.28	0.99
2,000	1.00	1.00	0.02	0.38	0.08	0.79
3,000	0.95	1.00	0.00	0.20	0.04	0.55
4,000	0.85	1.00	0.00	0.12	0.02	0.38

a. TARGET TYPES: PERS (CROUCHING MAN) = 0.50 METER WIDE X 0.87 METER HIGH; TANK = 4.6 METER WIDE X 2.3 METER HIGH.

b. 1 MIL DIAM INTRINSIC ERROR: SIGMA = 0.18 MILS IF ALL OF SAMPLE OF 100 LASER PULSES IMPACT IN CIRCLE OF 1 MIL DIAMETER; 0.26 MILS IF SAMPLE = 10 PULSES.

c. 0.92 MIL SIGMA AIMING ERROR APPROXIMATED USING ESTIMATE FOR INFRARED TRACKER FROM TRIPOD (AMSAA DAZER STUDY); 0.46 MILS IS 1/2 OF 0.92 MILS; 0.18 MIL SIGMA POOLED WITH AIMING ERROR.

d. FRAC Y = Y/N = FRACTION OF MELIOS OT I TEST OBSERVATIONS WITH ERROR = < 5 METERS; SEE NOTE c, TABLE 2.8.

e. 1/4 MIL DIAM APPROXIMATES LRF ON M1A1 MAIN BATTLE TANK; 0.04 MIL SIGMA IS BEST CASE DISPERSION BASED ON SAMPLE = 100.

2.8: 0.92 mils and 0.46 mils SIGMA--the latter value was selected arbitrarily to be 1/2 of 0.92 mils in order to show the sensitivity of PRCT to changes in aiming error.

One ought to pose as a user and make a judgment in advance on how good the LRF must be--how often the LRF range measuring beam must strike the correct target--in order for it to be a worthwhile thing to acquire; in particular, a LRF that a sniper is willing to risk detection and other hazards and consequences in order to use. PRCT probably measures this sort of goodness in its simplest form, since a target must be hit in order to get the correct range. Put differently, Table 2.8A is probably best used to discover the limiting range to which a satisfactory PRCT is achieved (where satisfactory has already been defined as some minimum value of PRCT). The PRCT that defines a limiting range will vary from one weapon and application to another. This is only a beginning; after the user has selected the limiting PRCT and range, he must then undertake the more difficult task of deciding how nearly exact the range measurement (given a hit) must be for the particular weapon and fire mission he has in mind. (One logic for addressing this latter issue is discussed in Section 2.4.1.4.)

Suppose a commander did not want to expose his snipers to the risk of detection and other hazards (that would be occasioned by using the LRF) unless the sniper had a high (say, a 90 percent) assurance that he would range on the correct target when he "fired" the laser to measure range. There is a precedent for defining high assurance at 90 percent in the Field Manual (FM) dealing with nuclear weapon fire planning. (See page B-5, FM 101-31-1/FMFM 11-4, 1968.) Set in the context of the present discussion, this is to say that the commander required at least a 90 percent chance of ranging on the correct target (PRCT = 0.90) before he would risk exposing his snipers. Suppose also that the sniper's target is a crouching man (about 0.44 square meters).

Look at PRCTs for a MELIOS-type LRF (1 mil diameter laser beam) in Part A, under <2>. When the MELIOS total error includes what is called a lower-limit, more or less best-case intrinsic dispersion, and what is thought to be the most likely aiming error, the MELIOS has essentially no chance of successfully ranging on a crouching man at any range tabled (PRCT = 0.08 at 1,000 meters). For whatever it is worth, given these circumstances, this target would have to be at a range of about 170 meters in order for the operator to have a 90 percent chance of hitting it. At this very close distance, range is not a term that must be considered in any ballistic solution.

With the same intrinsic dispersion, and with aiming error halved, the PRCT against a crouching man is 0.28 at the relatively close range (for a LRF) of 1,000 meters. Even if the target were tank-size (10.6 square meters), if the most likely (0.92 mil SIGMA) aiming error is used, the commander's NO GO range for a 90 percent chance of successful ranging is less than 1,000 meters (PRCT = 0.79 at 1,000 meters).

Look now at <1>. What if aiming error could be eliminated altogether--something that should not be counted on--and the MELIOS were to have a best-case intrinsic dispersion? If the target were about crouching-man size, the commander's 90 percent NO GO range is less than 1,000 meters (PRCT = 0.84 at

1,000 meters). As would be expected, the PRCT is higher against the tank; a sniper could be assured that he would hit this target at least 90 percent of the time with his LRF as far out as 4,000 meters with the best-case (0.18 mil) intrinsic dispersion. It is important to restate once again that this assessment does not consider aiming error.

Continued analysis would produce different limiting ranges if assurance levels other than 90 percent and other target sizes were selected for examination; nonetheless, the basic conclusion would remain: except at close range where a range finder is probably not needed, a 1 mil diameter beam MELIOS can only be used against targets larger than a crouching man, and only at a range of about 2,000 meters--a relatively close range for a range finder.

Look at Part B and see what might happen if the MELIOS had, like the LRF on the M1A1 MBT, a beam about 1/4 mil diameter. The same methodology that produced a best-case intrinsic dispersion of 0.18 mils SIGMA for a 1 mil diameter beam, would produce the 0.04 mil SIGMA intrinsic dispersion for the 1/4 mil diameter beam seen in <4>. [25: Table 7] It is not known if it is feasible to design, build and support a small, portable LRF with a 1/4 mil diameter beam. No matter, its value can be summed up in two simple comments:

- o First, look at the PRCTs in <4> and see that if aiming error were not considered, and the LRF had an intrinsic dispersion of about 0.04 mils SIGMA, it would provide a high (90 percent) assurance of ranging on (hitting) targets as small as a crouching man almost to 4,000 meters.

- o Second, the relative improvement in PRCT of a 1/4 mil diameter beam, compared to a 1 mil diameter beam, is totally lost when an aiming error is added to the error budget (as it must be). In this regard, compare PRCTs for the smaller aiming error--the one most likely to show differences--in <2> and <5>.

There is a final, simple method of visualizing the performance of the MELIOS in OT I: Remember that the fractions seen under the heading FRAC Y in <3>, Table 2.8A, are produced by dividing Y (the number of targets in each range band whose range error was no more than 5 meters) by n (the number of test samples taken at that range). Both of these values are from <2>, Table 2.8. Y can be used to approximate a target hit with the MELIOS laser beam.

It might be questionable to attempt to correlate the FRAC Y with PRCT exactly even though both quantify the same event, more or less. Among other reasons, the FRAC Y combines hits on targets of all sizes into one large numerator. The important notion to be gained from rationalizing PRCT with the FRACY Y, and the reason they are arrayed side-by-side in Part A, is that FRAC Y, calculated using test data, does not remain fixed at some high value, but decreases with range at about the same rate as does PRCT. Given this fact, it should be difficult to insist that the MELIOS really has, "five meter accuracy at all ranges," as has been touted in the past.

Need for Operator to See Laser Spot.

Lyndon S. Cox, representing Harry Diamond Laboratories on the 1988 Small Arms Technical Assessment Fire Control SubPanel, raised a caution regarding the use of LRF as part of the small arms fire control solution. The MELIOS OT I test results provide a suitable foundation for the following critique of LRF that Mr. Cox provided to the fire control sub-panel chairman:

> Unless the laser spot illumination can be visualized, the soldier receives no strike feedback. Laser Rangefinders are limited to first return (nearest object) or last return (furthest object) ranging of illuminated objects because the beam is not a point but an area, and can obtain a return from several objects on the same illumination. This adds complexities which indicate that the laser rangefinder is poorly suited to small arms application unless the illumination can be visualized and used for aiming also. [Reference 26]

Summary: Small, Portable LRF.

a. There is an exact analogy in the error budgets of the LRF and GP rifle. The values are different, but there is an almost perfect correspondence between the GP rifle and LRF in the relative contribution of the device and soldier-operator--the two basic error sources. Both systems have small precision errors, but in both cases, the soldier imposes an aiming error on the system gross enough to seriously degrade its performance.

b. Unlike optical range measuring devices and eyeball range estimation, a LRF must hit its target before it can measure range; thus the MELIOS adds a unique element to the system error budget of the weapons it supports.

c. The LRF is an active device, thus its location can be detected by suitable equipment.

d. The LRF range measurement error is uniquely influenced by terrain (type, convolution, vegetation), and the way the ground may be cluttered with potentially false targets. The LRF error is sensitive to the relative location of the LRF and its target.

e. The concept of a limiting range within which a LRF operator has some specified assurance that he will hit the target he ranges on is a useful evaluation tool. The user must specify the target size and the limiting assurance level. AMSAA used a "high" (90 percent) assurance level in this evaluation.

f. The actual intrinsic dispersion of the MELIOS is not known; however, a type LRF whose intrinsic dispersion is contained inside a 1 mil diameter circle probably only has the precision needed to measure range to small (man-sized targets) at ranges less than about 1,000 meters.

g. A type LRF with a 1/4 mil diameter beam has the precision needed to measure range to a small (man-sized) target to about 4,000 meters.

h. If the user required that the LRF operator have a 90 percent assurance of hitting a man-sized target each time he ranged on it, the LRF must have an intrinsic dispersion of about 1/4 mil.

i. The actual aiming error of a LRF operator is not known; however, this error must not exceed 0.08 mils SIGMA in order for a 1/4 mil diameter beam LRF to have a 90 percent assurance of hitting a man-size target at 2,000 meters. It does not seem likely that a LRF can be fielded with an aiming error that small.

j. The fraction of targets to which MELIOS measured range with accuracy acceptable to the user (no more than a 5 meter error) was never more than 68 percent (in the 0 - 1,000 meter range band), it decreased with range at a rate that has the general outline of the fall off seen in the hitting performance of small arms.

The AMSAA evaluation of the MELIOS system error budget indicates that a LRF will not provide a range measurement with the 5 meter accuracy claimed at its present stage of development. What else might be used to measure range?

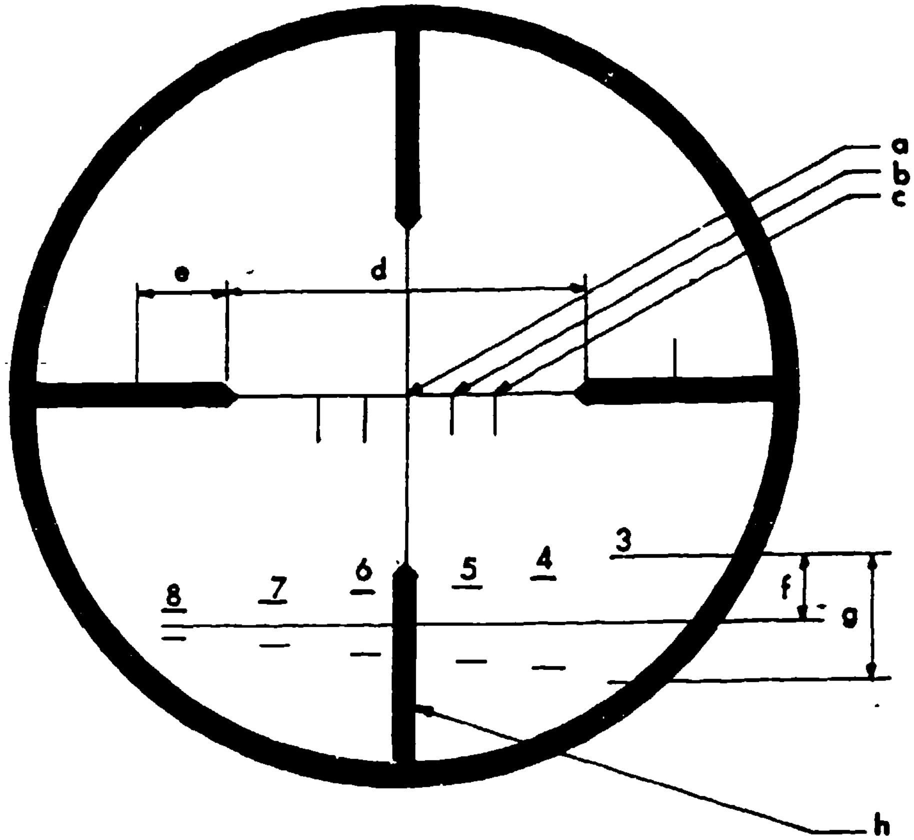
<u>2.4.1.3 Errors Using Stadia</u>. Stadia are sometimes placed in optical sights to assist the gunner in measuring range. One of the telescopes used on a sniper rifle tested by CSTA several years ago had a stadia range measurement feature. This stadia was designed for use against standing and crouching-man targets from 300 to 800 meters. [30: encl 1,p.10] The reticle of this sight is shown in Figure 1a.

One of the HELBAT I authors has said that placing stadia lines in an optical sight only reduces the range measurement error from about 21 (eye estimation-HELBAT I) to about 18 percent SD. Note that a nominal 3 percentage point reduction in error is probably not a worthwhile benefit to pose against the burdens involved in owing a stadia device. Stadia (and other optical range finders, perhaps) might become a more attractive proposition if the eye estimation errors were double the HELBAT I values--as the 1985 MELIOS OT I data show it to be (Table 2.8), and the user finds the MELIOS to be an unsatisfactory range finder.

In 1951, Development and Proof Services (D&PS) (the predecessor of CSTA), did a test of a commercial version of the M82 sniper telescope with an experimental stadia system. The operator indexed the sight by setting his estimated target height on the sight; then, holding on the target, he turned a knob to enclose the height of the target inside the stadia lines. This action rotated a ballistic-range cam that applied the proper superelevation for that range and ammunition. The sight was tested from a bench rest by four proving ground gunners at ranges from 200 to 1,000 yards.

D&PS concluded the following:

> Determination of range by stadia-adjustment was, on targets of known size, considerably better than unaided, visual estimation at ranges up to and including 900 yards. However, an element of uncertainty regarding the target size, which would exist in field use of this instrument, did not exist in this test. [17: p. 9]



a. CENTER CROSSHAIR, THICKNESS 0.1 MIL.
b. LEAD MARKS FOR LEFT AND RIGHT MOVEMENT OF TARGET. SPEED OF MOVEMENT = 5 KM/HR AT 500 METERS RANGE. CAN ALSO BE USED FOR MEASUREMENT. HEIGHT OF MARK IS 2.5 MILS. DISTANCE FROM VERTICAL CROSSHAIR IS 2.5 MILS. DISTANCE FROM LEAD MARK "C" IS 2.5 MILS.
c. LEAD MARKS FOR LEFT AND RIGHT MOVEMENT OF TARGET. SPEED OF MOVEMENT 10 KM/HR AT 500 METERS RANGE. CAN ALSO BE USED FOR MEASUREMENT. HEIGHT OF MARK IS 2.5 MILS. DISTANCE TO VERTICAL CROSSHAIR IS 5.0 MILS.
d. DISTANCE IS 20 MILS. (HEIGHT OF THE TWO INNER HORIZONTAL RANGE MARKS IS 4 MILS.)
e. DISTANCE IS 5 MILS. (HEIGHT OF THE TWO OUTER HORIZONTAL RANGE MARKS IS 2.5 MILS.)
f. MARKS FOR RANGE FINDING FROM 300 TO 800 METERS FOR TARGETS WITH THE HEIGHT OF 0.89 METER (HALF-MAN HEIGHT).
g. MARKS FOR RANGE FINDING FROM 300 TO 800 METERS FOR TARGETS WITH THE HEIGHT OF 1.80 METERS (FULL-MAN HAIGHT).
h. THICKNESS OF HEAY PORTION OF VERTGFICL AND HORIZONTAL CROSSHAIRS IS 1.0 MILS.

Figure 1A. Reticle Pattern of the Leupold and Stevens Model 10x-M3A Telescopic Sight.

> The mean error in stadia separation, due to the instrument alone, was ten percent for all ranges and target sizes tested; the probable error was eight percent. [17: p. 10]

A probable error of 8 percent is equal to a SIGMA estimate of 12 percent. This is not as large as the estimate used by the HELBAT I author, but as will be seen in subsequent pages, is sufficiently large to remove stadia from serious contention as a range measuring device for snipers.

Figure 2 shows the reticle pattern of the M3 telescope used with the M24 SWS. This is known as a mil dot reticle. The TM issued with M3 explains how to estimate range using the mil dots but also acknowledges that the accuracy of the estimate depends on an estimate of the targets size. [TM 9-1500-306-10: p. 2-26]

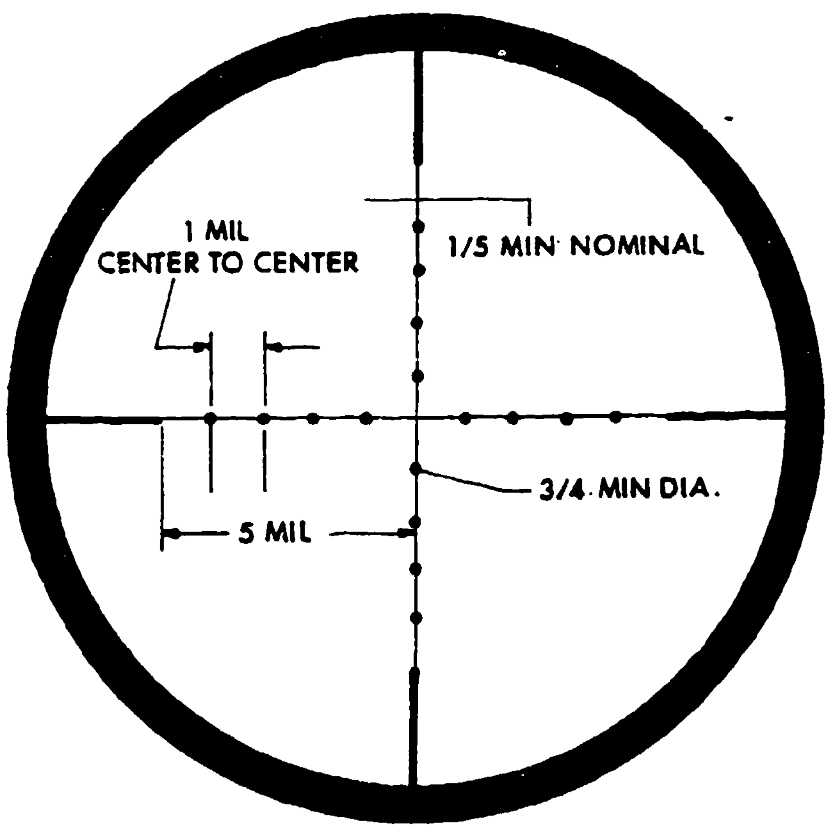


Figure 2. Reticle Pattern, M3 (10x) Telescope, M24 Sniper Weapon System (SWS).

In sum, the author is satisfied that stadia is not likely to provide the level of accuracy a first-round-kill-sniper requires at long range where it is critical to a firing solution. Further, stadia is something that can be broken, increases the cost and clutters up the field of view of an optical sight.

Having roundly criticized stadia, it is necessary to balance the criticism: First, stadia and other direct-view, passive, optical range measuring devices are not burdened with an aiming error. None of this class of devices emits a detectable range-measuring signal; in abstract, at least, this fact should contribute to the sniper's survivability. Second, stadia with a 12 to 18 percent SIGMA range error probably does not provide a worthwhile increase in performance over eye-estimated range when the latter error is about 21 percent SIGMA. Stadia might become a more desirable option if eye-estimated range errors were, as is shown in the MELIOS OT I data, really 40 to 50 percent SIGMA. The relative desirability of stadia also is increased when it is recalled that the MELIOS, at the closest ranges tested, measured range with the user's required accuracy 68 percent of the time.

2.4.1.4 A Method to Approximate the Required Precision of Range Finders Used by Snipers. The importance of an accurate range measurement varies with the size of the target and with the type weapon being employed; for any small arms it is directly related to the common engagement ranges expected and to the intrinsic shape of the trajectory of the weapon considered--a weapon (its bullet, actually) with a flat trajectory is less sensitive to range errors than is a weapon with a more curved trajectory. Normally, the maximum ordinate (height) of the trajectory is used as the point of comparison between two small arms weapons or cartridges; however, the angle of fall is, generally, a more useful measure.

Concept and Basic Assumption.

In the discussion at hand, the angle of fall together with a target of interest (one of some specified height) will be used to determine the limits--called danger space--along the falling branch of the trajectory within which the target will be struck. Other errors are not considered. Used in this manner, danger space is treated as a solution space-a finite limit on the amount of range error (estimated by eye or measured by a range finder) that can be tolerated in a particular fire mission. In this regard, a tolerable error is one where virtually the entire distribution (+ and - 3 SIGMAs) is contained within the calculated danger space of the projectile-range-target of interest.

Bear in mind that the effect of an error made in estimating or measuring range is to create a vertical error that offsets the trajectory from the point of aim. The effect of the vertical bias depends on things like the shape of the trajectory, the size of the target, the type of sights and the aiming policy used. Generally, the effect of this bias on hitting is lost when the shooter has a large aiming error--as is the case with the GP rifleman. The full effect of a Y bias created by a range measurement error is only evident with small aiming errors like those that are estimated for the sniper in Table 2.19. A shooter who is firing rounds into the blue would not profit from knowing the range to his target exactly.

The core assumption of the method now being explained is that the shooter has an aiming error small enough that it makes sense to provide him with a range finder of a certain quality (precision). The outcome of the method is a basis to quantify the level of precision needed by a sniper, and using OT I data, to see if the AN/PVS-6 (MELIOS), without aiming error has that intrinsic level of precision.

Danger Space Defined.

Before developing estimates of the required precision of a range finder to be used by snipers, it is necessary that all have a common understanding of the meaning of the term danger space. Danger space (measured along the ground) is the space within which the trajectory of a bullet is not above the height of some specified target (historically taken to be a standing man--a height of 1.8 meters--70 inches is used now). Soldiers are mostly interested in the continuous danger space on the rising (near) end of the trajectory. The limit of continuous danger space, once a subject of serious study by theoretical tacticians and line officers, has always been a major point of comparison between two small arms weapons or cartridges.

Danger space calculations are usually based on level ground and normally consider the dispersion of the scatter of shot about the mean trajectory; doing this increases the dimensions of the danger space. The method of estimating the required precision of a range finder explained in this section is based on the mean trajectory on the falling branch; it does not consider the RRD of the sniper rifle and ammunition being used as examples. For this reason, the method provides a conservative estimate (allows smaller errors) of the precision required of a range finder. Figure 3 illustrates the concept.

DANGER SPACE = COTANGENT (1/TANGENT) ANGLE OF FALL TIMES TARGET HEIGHT

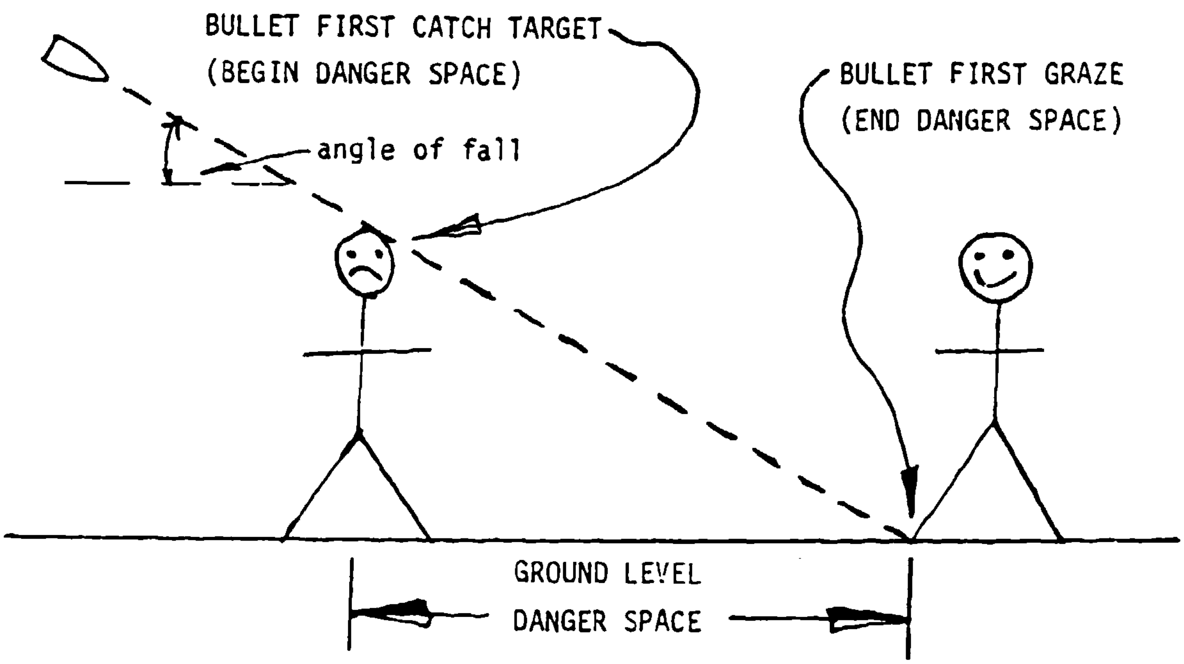


Figure 3. Danger Space on the Falling Branch of a Small Arms (Flat-Fire) Trajectory.

Note that danger space on the rising branch depends on the height of the weapon being fired, the height of the target and the point of aim. In 1918 the "Rules for the Management of the United States Rif'e, Caliber .30, Model 1903," showed a table of calculated "Dangerous Spaces" against standing infantry (68 inches high) and cavalry (8 feet) fired from the prone position (weapon height 12 inches) aimed at the center of the targets. The maximum continuous dangerous space against a standing man was given as 695 yards on page 67.

The method used here to estimate the required precision of a range finder was borrowed from a section dealing with coast artillery danger space in LTC Tschappat's Textbook for Ordnance and Gunnery, used at West Point in 1917. [16; p.465] LTC Tschappat showed in his text that danger space at some range of interest on the falling branch of the trajectory, is calculated by multiplying the height of the target in units of range by the cotangent [1/TAN] of the angle of fall (degrees). Coast artillery danger space calculations usually used a hypothetical warship, so considered the width of the target along the postulated line of fire in addition to the target height. This is an unnecessary refinement against a man target, but might have application against targets like tanks and APC for weapons like the 40mm MK19 that have large angles of fall.

Note in Figure 3 that danger space on the falling branch begins at the first catch and ends at first graze, and that the target will be struck within these limits. Both are archaic terms once used mostly to visualize the effects of MG indirect fire missions, but have been used here since they are descriptive as well as simple.

Danger Space for Two Sniper Rifles and Two Targets.

Table 2.9 shows several exterior ballistics characteristics of two rifle cartridges: The 7.62 x 51mm, M118 Match (sometimes called the M118 Special Ball) cartridge was type classified to be used in competition shooting where something more accurate than the standard M80 Ball cartridge was desired, so may be taken as representative of a GP rifle-caliber sniper cartridge in the field today. The M118 is likely to be the ammunition used by ordinary snipers on operations. The .358/.50 cartridge was designed by Mr. Bob McCoy of BRL for long-range sniper wor . (Reference 24) If this conceptual cartridge (one of several parametric designs for the SASR) were developed, it would use a .50 caliber cartridge case resized to .358-inch. Compare velocity, time of flight, maximum ordinate and angle of fall for the two cartridges: Notice how a shallower angle of fall is associated with a shorter time of flight and a lower maximum ordinate.

Table 2.9 also provides the danger space calculated using LTC Tschappat's method for a standing (ST) target: 1.80 meters high, and a crouching (CR) target: 0.87 meters high. No information on the width of the two targets is provided since danger space depends on target height only. Notice how the length of the danger space increases as the angle of fall becomes smaller and as the target height increases. The values in Table 2.9 are approximate, and in keeping with statements made earlier, do not consider the variability in RRD, but clearly such random variation could be included when appropriate.

Two different man-sized targets have been used because of their relevance to the classic sniper function. The fact that both are "soft" targets does not matter; the only thing of importance in this application is its vertical dimension.

Table 2.9. Exterior Ballistics and Danger Space for Two Possible Sniper Rifle Cartridges

VALUES ARE APPROXIMATE AND DO NOT CONSIDER VARIABILITY

	7.62MM, M118 MATCH (TYPE CLASSIFIED)						.358-.50 McCOY [a] (CONCEPTUAL SASR)					
RANGE METER	VEL MPS	TOF SEC	MAX ORD M	ANGLE FALL MIL	[b] DANGER SPACE METER ST	[b] DANGER SPACE METER CR	VEL MPS	TOF SEC	MAX ORD M	ANGLE FALL MIL	[b] DANGER SPACE METER ST	[b] DANGER SPACE METER CR
0	818	-	-	-	-	-	1006	-	-	-	-	-
500	532	0.8	0.7	7	262	127	830	0.6	0.4	3	611	295
1,000	326	2.0	4.9	27	68	33	667	1.2	1.8	9	204	98
1,500	259	3.7	18.8	70	26	13	520	2.1	5.2	18	102	49
2,000	219	5.9	49.7	131	14	7	393	3.2	12.4	35	52	25

a. REFERENCE 24, TABLE III.
b. DANGER SPACE ON FALLING BRANCH OF TRAJECTORY = COTANGENT (1/TAN) ANGLE OF FALL X HEIGHT OF TARGET OF INTEREST: ST = STANDING MAN (1.8 METERS HIGH), CR = CROUCHING MAN (0.87 METERS HIGH).

What the Estimates of Required Precision Represent.

Table 2.10 illustrates the development of a first cut estimate of the required precision of a range finder whose application is broadly described in Table 2.9. Table 2.10 continues the exposition begun in Table 2.9.

It is important to understand that Table 2.10 provides two sets of estimates whose differences depend on the definition of the terms system and intrinsic as they are used here. The estimates in <2> show the system precision required of a range finder. The 1 SIGMA values in <2> must not be exceeded if the range finder is to work inside the solution space generated by any of the cartridge-target-range danger spaces tabled. The term system is used to highlight that the allowed range finder error includes the device intrinsic error and other errors that distort, bend and otherwise perturb visibility and range measurement. In the case of a LRF and other active devices, an aiming error must be considered as well.

Table 2.10. Required Precision of Range Finder (RF) for 7.62, M118 and .358/.50 McCoy Sniper Cartridges; with Assessment of AN/PVS-6 (MELIOS) Intrinsic Performance [c]

VALUES ARE APPROXIMATE
PROVING GROUND ENVIRONMENT (NO OPERATIONAL STRESS)
INTRINSIC PERFORMANCE OF PVS-6 FROM 1985 USAIB OT I

<1>					<2>				<3>	<4>
DANGER SPACE [a][b]					SYSTEM PRECISION REQUIRED OF A RF: (1 SIGMA NOT EXCEED THE VALUES BELOW) [c] (% OF TRUE RANGE)				[d] PVS-6 (MELIOS) INTRINSIC ERROR SPACE	
RANGE	M118		.358/.50		M118		.358/.50		1 SIGMA	+ - 3 SIGMA
METER	ST	CR	ST	CR	ST	CR	ST	CR	% RANGE	METER
500	262	127	611	295	8.7	4.2	20.4	9.8	0.9	27
1,000	68	33@	204	98	1.1	0.6	3.4	1.6	0.7 I	42
1,500	26@	13@	102	4	0.3	0.1	1.1	0.5	0.5	45
2,000	14@	7@	52	25@	0.1	NOGO	0.4	0.2	0.3 I	36

@ = INTRINSIC PERFORMANCE OF PVS-6 IN <1> NOT SUFFICIENTLY PRECISE FOR THIS CARTRIDGE-TARGET-RANGE (+ OR - 3 SIGMA ERROR SPACE (METERS) IS GREATER THAN DANGER SPACE).
I = INTERPOLATED.

---

a. TRAJECTORY INPUT FOR DANGER SPACE FROM TABLE 2.9.
b. DANGER SPACE ON FALLING BRANCH OF TRAJECTORY = COTANGENT (1/TAN) ANGLE OF FALL X HEIGHT OF TARGET OF INTEREST; ST = STANDING MAN (1.8 METERS HIGH), CR = CROUCHING MAN (0.87 METERS HIGH).
c. IN ORDER THAT + OR - 3 SIGMA (99.7 % OF NORMAL DISTRIBUTION) OF RF ERROR SPACE DOES NOT EXCEED DANGER SPACE FOR CARTRIDGE AND TARGET OF INTEREST.
d. FROM <5>, TABLE 2.8.

A conscious decision was made to make the estimates shown in Table 2.10 conservative by not including the variability always found in the RRD of a weapon, its ammunition and its shooter. This course was taken even though it was understood that if variability were included, the size of the solution space would be increased--making the range finder's task easier, so to speak.

Required Precision of Range Finder.

It was said earlier that the distribution of range estimation errors in <1> and <4>, Table 2.8, is not symmetrical as it is usually thought to be. The data from the MELIOS OT I indicate that troops tend to estimate range long more often than they estimate it short--and with approximately double the error estimated in HELBAT I. This is an interesting development, since the conventional wisdom holds that the distribution of range measurement errors (troop range estimation, stadia and optical range finders) is approximately normal. Given this, it is likely that the intrinsic performance error of a LRF is also approximately normal. That said, there is no compelling reason to modify a major underpinning of the solution space method in order to satisfy potential challenges to the conventional wisdom.

Recall from the discussion of MELIOS range errors that six SIGMAs (plus and minus three SIGMAs) will contain about 99.7 percent of the population of a normal distribution. Thus, one SIGMA of the range finder error (expressed in meters) must be equal to or less than the length of the danger space for some weapon-range-target of interest divided by six. When this result is divided by range, the outcome is the maximum error that can be tolerated, expressed as a one SIGMA value in percent of true range. There is no reason to expect that, over the long term, any range finder including a LRF will systematically measure range long or short; accordingly, in the examples that follow, the mean range error will be taken to be zero.

Here is how the values in <2> were derived: Danger space in <1> at 1,500 meters for the M118 is about 26 meters for a standing man and about 13 meters for a crouching man. The.358/50 because of its less steep angle of fall has a danger space of 102 and 49 meters for the same targets at 1,500 meters range. A conceptual range finder must measure range to the two example standing targets with a one SIGMA precision error of approximately 4 meters for the M118 (26 divided by 6), and 17 meters (102 divided by 6) for the .358/50. Divide these values by the range of interest to obtain the SIGMAs expressed as a percent of true range--the values in <2> for 1,500 meters range are 0.3 percent for the M118 and 1.1 percent for the.358/50.

MELIOS Precision Included Only by way of Illustration.

The estimates in <3> and <4>, Table 2.10, represent the intrinsic performance of the MELIOS based on empirical data seen in OT I (they are from <5>, Table 2.8). Recall that the PRCT estimates in Table 2.8A showed that the MELIOS could not be used to measure range to a small target when the operator's aiming error was included in the error budget. For this reason, values representing the MELIOS intrinsic performance have been included in Table 2.10 only to illustrate how the danger space solution space idea might be used to evaluate the performance of a hypothetical range finder. (What follows can also be taken as an assessment of MELIOS if, in the unlikely event, its aiming error could be removed by some means.)

The value for the + and - 3 SIGMAs error space in meters in <4> is calculated by multiplying the 1 SIGMA percent of range value in <3> times 6, then multiplying this result by the range of interest. For example, a 1 SIGMA MELIOS intrinsic error of 0.5 percent of range is equal to about a 45 meter error space at 1,500 meters. This done, assessments that match the performance of a range finder with the imperatives imposed by a cartridge-target-range danger space can be made simply and directly: When the value in meters shown in <4> exceeds the danger space shown in <1>, the range finder does not have the necessary precision.

Those occasions when the MELIOS does not have sufficient intrinsic precision are highlighted with the symbol @ immediately to the right of the appropriate danger space in <1>, Table 2.10. In the case of the M118 cartridge, the MELIOS only has the intrinsic precision to locate a crouching man at ranges less than 1,000 meters, and a standing man at ranges less than 1,500 meters (M118 cartridge).

The MELIOS has adequate precision to support the conceptual 358/50 cartridge against a standing man at least to 2,000 meters. The case is less compelling against crouching targets beyond 1,500 meters, since the MELIOS error space shown in <4> at 1,500 meters range (45 meters) just fits inside the 49 meter danger space for that target.

2.4.2 Deflection (X) Bias Caused by Wind. Other things being equal, a projectile with a good aerodynamic shape retains its initial velocity during flight better than a less "efficient" projectile. One tangible benefit of this is a reduction in the time of flight (TOF) of the projectile. The sensitivity of the projectile to wind and to gravity is influenced directly by TOF, so the end result of an efficient aerodynamic shape is a reduction in bullet drop and in the distance a bullet is offset laterally by the wind.

2.4.2.1 GP Rifle Projectiles. Table 2.11 shows the sensitivity of four military GP small arms cartridges to a constant 2.24 mps (5 mph) cross wind, 90 degrees to the line of fire. (For whatever it is worth, winds crossing the line of fire at right angles are known as "full-value winds".) Note that the AK-74 round, with a nominal muzzle velocity less than the M193 has a smaller wind deflection than the M193 from about 100 meters to the limit of Table 2.11.

The M855 is least affected by wind of the four bullets; it is launched at a relatively high muzzle velocity and weighs about a half gram more than the M193 and AK-74 Type PS projectiles. The M855 has an efficient aerodynamic shape, so the combination of velocity and shape give it the shortest TOF and wind sensitivity of the four bullets.

Note in Table 2.11 that the 7.62 x 39mm, Type PS bullet is deflected much more by the wind than the M855, and only slightly less than the M193. It is not always true that a larger caliber rifle bullet will be less sensitive to the wind than a bullet of smaller caliber.

Table 2.11. Wind Deflection of Several GP Rifle Projectiles [a]

WEAPON	AK-47	AK-74	M16A1	M16A2
CALIBER	7.62X39MM	5.45X39MM	5.56X45MM	5.56X45MM
CARTRIDGE	TYPE PS	TYPE PS	M193	M855
V_0 (MPS)	715	900	991	940

2.24 MPS (5 MPH) CROSS-WIND (90 DEGREES TO LINE OF FIRE)

DEFLECTION (X BIAS) (METERS) [b]

RANGE METERS	TOF SEC	DEFL M	TOF SEC	DEFL M	TOF SEC	DEFL M	TOF SEC	DEFL M
100	0.15	0.02	0.12	0.02	0.11	0.02	0.11	0.01
200	0.32	0.09	0.25	0.06	0.24	0.09	0.24	0.06
300	0.52	0.22	0.41	0.17	0.39	0.20	0.38	0.14
400	0.76	0.45	0.59	0.33	0.57	0.37	0.54	0.26
500	1.04	0.76	0.80	0.55	0.78	0.62	0.72	0.42
600	1.35	1.14	1.04	0.83	1.06	1.02	0.93	0.65
700	1.69	1.59	1.32	1.21	1.39	1.53	1.18	0.97
800	2.05	2.08	1.64	1.68	1.77	2.15	1.48	1.41

a. REFERENCE 9, TABLE 4.6.
b. TOF (TIME OF FLIGHT) FROM BRL FIRING TABLES BRANCH; DEFLECTION CALCULATED USING METHODOLOGY CONTAINED IN REFERENCE 33.

2.4.2.2 Sniper Rifle Projectiles. Table 2.12 also provides estimates of wind-caused deflection, but for three cartridges having potential application with sniper rifles. Other exterior ballistics characteristics of the M118 and the.358/50 are shown in Table 2.9. The 12.7x 99mm, EX211 has been added because it is presently being used by U. S. Navy Sea Air Land (SEAL) snipers. Remember that the caliber .358/50 cartridge is conceptual only.

Wind deflection for both tables was calculated using TOF provided by the BRL and Bob McCoy's methodology contained in Reference 33. The offset caused by other wind speeds can be obtained directly from both tables. A 10 mph wind would deflect the projectile twice as much as a 5 mph wind. Winds blowing from other than 90 degrees have proportionally less effect on the projectile.

Table 2.12. Wind Deflection for 3 Sniper Cartridges

CTG	7.62 X 51MM, M118	12.7 X 99MM, EX211	.358/50 CONCEPTUAL
V_0	818 MPS	866 MPS	1006 MPS

2.24 METER/SEC (5 MPH) CROSS WIND (90 DEGREES TO LINE OF FIRE)

DEFLECTION (X BIAS) METERS AND MILS [@]

RANGE METER	TOF SEC	DEFLECTION METER	DEFLECTION MIL	TOF SEC	DEFLECTION METER	DEFLECTION MIL	TOF SEC	DEFLECTION METER	DEFLECTION MIL
500	0.76	0.33	0.68	0.68	0.23	0.47	0.55	0.12	0.24
1,000	1.98	1.69	1.72	1.63	1.06	1.08	1.22	0.51	0.51
1,500	3.74	4.26	2.89	3.00	2.83	1.92	2.07	1.29	0.88
2,000	5.85	7.61	3.88	4.74	5.43	2.77	3.18	2.66	1.36

@ TOF FROM BRL FIRING TABLES BRANCH; DEFLECTION CALCULATED USING METHODOLOGY CONTAINED IN REFERENCE 33.

2.4.3 Range (Y) Bias Caused by Use of Battle Sights. While the author has not made a deliberate search to find the first use of battle sight, he has observed a drawing of the Springfield Rifle rear sight, model of 1879. Ranges less than 600 yards are set by moving a slider containing a "buckhorn-shaped" eye-piece up and down a ramp. A narrative accompanying the drawing says:

> The letter B opposite the 260-yard mark indicates the most suitable elevation for firing at an enemy's line of battle within a range of 400 yard,'aiming low'. [18: p.14]

Battle sights have been used for a long time with the understanding that the average rifleman probably cannot be relied on to set his sights in combat with the correct range as the target range changes--in effect, more often than not, his sights would be set wrong. Highly trained marksmen such as snipers are generally thought to be immune to this problem. The author has not found any hard evidence to support this claim for snipers, so remains skeptical.

2.4.3.1 Definition and Doctrine. Before discussing the battle sight range (BSR) for U.S. and Soviet GP rifles, the term should be defined. The Army Dictionary [AR 3205], defines a battle sight as:

> A predetermined sight setting that, carried on a weapon, will enable the firer to engage targets effectively at battle ranges when conditions do not permit exact sight setting.

The dictionary leaves the reader to make his own judgment concerning the meaning of the terms "engage effectively" and "battle ranges". The selection of the BSR to be used on a weapon is an important matter since the rear sight trajectory solution is only exact at the range selected and a vertical (Y) offset (bias) will occur at any other range.

U.S. doctrine requires that the rifle be carried habitually with the sights set to BSR unless there is need to set the sights to some other range and the time to do so. Soviet doctrine for the 7.62 mm, AK-47 rifle also requires the rifleman to carry his rifle with sights set, habitually as well, at battle sights. The AK4 FM tells the rifleman that firing is to be done with a sight setting corresponding to the range to the target, at ranges beyond 300 meters.

By doctrine, the American rifleman is taught to aim at the center of the visible target at all ranges [46: p.87]. This policy, theoretically, centers the densest portion of the round to round dispersion in the center of the target (COT) and maximizes the chance of a hit. It is difficult to aim at the same spot consistently on a relatively large target using a COT POA. At anything but very close ranges, the apparent size of the front sight obscures a small target. A POA at the center of the bottom of the target (BOT) makes for more discrete and consistent aiming. In theory only the upper half of the round to round dispersion pattern is contributing hits when a BOT POA is used, although it is true that rounds impacting short of the target are potential ricochet hits.

<u>2.4.3.2 Battle Sight Range</u>. At the present time BSR for the M16A1 rifle with M193 ball is 250 meters (the short-range sight); BSR for the M16A2 with M855 ball is 300 meters. As a matter of interest, BSR of the U.S. 7.62mm, M14 rifle is 250 meters [FM 23-71, 1964], BSR of the .30 caliber M1 rifle is 300 yards (274 meters). [FM 23-5, 1958] The Soviet AK-47 FM uses the term <u>standard sight setting</u> to describe what the U.S. calls battle sight, and gives 300 meters as BSR for the AK-47.

AMSAA estimates that the BSR of the 5.45mm, AK-74 rifle is 450 meters. [9: p.20] Reference 9 contains additional information on the subject of battle sight doctrine and aiming policies, together with the test data and analysis that led to the conclusion regarding BSR of the AK-74.

<u>2.4.3.3 Range (Y) Bias</u>. When any rifle is used with battle sights, the descending branch of the trajectory will only cross the line of aim (LOA) at the selected BSR. Figure 4 illustrates the idea. [9: Fig.7] This situation creates a range (Y) bias at any range other than BSR. The Y bias has the potential of influencing hitting in a manner similar to the X bias caused by wind effects on the projectile. Table 2.12A shows the range bias for the AK-74 rifle with a 450 meter BSR; Y biases are also tabled for a 300 meter BSR. This has been done in order to illustrate the importance of BSR selection on hitting performance.

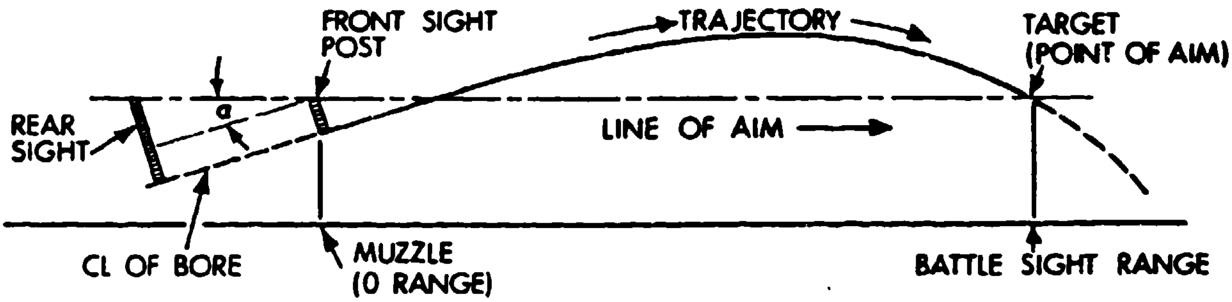


Figure 4. Battle Sight Range: Relationship of Trajectory to Line of Aim.

The values in Table 2.12A given for the appropriate Y bias at range are from a 3 degree of freedom (point mass) trajectory exercised by BRL. The values are approximate but of sufficient accuracy to be used to account for vertical bias when estimating P_H.

Table 2.12A. Height of 5.45mm, Type PS (AK-74) Projectile Ordinate with Respect to LOA (Y Bias): Rear Sight Set at Battle Sight Range (BSR) (450 Meters) and at 300 Meters Range

	RANGE = 300 METERS		RANGE = BSR (450) METERS		
	HEIGHT OF ORDINATE ABOVE OR BELOW [-] LINE OF AIM			HEIGHT OF ORDINATE ABOVE OR BELOW [-] LINE OF AIM	
RANGE METERS	CM	(MILS)	RANGE METERS	CM	(MILS)
50	4.7	(0.96)	50	14.7	(2.99)
100	14.2	(1.45)	100	30.6	(3.12)
150	15.8	(1.07)	150	42.7	(2.90)
200	17.4	(0.89)	200	50.3	(2.56)
250	8.7	(0.35)	250	52.7	(2.15)
300	0.0	(0.00)	300	49.3	(1.67)
350	-22.4	(-0.65)	350	39.1	(1.14)
400	-44.7	(-1.14)	400	21.0	(0.53)
450	-85.5	(-1.94)	450	0.0	(0.00)
500	-126.3	(-2.57)	500	-44.1	(-0.90)
550	-192.2	(-3.56)	550	-94.4	(-1.75)
600	-258.0	(-4.38)	600	-159.4	(-2.71)
700	-458.2	(-6.67)	700	-343.2	(-4.99)
800	-746.2	(-9.50)	800	-614.7	(-7.83)

NOTES ON FOLLOWING PAGE.

a. REFERENCE 9, TABLES 4.4, 4.5.
b. VALUES BETWEEN EVEN 100 METERS BY STRAIGHT-LINE INTERPOLATION
c. ESTIMATE USING 3-DEGREE OF FREEDOM (POINT MASS) TRAJECTORY.

2.5 Aiming Error.

2.5.1 General. This section deals with the shooter's contribution to the error budget. All must understand at the outset that the aiming errors developed in this section (and all other aiming errors that the author has ever seen) represent a soldier in peacetime. The reader is advised to treat any estimate of aiming error or hit probability that is labeled or sounds like "combat" or "combat-stressed" with extreme caution. The important thing to understand is that the aiming errors developed from peacetime experiments provide an adequate basis for engineers to design effective materiel and for tacticians to employ the materiel intelligently.

Riflemen and other soldiers armed with a GP rifle, generally engage, or at least are interested in, targets within a range band where range estimation and wind errors only have a modest effect on his hitting performance. Sniper materiel must be designed to allow the sniper to engage at long-range. Given this, there are distinctly different (especially for the fire control engineer) error budgets for the rifleman and for the sniper. They may be characterized as follows:

GP Rifleman - Small bias errors, large aiming errors.

Sniper - Large bias errors, small aiming errors.

These characterizations oversimplify the situation, but serve as convenient points of departure for a more robust analysis.

It should be obvious that the characterization of the GP rifleman was made by an analyst who believes that his targets will, in general, be at relatively close range. For this reason, problems with miss-estimating wind and range and other effects that perturb accuracy are not operative elements of the ordinary rifleman's error budget. Aiming error dominates all else.

Do not look for a single aiming error that is characteristic of all situations--particularly for the rifleman. It would be better to consider the two aiming errors shown in this report as snapshots from a continuum. The author once thought it would be possible to define the sniper's aiming error within very narrow limits. Enough test data have been seen to show that such an idea was wrong. The sniper's aiming error is more narrowly banded than the rifleman's, but not all snipers are alike.

Training almost certainly accounts for the differences that have been seen in the performance of snipers. Given the information presently available, the author is satisfied that cartridges of extraordinary power (greater than, say, .300 MAGNUM) will add to the sniper's error budget; for convenience, the error will be called an aiming error.

This introduction ends with a final caution. The author has seen great variation in the performance of small arms weapons, ammunition and shooters. Sometimes it is possible to attribute the differences to different test conditions, but most times the variability is real.

2.5.2 GP Rifleman. By far the largest error term in the GP rifle error budget is attributed to the rifleman. The rifleman's hitting performance is influenced by two factors at least: training and stress. Stress is probably the dominant error source in an operation. Fear is probably the major cause of stress in combat, but the impact of fear on operational aiming error has not been quantified. The practical limits of what can be done to a test subject in a peacetime experiment to induce stress are severely constrained. The experimenter can create fatigue and anxiety to a limited degree. Simply reducing target exposure time (TET) and introducing targets in unexpected numbers, patterns, distances and directions reduces hitting performance, but does not replicate combat stress.

GP rifles and the ammunition they use are, intrinsically, more "accurate" than the typical rifleman (of any nationality) who shoots them. This statement holds true for all GP rifles and all riflemen. The key words are "typical rifleman." A championship-quality shooter can detect differences in "accuracy" caused by the RRD of GP rifles such as the AK-74 or M16A2 by the scores he turns in and by the size of his groups; it is unlikely that the typical rifleman can. The high scores the National-Match shooter records at long range are fired in events where he knows the range to the target and has a relatively long time to fire his rounds. Generally, the rifleman does not know the range to the target and has only a brief time to get off his rounds because people are trying to kill him.

In abstract, the rifleman must do several things to obtain a hit. In the broadest sense, he must determine a firing solution, and then point the weapon in space so the bullet hits the target. There are some obvious sub-tasks: But first, the rifleman must first make an assessment of how much time he will have to get off a round based on the description and activity of the target to be engaged. His firing solution will include an estimate of the distance to the target and the effect the wind will have. He must set his sights if he has this type of sights, thinks he will have time and has been trained to do so. Alternatively, he must determine an offset POA (Kentucky elevation and windage) with respect to the target if he is using fixed sights or battle sights. Finally, he must hold the rifle steady on the target. Prior to and concurrent with the accomplishment of these tasks, the rifleman will have assessed his perceived personal vulnerability in the situation. In the end he may not fire his rifle; if he does, the result will vary widely from one occasion to another, but will generally be poor.

Quantifying the rifleman's delivery error is difficult. There is no such thing as a single value that can be used under all circumstances, since the amount of stress he experiences as he shoots his rifle varies so widely and is so difficult to characterize. Two of the several empirical delivery error estimates that have been developed by the author for U.S. Army rifleman are shown in this section. One error is presented to represent a situation of relatively low stress, the other error is meant to portray the low-hitting-performance end of an experiment designed to represent an operational situation.

Note particularly, that the author does not represent the large delivery errors of Table 2.14 as "combat" delivery errors. The delivery errors in Tables 2.13 and 2.14 will be used to place practical upper and lower limits on the typical rifleman's peacetime delivery error for the hitting performance estimates that follow in Section 4. It will be shown later in the hitting performance estimates that the larger peacetime aiming error dominates the error budget.

AMSAA does not have any estimates of the Soviet rifleman's delivery error. Delivery error estimates developed for the U.S. Army rifleman will be used in estimating the hitting performance of the AK-74 and selected other rifles.

2.5.2.1 Aiming Errors Characteristic of U.S. Army Rifle Qualification Firing. The first delivery error is the smaller of the two delivery errors presented for the GP rifleman. The values in Table 2.13 represent the delivery error derived for a "typical" Army rifleman on the rifle qualification range. These estimates are for a relatively unstressed situation--for example, target exposure times run from 3 - 12 seconds. The hit/miss data in Table 2.13 are based on a sample of 1651 male recruits at Ft Benning, GA, ca. 1984. Note that there are no data for ranges less than 50 nor more than 300 meters--the limiting ranges used then in U. S. Army rifle practice and qualification. The values shown for the total delivery error were calculated using a polynomial (power fit) regression model.

Table 2.13. Empirical Delivery Error of GP Riflemen: Troops During Rifle Qualification Firing (Rifle Qual) [a]

RANGE (METERS)	50	100	150	200	250	300
TYPE TARGET [b]	F	F	E	E	E	E
NUMBER OF TGT	5	9	10	8	5	3
TOTAL SHOTS	8,661	13,172	14,817	12,360	8,621	6,032
TOTAL HITS	7,754	10,381	11,298	8,297	4,637	2,559
HIT FRACTION	0.90	0.79	0.76	0.67	0.54	0.42
TOTAL DELIVERY ERROR SD (MILS)	1.96	1.54	1.34	1.21	1.12	1.06

a. REFERENCE 9, TABLE 4.9.
b. RECTANGULAR APPROXIMATION OF TGT SIZE (METERS): F (PRONE) = 0.66 WIDE, 0.35 HIGH; E (CROUCHING) = 0.50 W, 0.87 H.

2.5.2.2 Aiming Errors Based on Worst Hitting Performance in Peacetime Experiments. The delivery error labeled WORST FLDEX shown in Table 2.14 represents the lowest (worst) 1/3 of the hitting performance continuum observed in experiments designed to represent an operational situation. These data have been selected from a data base of 188 hit/miss observations from eight different U.S. Army experiments. The earliest experiment was conducted by the Operations Research Office (ORO), Johns Hopkins University, for the Department of Army (DA) in 1951. The most recent experiment was done by AMSAA at APG in 1982. The majority (155) of the observations were taken at 300 meters or less range. There are no data for ranges beyond 500 meters. The aiming errors in Table 2.14 are not "combat" aiming errors; they are, however, the largest aiming errors that have been observed.

Note how the delivery errors decrease with range even though the error is quantified as an angle (mils). This is also true for the errors observed during annual Army rifle qualification firing--although not nearly so dramatically as the WORST FLDEX errors decrease. A major significance of this observation is that it is only possible to compensate for large aiming errors in a fixed, relatively narrow range band. This means that it will not be possible to design a muzzle brake compensator (MBC) to compensate for aiming errors at all ranges.

Table 2.14. Empirical Delivery Error of GP Riflemen: (Worst FLDEX) Worst Hitting Performance of Troops in Field Experiments - (Large, but are not Combat Aiming Errors) [a]

TOTAL DELIVERY (AIMING) ERROR POPULATION SD (MILS) [b]

RANGE (METERS)	25	50	100	150	200	300	400	500
DELIVERY ERROR SIGMA (MILS) [c]	11.79	7.99	5.42	4.31	3.67	2.92	2.49	2.20

a. REFERENCE 9, TABLE 4.10.
b. SIGMA REPRESENTS A POPULATION STANDARD DEVIATION.
c. VALUES ARE FROM A LEAST SQUARES REGRESSION OF DATA.

The term total delivery error is used in both tables in order to indicate that the error estimated is the sum of all errors for the occasion observed. The total delivery error includes those attributed to the weapon and ammunition, although these errors are relatively small compared to the errors attributed to the rifleman. For simplicity--and because most of the errors cannot be separated and quantified--all of the rifleman's errors are collected and designated an aiming error.

Estimates of the delivery error are quantified as a SIGMA so they can be combined (pooled) variously with the other system errors as was shown in formula [2]. The resultant total system error SIGMA is part of the input used in different algorithms to estimate P_H. The estimates are framed in mils in order to detect where phenomena that normally change in direct proportion with range have increased or decreased non-linearly.

2.5.3 Sniper. Much less is known about the sniper's aiming error than is known about the rifleman's error; accordingly, estimates of the sniper's aiming error are made with considerably less confidence by the author. The

1968 Sniper Capability Study is the only test the author is aware of where the sniper was exposed to anything resembling an operational setting; it is also the only test where the snipers used a field (silhouette) target and were in any way stressed by time. The limited data that have been seen discloses a great deal of variability in the sniper's performance. One can imagine that the sniper is highly trained, so it is reasonable to give him a small aiming error and visualize his error to be, generally, the smallest element of the error budget. The sniper's contribution to the system error budget would become a matter of some concern if the more gross bias errors (wind, range) were eliminated.

2.5.3.1 Combat Developments Command Sniper Capability Study Test, USAIB, ca. 1968. Table 2.15 is interesting in that it allows a comparison to be made of several weapons and classes of shooters directly from the same experiment. The hit fractions in Table 2.15 were not calculated by the author, but taken directly from the final draft of the 1968 Army Combat Developments Command Infantry Agency (CDCIA) Sniper Capability Study. The author, Langhorn Withers, said there was no attempt to design combat stress into the CDCIA test, and defined the hit fractions (the best estimates of P_H) as the ratio of the rounds hitting the target to the total number of rounds fired at the target. [22:p.C-2, C-5] Note that different values of P_H would have resulted if the hit fraction were defined as the ratio of rounds hitting the target to the number of targets exposed. In the latter instance, any rounds not fired (because the firer did not acquire the target, had a stoppage, was changing a magazine or was lolly-gagging) would count as a miss.

Test Conditions.

The trainee hitting performance with the M16A1 is provided to give perspective to the values for the AMU Shooters. Note that the total delivery errors for troops with the M16A1 are about 1/2 those shown in Table 2.14, although the hit fractions at 600 and 700 meters are about what is estimated in Table 4.2 using the aiming errors from Table 2.14. Table 2.15 contains some of the very few data points for riflemen firing the M16 rifle at ranges beyond 300 meters.

As nearly as the author can determine, the 1968 CDCIA study was never published. If true, this is unfortunate since it is an outstanding source of information. Any serious discussion of sniper capabilities, functions, organizations and materiel should include the information contained in the 1968 ACTIV Report (Reference 20) and the CDCIA report.

The "Sniper" in Table 2.15 is actually from the Infantry Officer Candidate School (OCS). Eight were selected from a group who were designated as Expert marksmen after rifle qualification firing. These men can be used as surrogates, representing the performance of a non-school trained sniper. The M84 (2.2 power) telescope they used had been characterized in other evaluations as only of marginal benefit at longer ranges, so it is not known if these test subjects would have done better with the 3 - 9 power variable range (VR) scope used by the shooters from the AMU.

The AMU provided the four "experienced snipers" who used the accurized M14 with the 3 - 9 power VR scope and the caliber .30/338-MAGNUM-a heavy-barreled, special-purpose rifle with 14 power telescopic sight, firing handloaded match ammunition. (Hand loads are usually of higher quality than standard ammunition.) [22:p.C-20] The M14 with the VR scope is very much like the present-day M21. E silhouette (crouching man) targets were exposed for 5 seconds at 50 and 100 meters, for 10 seconds up to 700 meters and for 15 seconds beyond 700 meters. [22:p.C-10]

Table 2.15. Total System Error (Weapon, Ammunition & Shooter) and Approximate Sniper's Aiming Error for Trainees and for Sniper-Quality Shooters

TESTED AT USAIB, FT BENNING, GA., ca. 1968 [a]

FIELD RANGE + CROUCHING (E) TARGET + TIME CONSTRAINED

NO COMBAT STRESS

A. TEST DATA AND TOTAL SYSTEM ERROR SIGMA (MILS) [b]

	TRAINEE M16A1 IRON SIGHTS M193 BALL		"SNIPER" W/ < 2 YR SERVC ACC M14/M84 M118 MATCH [c]		ARMY MKSMNSHIP ACCURIZED M14 3-9X VR SCOPE M118 MATCH [d] [e]		UNIT SHOOTER MATCH-GRADE 14X SCOPE .30-338 HLOAD [f]	
RANGE METERS	HIT FRAC	SIGMA MILS	HIT FRAC	SIGMA MILS	HIT FRAC	SIGMA MILS	HIT FRAC	SIGMA MILS
50	0.91	3.02	0.98	2.26	1.00	1.67	NO DATA	
100	0.84	1.78	0.89	1.59	1.00	0.83	NO DATA	
200	0.74	1.07	0.72	1.10	0.98	0.56	NO DATA	
300	0.45	1.12	0.50	1.03	0.92	0.49	NO DATA	
400	0.35	0.99	0.65	0.62	0.94	0.34	0.94	0.34
500	0.17	1.22	0.52	0.60	0.77	0.41	0.90	0.31
600	0.09	1.44	0.52	0.50	0.52	0.50	0.80	0.32
700	0.04	1.88	0.30	0.63	0.28	0.65	0.60	0.38
800	NO DATA		0.16	0.79	0.35	0.50	0.55	0.36
900	NO DATA		NO DATA		0.23	0.57	0.50	0.34
1,000	NO DATA		NO DATA		0.13	0.71	0.38	0.38
1,100	NO DATA		NO DATA		0.20	0.51	0.38	0.34
1,200	NO DATA		NO DATA		0.05	0.98	0.20	0.46
1,300	NO DTA		NO DATA		0.00	----	0.05	0.90

B. APPROXIMATE TOTAL SYSTEM ERROR AND SNIPER'S AIMING ERROR BEYOND 500 METERS (SIGMA MILS):

TOTAL SYSTEM ERROR	0.60 -0.80	0.40 - 0.70	0.30 - 0.50
LESS WPN/AMMO ERROR	0.20	0.20	0.15
SNIPER'S AIMING ERROR	0.60 - 0.80	0.30 - 0.70	0.30 - 0.50

NOTES ON THE FOLLOWING PAGE.

NOTES TO ACCOMPANY TABLE 2.15

a. REFERENCE 22, PP. C-19 TO C-21.
b. TOTAL SYSTEM ERROR CALCULATIONS BASED ON CROUCHING MAN TARGET.
c. "SNIPER" IS OCS CANDIDATE WHO QUALIFIED AS AN EXPERT MARKSMAN; M84 BEGAN AS THE STANDARD 2.2 POWER SCOPE FOR THE M1 RIFLE.
d. ACCURIZED M14 WITH 3 - 9 POWER VARIABLE RANGE (VR), APPROXIMATELY EQUAL TO PRESENT-DAY M21.
e. FOUR "EXPERIENCED SHOOTERS" FROM ARMY MARKSMANSHIP UNIT.
f. "HEAVY BARREL" WITH .30-.338 MAGNUM HANDLOADS AND 14 X SCOPE.
g. TARGET EXPOSE TIME: 5 SEC TO 100; 10 SEC TO 700; 15 SEC BEYOND.

1968 Sniper Capability Study Conclusions.

The range to which about 100 percent hits are made is about 200 meters for the accurized M14. Even in the absence of data, one can be pretty sure that it is 300 meters for the .30-338. Recall that the ACTIV report thought that weapons of this type were capable of much greater "effective" ranges.

Lang Withers, using P_H of 0.5 to define "maximum effective range," concluded: [22:p.16]

a. The average maximum effective range for all ordinary riflemen, using either the [GP] M14 and M16 is 300 meters. [Table 2.15 does not show data for the GP M14.]

b. A "well trained" sniper using an accurized M14 with the 3 - 9 power VR scope has a maximum effective range of 600 meters.

c. A "highly trained" sniper using commercial equipment has a maximum effective range of 900 meters.

Aiming Error.

No attempt has been made by the author to smooth the data presented in the Sniper Capability Study. One must take the hit fractions as estimates for this situation only. It is expected that another experiment would produce somewhat different results and that smoothing would occur only after the course of many experiments.

The estimates that follow are based on rough-and-ready, eyeball fits of the test data. The TOTAL SYSTEM error (including some aiming error) for ranges beyond 500 meters is:

a. For the two sniper rifles shot by AMU shooters, about 0.4 to 0.7 mil SIGMA for the accurized M14 and about 0.3 to 0.5 for the .30-338 MAGNUM.

b. For the less experienced "sniper" (OCS candidate) with a less capable sight, an error of about 0.6 to 0.8 mils SIGMA.

The following method was used to develop the sniper's approximate aiming error shown in Part B, Table 2.15: A weapon and ammunition error SIGMA of 0.2 mils (taken from Table 2.2) was given to the M14/M118's beyond 500 meters. The intrinsic RRD of the .30-338 should be somewhat smaller than the M14/M118, so it was given a SIGMA of 0.15 mils. These approximate weapon and ammunition error SIGMAs were removed from the total system error SIGMA using the the method shown in formula [2], and the remainder was attributed to the sniper as an aiming error. Note that with the weapon and ammunition error used in Table 2.15, the sniper's aiming error becomes the dominant error in the system error budget.

Note how the total system error drops rapidly with range to about 400 - 500 meters and then seems to increase. Note also the steep drop in hitting capability (and consequent increase in delivery error) beyond 1,200 meters. The same trend is apparent in Table 2.18 with a .50 caliber sniper rifle, but the author is not certain what is causing the apparent increase in aiming error in either case. Without doubt, the variability to be expected in any experiment (particularly one measuring the performance of soldiers) will account for some, perhaps much of the differences seen in the two situations.

2.5.3.2 Test of AMU Master Riflemen, USAIB, 1977. Table 2.16 adds a bit more information about the sniper's aiming error; however, these estimates are very restrictive, representing the performance of high-quality military snipers under very benign peacetime conditions. The USAIB describes the six test subjects as Master Riflemen. The estimates are for a bull's-eye target, a target that allows more exact aiming than does a silhouette target.

As a matter of interest, the data in Table 2.16 and in Table 2.2 are from tests of identical rifles. A sample of three of each manufacturer's type was used in both tests. Different lots of M118 Special Ball test ammunition were used, however.

Table 2.16 is based on test data taken at Ft Benning during November and December 1977. Five of the six Master Riflemen had one year of combat experience as a sniper; in sum, the six test subjects represented a minimum of 60 years of competitive shooting. Each test subject fired each of the three-weapon sample tested. [27:p.1-13]

The aiming errors attributed to the sniper in Table 2.16 are small in comparison with the errors shown in Table 2.15, yet both groups of test subjects came from the AMU at Ft Benning--in tests done nine years apart. Given the same quality test subject, more than likely, most of the difference in aiming errors can be attributed to the different targets and TET used in the two tests. It may well be that the Master Riflemen were more skilled than the AMU test subjects used in the 1968 test. The role that range and wind errors may have played is unknown.

The test portrayed in Table 2.15 was against a field (silhouette) target exposed for 15 seconds. The data used in Table 2.16 represent a test using the standard National and Palma Match bull's-eye targets where the shooter had one minute per round. Range estimation did not enter into the error budget. Table 2.16 represents firing from the most stable firing position; firers zeroed at each range; one man "doped" the wind and announced wind conditions to all firers; firers had strike feed-back. [29:p.2-4, 2-12]

Table 2.16. Approximate Sniper Aiming Error: Benign, Peacetime Conditions
Data from 1977 USAIB Sniper Materiel Test [a]

PRONE, SLING, SLOW FIRE, SIX "MASTER RIFLEMEN" FROM AMU
KNOWN RANGE + BULLS-EYE TARGET [e]

	SEMI-AUTO: 3 EA M21, M14 NATIONAL MATCH			BOLT-ACTION: 3 EACH M40, M70, PARKER-HALE		
	ALL USING ADJUSTABLE RANGING TELESCOPE (ART) (3-9 POWER)					
	ESTIMATED TOTAL SYSTEM SIGMA (MILS) [b] [c]					
RANGE METER	TOTAL SYSTEM	MINUS WPN/AMMO RRD	ATTRIBUTE TO SNIPER	TOTAL SYSTEM	MINUS WPN/AMMO RRD	ATTRIBUTE TO SNIPER
200 D	0.19	0.19 [d]	0.00	0.15	0.14 [d]	0.05
300	0.20	0.20	0.00	0.16	0.15	0.06
400	0.21	0.20	0.06	0.18	0.16	0.08
500	0.21	0.20	0.06	0.18	0.17	0.06
600 D	0.21	0.20	0.06	0.19	0.18	0.06
700	0.22	0.20	0.09	0.20	0.19	0.06
800	0.22	0.20	0.09	0.21	0.19	0.09
900	0.22	0.21	0.07	0.21	0.20	0.06
1,000 D	0.23	0.21	0.09	0.22	0.20	0.09
1,100	0.23	0.21	0.09	0.22	0.21	0.07
1,200	0.23	0.21	0.09	0.23	0.21	0.09

D = DATA AT THESE RANGES ONLY; TEST DATA IN INCHES/YARDS.

APPROXIMATE AIMING ERROR FOR BOTH = 0.10 MILS SIGMA

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a. AUTHOR'S UNPUBL WORK; DATA FROM REF 29, TABLES 2-4, 2-11.
b. ESTIMATES OF SIGMA USING POLYNOMIAL REGRESSION (POWER CURVE MODEL) OF MEAN RADIUS.
c. AMMUNITION USED IN THIS TEST (LC 60-6) HAD A RRD OF 0.10 MIL SIGMA AT 600 YARDS.
d. WEAPON/AMMUNITION RRD OF SAME SAMPLE OF WEAPONS FROM TABLE 2.2.
e. AIMING ERROR IS EXPECTED TO BE SMALLER AGAINST A BULLS-EYE THAN A LARGER LESS DISTINCT TARGET.

As in the case of Table 2.15, an approximation is made of the aiming error of the AMU Master Riflemen. It is important for all to keep in mind that the 0.10 mil SIGMA represents aiming on a bull's-eye target with practically unlimited time. One might make the case that we are interested in estimating the performance of a sniper in an operation. It is quite true that Table 2.16 is useless in this regard, that Table 2.15 is closer to the truth. Table 2.16 has been included to provide some basis to anchor the best performance (smallest aiming error) of the upper end of this class of military snipers.

The USAIB did an analysis of variance (ANOVA) of the data used in Table 2.16 at the ten percent level of significance; they concluded that there was no significant difference in the measures of accuracy they evaluated (including the mean radius) among the six makes of sniper rifles at any range. [27:p.2-8, 2-13] Note here that the mean radius is the summary measure reported by the USAIB that was selected by the author for use in the least squares regressions.

Taken at face value, the conclusion reached by the USAIB ANOVA has the effect of saying that Table 2.16 should only have a single set of (mean) values for the sniper system error, rather than the separate estimates shown for semi-automatic and bolt-action weapons. The author has not done a statistical test of these data, but is inclined to agree with the USAIB in this regard.

The author would expect the aiming error contribution to the system error budget to be the same for semi-automatic and bolt-action rifles, since the same telescope was used by all. Recall that the discussion accompanying Table 2.2 said that the intrinsic RRD of two different GP or sniper rifles will be the same at some range--taken by the author to be the range where the velocity of the bullet approaches the speed of sound.

Having said all of this, until further tests are done, separate estimates of the intrinsic RRD will be maintained for bolt-action and semi-automatic sniper rifles--even with the understanding that the differences, if real, can only have any practical meaning under the most restrictive, assumptions.

2.5.3.3 Practical Lower (Best) Limit of Aiming Error. Mr. Chronister's ability as a benchrest shooter was commented on in Table 2.6; his ability will be cited one more time to assist in fixing the lower limit of the sniper's aiming error. Mr. Bob McCoy of BRL passed this information to the author: Mr. Chronister was the winning shooter during the 1987 shooting season of the Original Williamsport (Pa.) 1,000 Yard Bench Rest Club. His performance makes useful data to include in this report. Figure 5 shows that Mr. Chronister shot a 10-round group at 1,000 yards whose extreme spread measured 4 3/8-inches (111 mm); this is equal to a Total System SIGMA estimate of 0.03 mils. This is less than the RRD SIGMA estimated in Table 2.5 for this class of rifle at that range.

The performance of Mr. Chronister and his system can be placed in perspective with the following, from the 1978 test done at APG on which the estimates in Table 2.2 are based: The smallest 10-round shot group using M118 test ammunition at 1,000 yards was recorded for an M40A1. The group, fired from a machine rest, had an extreme spread of 54.5 cm. (21.4"), equal to 0.16 mils SIGMA).

NAME OF WINNER: EARL CHRONISTER, YORK, PA.
RIFLE: HAND MADE .30-.378 CALIBER
SCOPE: PROBABLY 24 POWER WITH 50 mm (2") OBJECTIVE LENS IN A FLOATING MOUNT
BULLET: 250 GRAIN SIERRA MATCHKING HOLLOW POINT
EXTREME SPREAD FOR 10 ROUNDS: 4 3/8 INCH (111 mm) @
RANGE: 1020 YARDS (932 METERS)
TOTAL SYSTEM ERROR SIGMA: 0.03 MILS

SOURCE: PRIVATE CORRESPONDENCE, MR. BOB McCOY, BRL, TO AUTHOR, JULY 1987.

@ PREVIOUS SMALLEST GROUP = 5 INCHES; ALSO SHOT SMALLEST GROUP (41.5" ES = 0.16 MIL SIGMA) AT 1,870 METERS AT McCOY'S 1984 "ONE MILE SHOOT" AT FORT INDIANTOWN GAP, PA.

Figure 5. Smallest Round-to-Round Dispersion of 1987 at The Original Williamsport [Pa.] 1,000 Yard Bench Rest Club.

The exit pupil of a telescope (the usable light coming through the optical path) can be calculated by dividing the diameter of the objective lens (mm) by the magnification. The telescope described in Figure 5 has as exit pupil of about 2mm--about the diameter of the pupil of the human eye in very bright light. An exit pupil of this diameter is too small to be used effectively by a sniper under general operational conditions.

Appendix A provides additional information concerning the relationship of ambient levels of brightness to the diameter of the pupil of the human eye. Appendix A is interesting because it contains the original field data (six test subjects) dealing with the topic that was reported by Prentice Reeves in the Journal of the Optical Society of America (JOSA), March 1920. As nearly as the author can tell, the numerical values Reeves used in that JOSA article have been used, unchanged in any way, ever since. Hardy and Perrin, authors quoted many times in other works dealing with optics, credit Reeves' JOSA article as the source for their curve of the, "Variation of pupillary diameter with field brightness," in a text published in 1932. [36:p.189] More recently, TM 9-258, Elementary Optics and Application to Fire Control Instruments, December 1977, discusses the topic on pages 3-3 and 5-17. TM 9-258 credits Hardy and Perrin as the source of the information. [p.A-1]

The Enclosure to Appendix A contains basic optical formulas with which to see the interrelationship of the basic optical parameters. The interrelationships are illustrated using the optical characteristics of the 4 power telescope the UK is adding to its new 5.56mm, L85A1 GP Rifle.

2.5.3.4 Performance of Operational Snipers, USAIB, 1982. The author believes that the estimates contained in Table 2.17 are based on a test whose essential conditions--those that would tend to have an impact on the size of the RRD observed--were, with some exceptions that will be pointed out, the same as the test conditions portrayed in Table 2.16. An inspection of the two bottom-line aiming error estimates (0.10 mils for Table 2.16 vs. 0.65 mils for Table 2.17) shows that some sort of explanation is needed Different targets and times to fire were offered as a partial explanation of the differences seen in Tables 2.15 and 2.16. The same explanation cannot be used in the present situation.

Table 2.17. Performance of Army Snipers from Operational Units with Approximate Aiming Error

BULLS-EYE TARGET + BENIGN PEACETIME CONDITIONS
USAIB, FT BENNING, GA, SEPTEMBER - OCTOBER 1982 [a]
BENCHCHREST, UNLIMITED TIME, KNOWN RANGE, GOOD WEATHER

PART A. SIGMA (MILS) FROM MR WHEN THERE WERE 100% HITS:

		400 METER		600 METER		1,000 METER		1,200 METER
RIFLE	SCOPE	MR (IN)	SIGMA (MIL)	MR (IN)	SIGMA (MIL)	MR (IN)	SIGMA (MIL)	
M40A1	A	5.9	0.31	---------		----------		PLANNED
M40A1	B	NOT	TESTED	NOT	TESTED	NOT	TESTED	BUT NOT
M21	A	5.4	0.28	6.6	0.23	----------		SHOT
M21	B	5.2	0.27	7.3	0.25	17.3	0.36	DUE TO
C	A	5.7	0.30	7.4	0.26	----------		POOR
C	B	5.7	0.30	---------		----------		RESULTS
D	A	4.6	0.24	7.6	0.26	----------		AT 1,000
D	B	4.1	0.21	7.2	0.25	----------		METERS

PART B. SIGMA (MILS) FOR HIT FRACTION AGAINST 70" X 70" TARGET PAPER (WHEN THERE WERE LESS THAN 100 % HITS):

600 METER

RIFLE	SCOPE	FRACTION HIT	SIGMA (MILS)
M40A1	A	0.94	0.72
C	B	0.94	0.72

1,000 METER

RIFLE	SCOPE	FRACTION HIT	SIGMA (MILS)
M40A1	A	0.89	0.49
M21	A	0.91	0.47
C	A	0.56	0.79
C	B	0.83	0.54
D	A	0.96	0.40
D	B	0.88	0.50

Table 2.17 (cont'd)

PART C. APPROXIMATE AIMING ERROR FOR M40A1, M21 AND CODE C:

RANGE METERS	TOTAL SYSTEM ERROR LOW END (PART A)	TOTAL SYSTEM ERROR HIGH END (PART B)	ESTIMATED RRD OF M118 (TABLE 2.2)	ERROR (SIGMA MILS) ATTRIBUTED TO SNIPER LOW END	ERROR (SIGMA MILS) ATTRIBUTED TO SNIPER HIGH END
400	0.29	-------	0.20	0.21	0.69
600	0.25	0.72	0.20	0.15	0.69
1,000	0.36	0.59	0.21	0.29	0.55
			APPROXIMATE AIMING ERROR =	0.20	0.65

---

a. REFERENCE 34, SECTION III, APPENDIX A.
b. SAMPLE = 1 RIFLE EACH TYPE WITH 2 DIFFERENT SCOES; RIFLE CODE C = SEMI-AUTO USED WITH FOREIGN SPECIAL FORCES, CODE D = .338 CAL MODIFIED WINCHESTER M70; SCOPE A = 10 POWER, SCOPE B = VARIABLE 3 - 9 POWER.
c. TARGET = 20" DIA BULLS-EYE WITH 4" DIA CONTRASTING CENTER ON 70" X 70" TGT PAPER; 2" WIDE CROSS ON TARGET.
d. SNIPERS FROM 7TH & 10TH SPL FORCE GROUPS, 2D BN 75TH RANGER AND XVIII ABN CORPS MARKSMANSHIP TRAINING UNIT.
e. AMMUNITION (NOMINAL): M118 = LC12030, 1964, 175.5 GRAIN AT 2,550 FPS, .338 = HAND LOADED .338 WIN MAG CASE, 250 GRAIN SIERRA, SEMI-JACKETED, BOAT TAIL AT 2,700 FPS.
f. PROCEDURE: ZEROED, IF ZERO OBTAINED (NOT IN ALL CASES), FIRED 2 X 3-RD GP EACH WPN/SCOPE, EACH RANGE FROM CLEAN, COLD BORE.
g. MEAN ERRORS IN PART C. ARE ROOT MEAN SQUARES.
h. 9 * 2 * 3 = 54 POSSIBLE HITS.

Test Conditions.

The test in question was conducted at the USAIB in September and October 1982. Weather was generally hot and clear. Firing was conducted from a benchrest with a sandbag support and was terminated daily when atmospheric conditions might have influenced test data (when mirage conditions reached a "boil effect"); winds did not exceed two to four mph; it did not rain. It is unlikely that the weather degraded the performance of the test subjects. [34:p.2-6]

There were nine test subjects from the USAIMA, 7th and 10th Special Forces Groups; 2nd Battalion, 75th Rangers and the XVIII Airborne Corps MTU. Four were graduates of the 8 week USAIMA sniper school, another was a graduate of the 9th Infantry Division sniper course in Vietnam in 1969. The remaining three had no formal schooling in "long-range sniping". Familiarization firing was conducted to insure that test subjects were capable of using each weapon and telescope. [34: 1-13, 2-6] The author has the sense that these test subjects were not up to the skill level of the AMU Master Riflemen whose aiming error is represented in Table 2.16.

The test was done using a sample of one each of the following 7.62 x 51mm caliber sniper-quality rifles with M118 Special Ball: U.S. Army M21, USMC M40A1; a semi-automatic, delayed-blowback operated weapon used by a foreign Special Forces organization (CODE C). The CODE D weapon in Table 2.17 is a second party modification of a .338 caliber Winchester M70 bolt-action rifle (nominally a 16.2 gram (250 grain) bullet launched at 823 mps (2,700 fps). The caliber .338 was handloaded by the USAMTU at Fort Benning. There are no data concerning the RRD of either test ammunition caliber from an accuracy barrel. Each weapon was fired by each sniper with a CODE A scope (10 power) and with a CODE B scope (variable 3 - 9 power). [34:p.1-13]

The target, one that would allow precise, repeatable aiming, consisted of a 20-inch diameter bull's-eye with a 4-inch diameter contrasting center, on a 70 by 70-inch target paper. A 2-inch wide cross, running the full width and length of the target paper was added. See Figure 6 [34:p.1-13]

Firing was conducted at 400, 600 and 1,000 meters. Firing that had been planned for 1,200 meters was cancelled because of, " . . . the poor results achieved at 1,000 meters." Each firer zeroed his rifle/scope (probably at 400 meters); when the firer and a test officer were satisfied with the zero, the firer shot two, three-round groups from a cold, clean bore. [34:p.1-13] Firing from a cold, clean bore represents the operational sniper's environment; it probably affects the size of the shot group.

Aiming Error.

The SIGMAs in Part A, Table 2.17 were calculated using Dr. Grubbs' methodology based on a relationship with the mean radius. The SIGMAs shown in Part B were calculated by finding the value required to obtain the various hit fractions given for the 70 by 70-inch target at the different ranges. This was only done when there were less than 100 percent hits for the number of rounds fired. The latter method is less precise than calculating SIGMA using Dr. Grubbs' method and tends to overstate the SIGMA; nonetheless, it was used to obtain some information from the test data.

2.5.3.5 Operational Snipers Using 12.7mm SASR. Table 2.18 summarizes the hitting performance of U. S. Navy SEAL snipers with the .50 caliber SASR under benign conditions. Table 2.18 provides the basis for an estimate of the hitting performance of operational snipers under unstressed peacetime conditions; it also is one of the very few sets of data that measure performance of the same test subjects under the same test conditions from close to long-sniper range.

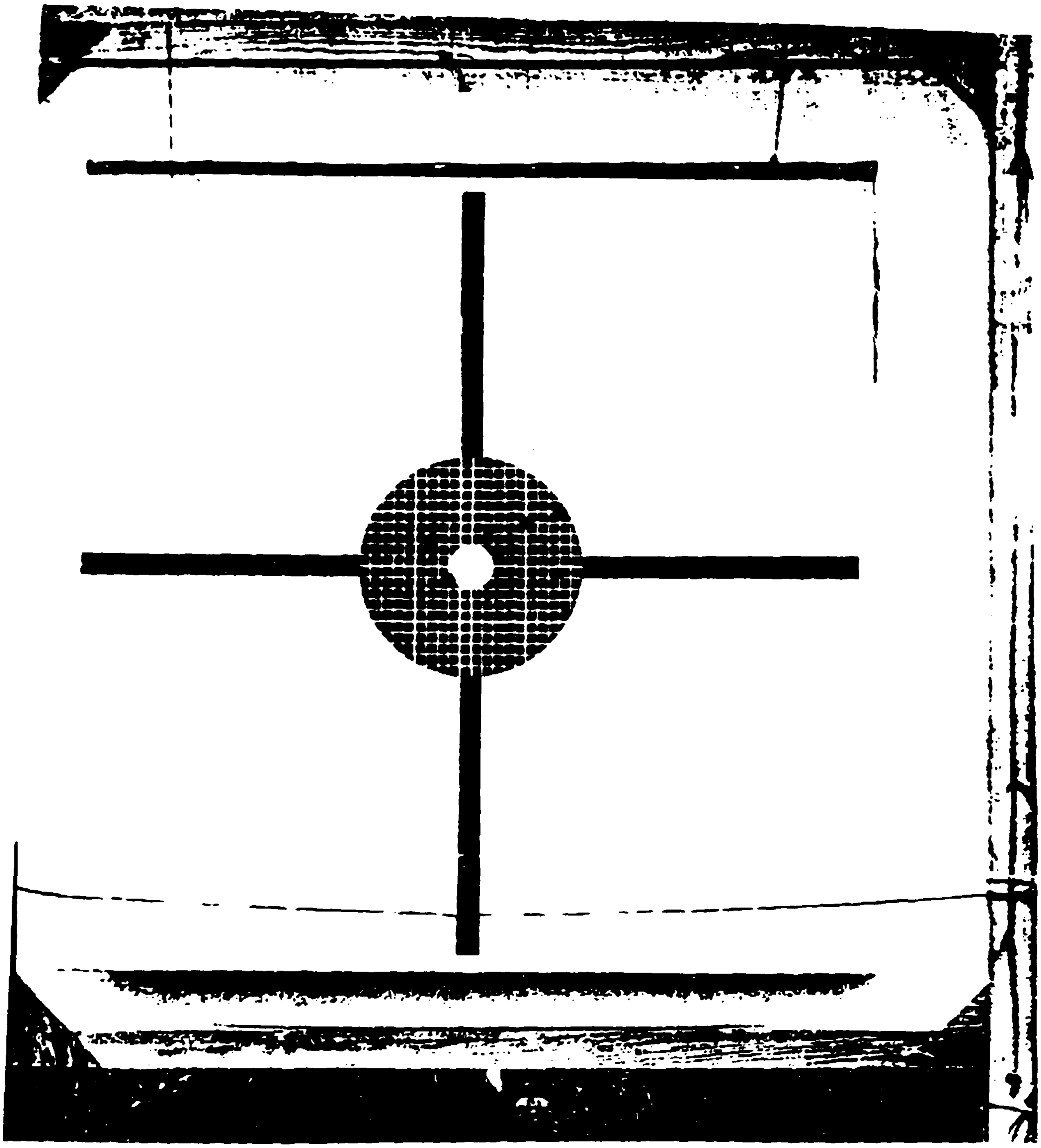

Figure 6. Target Used by USAIB in 1982 Test of Operational Snipers.

Table 2.18. 12.7mm Special Application Sniper Rifle (SASR) [b] with 12.7 X 99mm (U.S. .50 Caliber), EX 211 MOD 0 [c] Total System Error and Approximate Sniper's Aiming Error [a]

EARLIER VERSION OF DAISY SASR WITH 16 POWER TELESCOPE [d]
U.S. NAVY SEAL GUNNERS AT APG, MD, 1984-85
BULL'S-EYE TARGET + PRONE/BIPOD + BENIGN CONDITIONS + KNOWN RANGE

PART A. TEST DATA AND ESTIMATES OF SYSTEM ERROR:

TEST DATA (CENTIMETERS) [e]

RANGE METERS (YARDS)	ID OF SEAL	TOTAL SYSTEM ERROR [f] MEAN RADIUS	TOTAL SYSTEM ERROR [f] SIGMA (MILS)	LESS RRD OF EX 211 SIGMA (MILS)	AIM ERROR ATTRIBUTED TO SNIPER SIGMA (MILS)
183	1	6.5	0.30	0.25	0.17
(200)	2	6.4	0.30	0.25	0.17
[d]	3	6.0	0.28	0.25	0.13
POOLED MEAN (9 TGT) =			0.30	0.25	0.17
(600 YARDS) SEE NOTES g, h AND i.					
914	1	33.1	0.31	0.25	0.18
(1,000)	2	30.0	0.28	0.25	0.13
	3	34.2	0.32	0.25	0.20
POOLED MEAN (9 TGT) =			0.31	0.25	0.18
1,371	1	78.7	0.49	0.30	0.39
(1,500)	2	59.6	0.37	0.30	0.22
	3	64.9	0.41	0.30	0.28
POOLED MEAN (9 TGT) =			0.44	0.30	0.32
1,828	1	132.8	0.62	0.35	0.51
(2,000)	2	130.5	0.61	0.35	0.50
	3	127.2	0.60	0.35	0.49
POOLED MEAN (9 TGT) =			0.62	0.35	0.51

PART B. APPROXIMATE AIMING ERROR:

RANGE (METERS)	500	1,000	1,500	2,000
AIMING ERROR (SIGMA MILS)	0.20	0.20	0.30	0.50

NOTES ON FOLLOWING PAGE

NOTES TO ACCOMPANY TABLE 2.18

a. REFERENCE 32, TABLE 1.
b. DESIGNED BY RESEARCH ARMAMENT PROTOTYPES, ROGERS, AR; NOW OWNED BY DAISY MFG CO; APPROX 10.4 KG (23 POUNDS).
c. DESIGNED BY RAUFOSS, NORWAY; NOW OWNED BY OLIN.
d. 16 POWER LEUPOLD & STEVENS SCOPE ZEROED AT 200 YARDS.
e. MEAN BASED ON SAMPLE OF 3 TARGETS PER GUNNER EACH RANGE.
f. SIGMA CALCULATED USING GRUBBS' MEAN RADIUS FOR n = 10); SEE REFERENCE 25.
g. SIGMA (MILS) CALCULATED BY AUTHOR FROM MR DATA FROM NAVWPNSUPPCEN: SAME TYPE OF SHOOTER WITH SAME SASR = 0.26 MIL AT 600 AND 1,000 YARDS.
h. SASR FROM MACHINE REST AT 600 YARDS = 0.25 MIL EACH FOR M8 API AND MK 211.
i. RRD OF EX 211 INCREASED TO 0.30 AND 0.35 AT LONGER RANGES BASED ON DATA FOR 100 % VERTICAL CONE FROM .50 CALIBER M8 API FIRING TABLE.

Test Conditions.

The EX 211 Mod 0 API cartridge used in this test is a U.S. Navy designation for the NM 140A1 Multipurpose cartridge designed by A/S Raufoss of Norway. The EX 211, now owned by Olin, U.S.A., weighs 44 grams (679 grains). It contains an RDX explosive, an initiating pyrotechnic mix, a zirconium incendiary charge and a tungsten carbide penetrator. CSTA measured the muzzle velocity and recorded it as 865 mps (2,837 fps). [32: pp. 2, 11]

Each of three SEAL snipers fired one of three earlier versions of the SASR now owned by DAISY (16 power telescope) from the prone using the weapon's integral bipod. Each SEAL shot three 10-round shot groups at 200, 1,000, 1,500 and 2,000 yards at a bull's-eye target. Note that it is expected that the RRD would be somewhat larger if they had shot at a larger target without a clearly defined aiming point--an operational target.

Recoil Energy (Kick) of SASR.

CSTA limited firing to 30 rounds per day per sniper because of the high recoil forces. [32:p.2] The NAVWPNSUPPCEN calculated the recoil impulse of the weapons shown in Table 2.18A from measurements that they made on a ballistic pendulum during a 1987 test: The SASR marked with the symbol @ is the type used in the 1985 CSTA test. [27:p.14] Note in particular the impulse and recoil energy (kick) of the Daisy, bare muzzle, and the Daisy with a brake. The impulse of the 7.62mm, M14 rifle and 12 gauge shotgun, from the same test, are provided for perspective.

The phenomenon of kick (recoil energy) depends on the impulse of the cartridge (a function of bullet and powder weight, and launch velocity); it also depends on the weight of the weapon--a light weapon producing more kick than a heavy weapon. For this reason it is not, strictly speaking, correct to talk of kick--as will be done in succeeding paragraphs--without some notion of weapon weight, design and configuration in mind.

Recoil energy was calculated by the author with the weapon weights shown using a method outlined in Section XII of Hatcher's Notebook. [Reference 39] Hatcher appears to have relied to a considerable extent on the British Textbook of Small Arms, 1929, [40: Chapter VII] in developing his method, so both are cited as valuable references. The weights for the SASR were given in Reference 27, the author selected relatively light (stripped, empty) weights for the M14 Rifle and M870 Shotgun to represent the configuration that probably was used on the ballistic pendulum.

There is very little test data taken on a ballistic pendulum so almost all values for impulse and energy that are encountered have been calculated by one of several different methods--this is why the method used has been identified here.

Table 2.18A. Recoil Impulse And Recoil Energy of Several 12.7 X 99mm, Special Application Sniper Rifles [a]

WEAPON	APPROX WEIGHT (LB)	IMPULSE (LB-SEC)	RECOIL [b] ENERGY (FT-LB)
McMILLAN SASR, ORIGINAL BRAKE	24	5.5	20.3
@ DAISY SASR, ORIGINAL BRAKE	23	5.8	23.5
DAISY, BARE MUZZLE	23	17.1	204.7
7.62 X 51MM, M14 RIFLE	9	2.1	7.9
12 GA., M870 SHOTGUN W/ #4 BUCK	7	4.7	50.8

@ TYPE USED IN 1985 CSTA TEST.
a. REFERENCE 27: p. 14.
b. RECOIL ENERGY CALCULATED USING: [39: SEC. 12 & 40: CHAP. VII]

All methods of calculating recoil energy are sensitive to cartridge impulse and weapon weight. As an example, the author has calculated the recoil impulse of the 7.62mm, M80 Ball cartridge to be 2.67 lb-sec (11.87 newtons). In this instance, the recoil energy of the 9 pound M14 seen in Table 2.18A would be 12.7 ft-lb (17.3 joules) rather than the 7.9 ft-lb shown. This sensitivity is very important when recoil energy levels of certain weapons and munitions begin to approach the limits thought to be unsafe.

Aiming Error Methodology.

The TOTAL SYSTEM SIGMAs in Table 2.18 were calculated using the relationship between the mean radius and SIGMA outlined in Dr. Grubbs' "Red Book". [25: TABLE 5] The pooled mean values were calculated using formula [3] (Section 2.1.3). Look at Note g. These SIGMAs (0.26 mils at 600 and 1,000 yards), somewhat lower than those seen in the 1985 CSTA test, are from a test done by NAVWPNSUPPCEN in 1987. The SIGMAs calculated using the NAVWPNSUPPCEN data represent the performance of SEALs shooting what the author was told is a DAISY with "improved accuracy." This might explain the differences. Sample variability probably accounts for at least some, perhaps, most of the difference.

Any error in estimating the ammunition RRD will impact on the estimate of aiming error. This was never a problem for GP riflemen because his zone of interest was limited to say, 300-400 meters; his aiming error was gross compared to the weapon and ammunition error; a single value could be used for the weapon and ammunition error. It is different with the sniper's aiming error. His aiming error is generally relatively small; his zone of interest on occasion is far enough out that he is in a regime where the weapon and ammunition errors are non-linear with increasing range.

The ammunition error SIGMA was removed from the TOTAL SYSTEM ERROR SIGMA using formula [2], and the remaining error attributed to the sniper as an aiming error. Note in Table 2.18 that the RRD SIGMA of the EX 211 is 0.25 mils at 1,000 yards and less, but increases to 0.35 mils SIGMA at 2,000 yards. The amount of increase in the RRD of the EX 211 was approximated using the growth in the size of the 100 percent vertical cone as a function of range for .50 caliber M8 API, taken from FT .50-AD-1, 30 September 1965.

Part B of Table 2.18 provides an estimate of the SEAL's aiming error based on the APG test: 0.20 mils to 1,000 meters, 0.30 mils at 1,500 and 0.50 mils SIGMA at 2,000 meters. The estimate is qualified as an approximation--this is true of all of the author's estimates of sniper's aiming error at this stage in their development. Taken at face value, Part B says that the sniper's aiming error increases with range. This contradicts what is thought to be the case in the rifleman's regime--where aiming error decreases rapidly and begins to level off at some nominal value at about 200 - 300 meters.

The same apparent growth in aiming error was seen in Table 2.18. The SEALs used a bull's-eye for a target, so ambiguity concerning the POA is not adding to the error. The test was done at known range; CSTA reported that all testing was done in wind speeds less than 10 mph. A 10 mph wind usually would be expected to scatter the patterns somewhat; in this test, with few exceptions, the wind blew up-range where it has the least affect on RRD. [32:p.14] It should be understood that some unknown variability due to nonstandard atmospherics or test conditions may be present and is incorrectly being attributed to the sniper.

For the moment, the author cannot say if the sniper's aiming error truly increases with range, if the values in Tables 2.15 and 2.18 come from an artifact of his methodology, or if the situation is being clouded by sample variability Until further test data are seen, the author will, within the classes established in Table 2.19, generally use the same mean aiming error value for all ranges.

<u>Possible Relationship of Kick and Aiming Error.</u>

Another matter needs to be addressed here. The SEALs were shooting a weapon with a powerful kick. All, from MAJ Brophy in 1954 to the present, who have had anything to do with caliber .50 sniper weapons consider them to have a formidable kick. Although the SASR they fired at APG had an efficient muzzle brake, it may be that the SEALs unconsciously flinched and increased their aiming error beyond what it might have been with a rifle that kicked less or had less blast and noise. The author does not have any data for the same shooter firing 7.62mm and .50 caliber weapons under identical conditions, so will have to approach the matter from a different (and more hazardous) direction.

The tests described in Tables 2.16 and 2.18 are, on the surface at least, practically identical. Both tests were fired at known range from the prone position at a bull's-eye target; shooters were unstressed by time in both. The major apparent difference is that Table 2.16 represents shooters using a 3 - 9 power telescope, while Table 2.18 represents a 16 power telescope. The author cannot judge if the magnification of the two telescopes or some unseen subtle difference in the two designs had an effect on aiming error. If the quality (ability to shoot tight groups) of the AMU Master-class shooters in Table 2.16 can be taken to be approximately the same as the SEALs in Table 2.18, the difference in the value of the two aiming errors might be attributed to some difference in the kick, noise, blast or flash of the two weapons.

For the moment, the author is satisfied that at some level, increased kick will result in increased aiming error. The author believes that the magnitude of the kick can be correlated with caliber with sufficient accuracy to have practical utility in predicting aiming error. Until the analysis of other test data by him compels a change in his position, the author will, simplistically perhaps, increase the aiming error of a military sniper when he uses cartridges of extraordinary power (greater than .300 MAGNUM).

How much should the sniper's aiming error be increased to account for increased kick? Compare the 0.09 mil SIGMA aiming error at the 1,000 yard data point from Table 2.16 (7.62 mm) with the 0.18 mil SIGMA error at the same range in Table 2.18 (.50 caliber). The .50 caliber aiming error is twice the size of the 7.62mm aiming error. A 2.0 times increase in aiming error seems to be excessive, particularly for a single-round mission with a trained sniper. Until test data indicate something different, the aiming error of a sniper using a weapon greater than .300 MAGNUM caliber will be increased about 1.5 times. All snipers will be considered to be of the same quality in this regard.

2.5.3.6 Summary: Sniper's Aiming Error. Table 2.19 summarizes what the author has said about the sniper's aiming error so far. The estimates in Table 2.19 are labeled approximate, and should be characterized as the best the author can do with the data that he has seen. Whether or not the sniper's aiming error (mils) decreases with range to some low value and then increases is a puzzling aspect of the situation. The author would be more comfortable if he had a better feeling for the relationship of kick and aiming error. Probably the most worrisome problem with estimating an aiming error for a sniper is the total absence of any test data from a test done in anything resembling an operational setting (field targets, unknown range, wind).

Note in particular that Table 2.19 should not be used to estimate the performance of a sniper in a stressed, operational fire mission. The author is not aware of any data with which to make such an estimate.

Table 2.19. Sniper's Approximate Aiming Error for Unstressed, Non-Operational Conditions [a]

SIGMA (MILS) - CONSTANT ACROSS RANGE

CALIBER	QUALITY	[b] LEVEL 1 OPERATIONAL SNIPER	[c] LEVEL 2 CP PERRY QUALITY	[d] LEVEL 3 WMSPORT BENCH REST
UP TO .300 MAGNUM (SMALL CALIBER)	BEST	0.30	0.10	0.03
	WORST	0.80	0.30	0.10
> .300 MAGNUM (LARGE CALIBER)	BEST	0.50	0.20	NOT ESTIMATED
	WORST	1.20	0.50	

a. AUTHORS UNPUBLISHED WORK.
b. EXAMPLE: ANY SERVICES OPERATIONAL SNIPERS AT ENTRY LEVEL.
c. SUFFICIENTLY TRAINED TO COMPETE SUCCESSFULLY IN NATIONAL-LEVEL MATCH COMPETITION; AN EXPERIENCED SNIPER ON A GOOD DAY.
d. TAKEN BY AUTHOR AS REPRESENTATIVE OF THE TOP CLASS OF BENCH REST SHOOTERS; TOLD THAT THIS PERFORMANCE HAS BEEN BETTERED.
e. AIMING ERROR SIGMA TO BE ADDED TO WEAPON/AMMUNITION SIGMA; DOES NOT INCLUDE RANGE, WIND AND OTHER BIAS ERRORS THAT OFFSET COI FROM POA.
f. BASED ALMOST ENTIRELY ON BULL'S-EYE TARGETS, KNOWN RANGE, PRACTICALLY UNLIMITED TIME.

The final point to be made in a discussion of error budgets has to do with the great variability that characterizes the performance of materiel and soldiers; this situation has been mentioned several times in this report. Figure 7 portrays the variability graphically with plots of estimates of SIGMA (mil) taken from the same test data used in Table 2.18. Identical values were not plotted. Note in particular the scatter at 1,500 yards. Bear in mind that hitting performance is almost universally calculated using a central (mean) value for SIGMA, so the P_H reported is almost always a mean PH. Sometimes confidence intervals are placed around the mean value, but this is not a universal practice.

It is important to understand what the use of a mean value will have on perceptions of weapon hitting effectiveness. Table 2.20 illustrates this notion. P_Hs were calculated against a crouching target using the SIGMAs that had been calculated using the smallest, largest and mean hit fraction test data observed at 1,500 yards (Table 2.18). Note the very large variability in hitting performance that is masked when mean values are used.

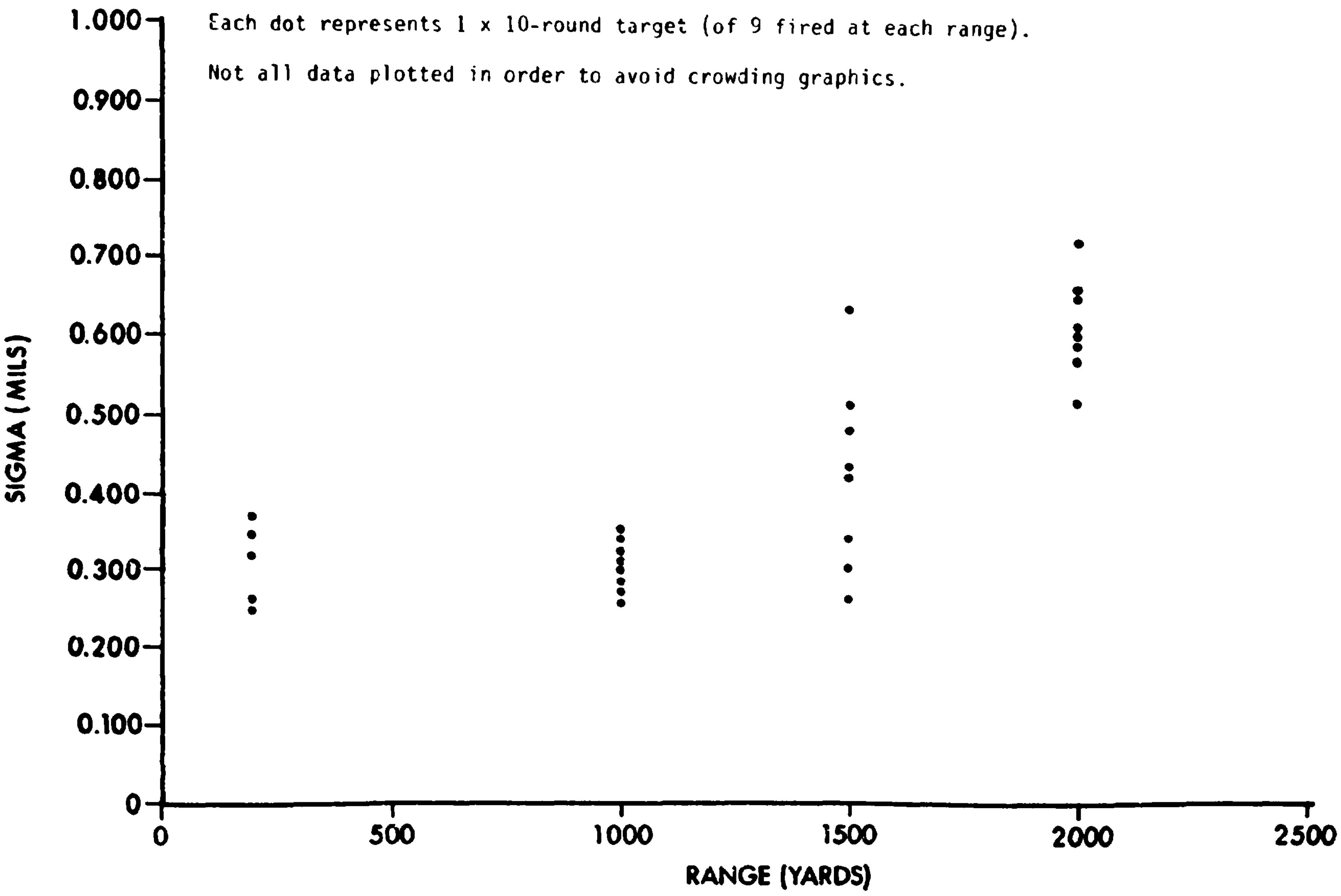

Figure 7. Round to Round Dispersion of 12.7 x 99mm (.50 Caliber) Special Application Sniper Rifle (SASR).

Table 2.20. Hitting Performance Calculations: [@]
Effect of Using Smallest, Largest and Mean Observed Test Data

U.S. NAVY SEAL WITH 12.7 X 99 SASR

SIGMA (MIL) REPRESENTS	VALUE	PH VS CROUCHING MAN AT 1,500 YARDS
SMALLEST	0.26	0.41
MEAN	0.44	0.17
LARGEST	0.63	0.09

@ AUTHORS UNPUBLISHED WORK USING TEST DATA FROM REFERENCE 32.

3. TARGET DISTRIBUTION

3.1 Small Arms Design and Target Distributions.

Users and developers of small arms need to have some understanding of the distribution of the ranges at which enemy targets are most likely to be encountered, and with what approximate frequency. Enemy targets are not evenly distributed over all ranges; consequently, the merit of any engineering approach to enhance the rifleman's performance, should be evaluated, in part at least, by assessing the degree to which it services targets in the most important (most dense) range bands.

It has already been said that the composition and magnitude of each element of the rifleman's error budget varies with range, and in the case of his aiming error, is non-linear over range. The size of a burst-fire or shotgun pattern increases with range, so it can only be optimized for a single, relatively narrow, range band. If it were desired to compensate for aiming error through use of a patterned dispersion, the size of the pattern should be selected to correspond to the range band where the enemy targets are expected to be most dense. An estimate of the rifleman's aiming error in this range band would be made and a compensating burst-fire pattern engineered. In some situations, the chance of a hit increases with the number of projectiles launched per trigger pull; unfortunately, the chance of wounding or inflicting damage given a hit decrease as the kinetic (striking) energy of the projectile decreases. In the end, questions of the most fundamental kind dealing with the size, number, composition, weight and velocity of a weapon's ammunition can only be answered with a notional target description and range distribution.

What follows provides a logic for dealing with questions concerning target-range distributions. The discussion begins by looking at the origin and development of the target-range distribution used almost universally since the early 1950's. This is done in order to provide a reasonable foundation from which to assess its validity. Some data from the recent action in Viet Nam and from campaigns in the Pacific in World War II are provided to show the effect that a jungle has on engagement ranges. Although not exactly germane to a discussion of target distribution, both of these sources comment on the relative lethal effect of bullet and fragmenting munitions.

3.2 Mission of Infantry.

Any discussion of rifle-caliber, small arms target distributions needs to be framed with an understanding of the mission of the infantry. The DA has given identical missions to the light infantry, airborne, air assault and mechanized infantry rifle companies:

> To close with the enemy by means of fire and maneuver to destroy or capture him or repel his assault by fire, close combat, and counterattack. [11:pp. 1-49, 2-43, 3-65, 4-51]

There will always be some uncertainty concerning the most likely range-target distribution. No matter which distribution is used, infantry small arms, particularly GP rifles such as the M16A2 must not acrifice close-range effectiveness. The issue of who is to own a particular piece of ground between motivated adversaries who have been given appropriate missions, ultimately will be decided at zero range.

3.3 Distribution of Targets.

3.3.1 ORO (WW II and Korea).

3.3.1.1 Impact on Small Arms Design. The curve labeled RBAR = 155 M.(1.0 X ORO) in Figure 8 (following Table 3.1) shows the cumulative form (the most common form seen) of a target distribution known worldwide since the early 1950's. To many it is known simply as the ORO Curve. The 1977 edition of Jane's Infantry Weapons (perhaps the world's most widely used small arms reference) shows a curve identical to Figure 8. [5:p.115]

The ORO Curve (together with ORO hitting performance estimates) has had a profound influence on the development, training and employment of small arms since the early 1950's. The ORO target distribution in Figure 8 was a major reason the U.S. Army made a fundamental change in its marksmanship training program. At one time the Army's recruit marksmanship training and annual rifle qualification firing shot at bull's-eye targets at known distances (KD) out to 500 yards; both programs were changed in the mid-1950's to shoot at human-sized targets to 300 meters only. (See Table 2.13 for additional detail.) The USMC marksmanship training program and its qualification firing still relies heavily on KD ranges.

3.3.1.2 Development of Original ORO Estimate. The ORO target distribution was first displayed in Technical Memorandum ORO-T-378, Salvo I Rifle Field Experiment, published by the Operations Research Office, Johns Hopkins University, in 1959. [1:p.78] The SALVO I report provided an analysis of work done for the DA by ORO that had begun at least as early as the Korean War.

The probable shape that the SALVO I ORO Curve would have in ORO-T-378, could be abstracted from the analysis and conclusions reached in ORO-T-160, published seven years earlier. ORO-T-160, reported on the outcome of the work done by the ORO for the DA in Project BALANCE. Three of its conclusions merit particular attention: [2:p.2]

a. 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 yards.

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

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

The major conclusion concerning target distribution in ORO-T-160 was based in part on several map analyses and intervisibility studies (terrain walks) and more importantly on the subjective input from riflemen with recent combat experience in the infantry. There were not enough data in 1951 to develop a numerical expression (fit) with which to construct a target distribution curve. ORO-T-160 relied heavily on information from two groups that had been sent to two different combat zones: The British had deployed an Operations Research Group to Europe during WW II and the U.S. Army had sent an ORO group to Korea in 1951. Both of the research groups interviewed experienced combat infantrymen; in the case of the ORO in Korea, at least, the interviews were conducted immediately after the action and on the actual ground, if possible. BG S. L. A. Marshall, with the ORO group in Korea, concluded that, "The great killing zone for the rifle is at less than 200 yards." [3:p.8] The ORO analysts examined the reports of the two research groups and noted that: [2:p.9]

> 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 [light machine gun] fire takes place at less than 200 yards and 90 percent at less than 300 yards . . . . 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 yards range (day time offensive fighting).

3.3.1.3 Target Distribution used in SALVO I. The conclusions regarding hitting performance in ORO-T-160 had been based on a modest two day experiment at Ft Belvoir, VA, in the fall of 1951. A sample of 16 men from the Engineer Replacement Training Center, qualified as Expert and 16 qualified as Marksman, used battle sights from the prone position against E silhouette (crouching-man) targets, located at 110, 205, 265 and 310 yards. The Project BALANCE analysts concluded in ORO-T-160 that a controlled (patterned) dispersion might compensate for the rifleman's large aiming errors and illustrated an idealized five shot pattern on page 94. ORO-T-160 recommended that several experimental weapons be designed and tested in a follow-on experiment (the SALVO I Rifle Field Experiment).

In order for the results of the SALVO I experiment to be accepted, in particular by the user, it was necessary for the experimental scenario to portray combat as faithfully as possible. Obviously, the scenario would have to have a credible enemy target array. The ORO group designing the SALVO I experiment wrote: [1:p.69]

> It is apparent that the test depends critically on the model of target system that is selected. The seven primary target characteristics that critically affect the aiming errors are size, range, exposure time, visibility, movement, disclosing activity and confusing context. . . . A good model should include a number of targets that are characterized by appropriate distributions in each of the seven characteristics.

The ORO test designers purposely designed the SALVO I experiment to accurately represent WW II and Korea by blending the seven target characteristics (including range) into a scenario controlling the number, type, interval, formation, range, duration and action of the targets to be used in the experiment. The exact values used came from a detailed questionnaire answered by twenty-six company grade officers with the Combat Infantry Badge stationed at Ft Benning in 1956. In effect, what we call the "ORO Curve" was an outgrowth of efforts to portray combat as realistically as possible in the SALVO I experiment.

<u>3.3.2 Target Distribution Formulas</u>. The target distribution for aimed fire derived from the responses of the 26 officers is shown in two parts in Figure C6 of the SALVO I report. The formula below at [4] is for calculating target frequency and the formula at [5] is for calculating the cumulative frequency; both are from Figure C6. ORO-T-378 used a mean range (RBAR) of 170 yards (155 meters) to produce the two curves seen in Figure C6.

$$f(R) = (4R \;/\; RBAR^2)\; e^{-2R/RBAR} \qquad [4]$$

$$F(R) = 1 - [1 + (2R \;/\; RBAR)]\; e^{-2R/RBAR} \qquad [5]$$

The notation f(R) is the fraction of all targets engaged by aimed fire at range R, F(R) is the cumulative fraction of targets at range R and RBAR is the mean range.

Credit should be given to R. H. Peterson of BRL (deceased) for providing the intellectual basis for ORO's work with range distributions. The authors of ORO-T-378 said that the analytical data fit shown in Table C6, " . . . had been found to fit data [from Europe in WW II] on ranges of fire received by U.S. tanks (with a different mean range of course)." [1:p.77] They cite Peterson's Memorandum Report 590, published by BRL in 1951, as the basis for their data fit. As a matter of interest, Peterson used a mean range of 660 yards in his report dealing with WW II tank casualties. [4:p.15] The two polar plots in Peterson's MR 590 may well be the first in the U.S. to represent the distribution of hits on tanks in the now familiar cardioid shape. Peterson is also given credit by the ORO for the methodology used by them in their terrain intervisibility studies. [2:p.13]

3.3.3 Target Distribution Estimates. Table 3.1 shows estimates of the cumulative fraction of targets engaged with aimed fire with a rifle, calculated using the formula at [5]. Figure 8 shows the estimates graphically.

Table 3.1 provides cumulative frequencies calculated starting with the ORO mean range of 170 yards (155 meters). Target distributions for two other mean ranges, 1.5 and 2.0 times larger than the ORO mean range are also tabled. This was done in order to show the effect different mean ranges have on target distribution.

Table 3.1. Estimated Target Distributions Based on an Estimate Made by the Operations Research Office, ca. 1959

AIMED RIFLE FIRE IN WW II AND KOREA [a]

CUMULATIVE FREQUENCY (PERCENT)

MEAN RANGE [METERS]	MULTIPLE OF ORO MEAN RANGE	AT RANGE [METERS] 50	100	200	300	400	500	600	800	1,000
155 [b]	1.0	14	37	73	90	96	99	100	100	100
233	1.5	7	21	51	73	86	93	97	99	100
310	2.0	4	14	37	58	73	83	90	96	99

a. REFERENCE 2, P.78.
b. ORO MEAN RANGE (RBAR) = 170 YARDS (155 METERS).

Jane's Infantry Weapons was cited earlier to show how universally the ORO Curve has been accepted; this may have overstated Jane's acceptance of the ORO Curve. Jane's offers this caveat in their 1977 Yearbook: [5:p.115]

> In fact, the figures are not universally recognized as having the required validity; nevertheless, in the absence of a convincing refutation, they are extremely persuasive.

Up until recently, the world of aimed GP rifle fires seemed to end at about 300 meters. Now the user wants to hit farther out with a GP rifle; for example, the Small Arms Master Plan requires a P_H of 0.90 at 500 meters. This change may have been caused by experience in the National Training Center (NTC) and the mid-east. The terrain at the NTC and in the mid-east will provide longer fields of fire than are found in the Korean or European terrain for which the ORO Curve was developed.

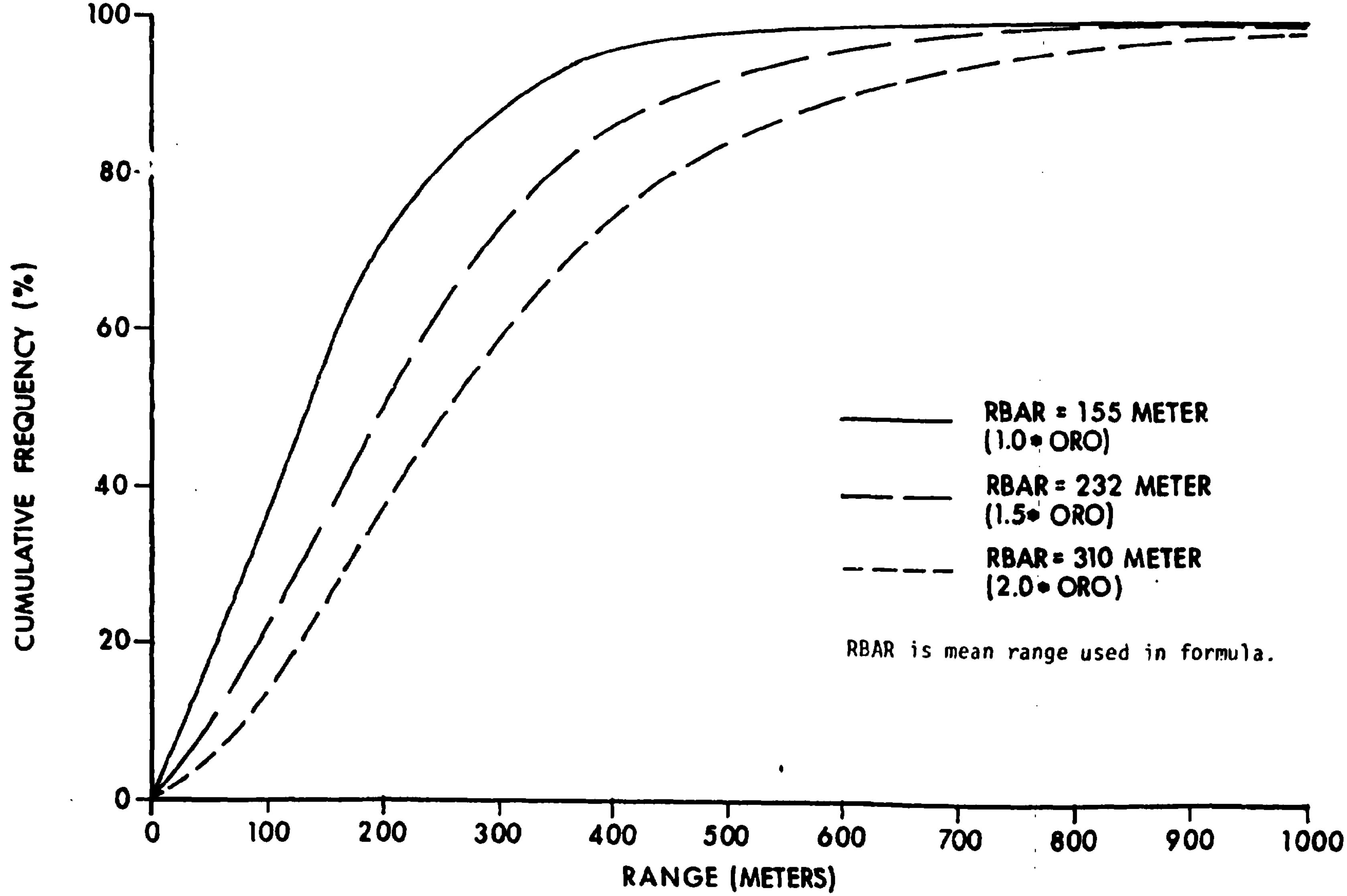

Figure 8. Target Distribution: Aimed Fire; Based on Operations Research Office (ORO) Estimate, c. 1959.

It is expected that a target distribution for desert and similar terrain with long-distance fields of fire, during conditions of unrestricted meteorological visibility, will lie about midway between the two greater mean ranges seen in Table 3.1 and Figure 8.

The actual target distributions used in any evaluation of small arms (any weapon system) is a matter of great importance. Most, perhaps all, of the measures that might be used to compare the effectiveness of different GP rifles are sensitive to the mean range used to represent the enemy target distribution. One simple measure of effectiveness is usually expressed as a single value that sums up the number of "enemy" (usually represented by one or more of the standard silhouette target types) that were killed at each range increment used in the engagement being modeled. The effectiveness number that is accumulated in this model is the product of the fraction of targets that are available at some range and the probability that the target will be killed (P_K).

The fraction of targets available to be engaged at any range in any effectiveness model is calculated by selecting some mean range (155, 232, 310 meters, or some other range) and using it in formula [4]. The importance of selecting the proper value to represent an operational situation typical of the sort that would be encountered by the system being evaluated should be obvious.

P_K depends critically on the ability of a GP rifle system to acquire, hit and kill. All of these parameters vary with range and may vary among weapons and ammunition of different designs, calibers and modes of fire. It is expected that differences large enough to influence the outcome of the ACR evaluation will be found in the probabilities of acquisition, hit and kill of the competing ACR technologies. The important point is that the curves describing the probabilities will have different shapes and slopes at different ranges. Think a moment of the differences in acquisition, hit and kill that might be found between the following: iron sights and optical sights; single shot and burst fire; single bullet, duplex, flechette; projectiles of relatively high and low mass, and velocity; now visualize the range where the differences are likely to be the greatest and the smallest.

If meaningful differences (to the ACR evaluation) are found in the probabilities of acquisition, hit and kill of the ACR candidates across range, the mean range selected to represent the enemy target distribution becomes a critical matter.

In preparation for the ACR evaluation, AMSAA requested the U. S. Army Training and Doctrine Command (TRADOC) to define the "infantryman's battlefield" including, "The distribution of the intervisibilities between firer and target and their time duration . . . ." AMSAA also requested that TRADOC provide the distributions for different geographic areas. If TRADOC does not provide the distributions (something that the author considers to be unlikely), AMSAA will evaluate the ACR contenders using the ORO distribution and a distribution representing a desert environment [a mean range of about 280 meters]. [55:p. 13] Bear in mind that evaluating the ACR candidates using both distributions still leaves unanswered questions concerning the relative importance of either--something that advocates of any particular system that may have been hurt will debate loudly.

3.3.4 Close-Range Distributions. It would be wrong to allow perceptions of long-range distributions to dominate the discussion. Close-range targets are relatively more important than long-range for a GP rifle. Table 3.2 shows one reason. In 1976, the Biomedical Laboratory, Edgewood Arsenal--then one of the Army's principal research agents for estimating lethality and wounding--conducted a study using data gathered by the Wound Data and Munitions Effectiveness Team (WDMET) in Viet Nam. From a total of 2,100 cases surveyed, 193 Army and Marine wounded were "definitely" identified as having been wounded by a bullet.

Note in Table 3.2 that better than 75 percent of the bullet wounds were fired by small arms at ranges less than 50 meters; note also that only two percent of wounds were from small arms at ranges of 300 or more meters.

Do not conclude from Table 3.2 that only nine percent (193/2,100) of casualties were caused by bullets. The 2,100 cases were screened and only cases in which bullets were identified by actual recovery, by x-ray, or by a witness to the wounding were selected. Casualties with more than one wound from different wounding agents were not included.

Table 3.2. Distribution of Engagement Ranges in Viet Nam for Wounds Caused by Bullets [a]

193 "DEFINITE" BULLET WOUNDS IN 2,100 WDMET CASES [b]

RANGE	FREQUENCY [c]	
METERS	OBSERVED	TOTAL
0 - 9	0.39	0.39
10 - 49	0.38	0.77
50 - 99	0.09	0.86
100 - 299	0.12	0.98
=>300	0.02	1.00

a. SOURCE: 1976 STUDY BY BIOMEDICAL LABORATORY, APG, MD., OF WOUND DATA AND MUNITIONS EFFECTIVENESS TEAM (WDMET) FIELD DATA. [6: TABLE 3]
b. U. S. ARMY AND MARINE CASUALTIES; 101 (52%) DIED.
c. N = 144; IT IS LIKELY THAT RANGE WAS NOT KNOWN BY THE BIOMED LAB IN THE REMAINING 49 CASES.

The Biomedical Laboratory made an assessment in the same memorandum on the severity of wounds caused by bullets. This is useful information to have in any discussion of the relative merits of bullets and fragmenting munitions as the ammunition for a GP rifle. [6:p.1]

a. Bullet wounds produce casualties who either die or require hospitalization in 98 percent of the cases.

b. Bullet wounds caused casualties to be, "functionally disabled", in 68 percent of the cases.

One of the volumes of the official history of the U.S. Army Medical Department in World War II is titled, Wound Ballistics. [Reference 7] Published in 1962, it is a major source of unclassified information and estimates dealing with this topic. Wound Ballistics consists of 883 pages with 364 figures and photographs and 308 tables; it provides comprehensive technical descriptions of enemy ordnance of that period and of the physics and physiology of wounding; it catalogs the number, type, location, severity and "causative wounding agent" for battle casualties in WW II (Bougainville, New Georgia, Burma, Italy, 8th Air Force) and in Korea. The study also contains detailed information concerning the value of body armor to 8th Air Force airmen during the European Bomber Campaign, and to Soldiers and Marines in Korea.

The Wound Ballistics study correlates the number, type and severity of wounds with the distance from the casualty to the weapon or bursting munition. This was done by way of answering medical workload questions, but the information can be used here to answer questions dealing with close-range target distributions. For example, the range to the Japanese rifles and MG causing the casualties in the WW II New Georgia and Burma Campaigns for 208 bullet casualties (93 rifle, 115 MG) is estimated in the study thus: ". . . the greater number of injuries occurred at distances under 75 yards." [7:p.271] In the Bougainville Island Campaign (Pacific, 1944) the approximate range of 460 rifle and MG was also estimated. About 80 percent of rifle-caused casualties and 86 percent of casualties caused by MG also occurred at a range of less than 75 yards. [7:p.421]

3.3.5 Distribution of Sniper Targets. In general, it is perceived that the classic sniper fire mission is against a target at long range. Defining the term long range with an actual range depends on the situation and terrain. Two examples suffice to demonstrate the actual engagement range variability that might be expected with a sniper weapon. In one case, the Army Concept Team, Viet Nam, examined 123 sniper fire missions and reported: [20: p.12]

Average range	400 meters
Maximum range	1,300 meters
Targets at 300 meters and less	22 percent
Targets at 300 to 600 meters	73 percent
Targets more than 600 meters	5 percent

The broken terrain and heavy vegetation in Vietnam are normally used to explain this relatively short-range sniper target distribution.

The longest sniper engagement range that the author can document came from the Korean War. In March 1952, William S. Brophy, then an Ordnance Captain, engaged enemy targets at a range of 1,200 yards (1,100 meters) using a commercial rifle and scope. [Report of sniping activities included with Reference 21] The author is satisfied that CPT Brophy is the first to use a caliber .50 rifle (a Soviet 14.5mm, PTRS-1941 antitank rifle mated to a barrel from a U.S. M2 MG) as a sniper's weapon against personnel targets.

4. HITTING PERFORMANCE

4.1 General-Purpose Rifle.

4.1.1 Historical Hitting Estimate. ORO-T-160 provided what may have been the first set of hitting performance estimates to have an impact on the acquisition of GP rifles. The author has seen contemporary reports by the BRL that provide a theoretical underpinning for work the ORO was engaged in, but cannot assess their influence on the movement toward a GP rifle replacement for the .30 caliber M1. Those interested in this matter might begin by examining two BRL Technical Notes by Donald L. Hall: TN 473, August 1951 and TN 883, March 1954; both report progress on Ordnance Research and Development Project No. TB3-0230I. (There is much valuable information in the TB3-0230I series.)

The values in Table 4.1 give some basis for the comments made in ORO-T-160 on the unsatisfactory hitting performance of the soldiers tested by the ORO in 1951. ORO-T-160 shows two P_H curves: one each for men whose rifle marksmanship qualification scores classified them as Expert and as Marksman.

The tabular P_Hs in Table 4.1 were picked off of the curve for Marksman directly from the report by the author. Ranges were converted by the author from yards to meters. Table 4.1 represents the earliest P_H estimates the author has seen, so are provided for their historical value.

The ORO P_H estimates in Table 4.1 appear as x's on Figure 9 (following Table 4.2). Note that the ORO P_Hs lie between present-day PHs calculated using RIFLE QUAL and WORST FLDEX aiming errors. No particular importance should be attached to this situation.

Table 4.1. Historical Hitting Performance of Soldiers [a]
Crouching man (E-Silhouette) Target Project Balance (ORO-T-160) Ft Belvoir, VA, 27 October and 10 November 1951

PERFORMANCE OF 16 SOLDIERS QUALIFIED AS MARKSMAN

DATA FOR TROOPS FIRING SIMULTANEOUSLY [b][c]

RANGE (METERS)	PH FROM ORO CURVE [d]
50	0.93
100	0.61
150	0.35
200	0.23
250	0.15
300	0.11
350	0.08
400	0.07
450	0.06
500	0.05

NOTES ON FOLLOWING PAGE.

NOTES FOR TABLE 4.1

a. REFERENCE 2, FIGURE A39, A40, TABLES A1 AND A2.
b. BATTLE SIGHTS FROM THE PRONE POSITION.
c. TARGETS EXPOSED FOR 3 SECONDS WITH 3 SECOND INTERVAL; ONE ROUND FIRED AT EACH.
d. ORO DREW SMOOTH CURVE TO 500 YARDS USING DATA POINTS AT 110, 205, 265 AND 310 YARDS (LAST DATA POINT).

4.1.2 Proportion of Ricochet Hits. The AMSAA Parametric Day Defense Test (PDDT) was conducted in 1968. Crouching-man targets, arranged from 50 to 300 meters, were engaged from a foxhole firing position. Test subjects were instructed to engage targets using single-shot-rapid-fire. The PDDT report estimated the following percent of hits to have been caused by ricochets: [41: Table VI]

RANGE (METERS)	7.62MM M14 RIFLE	5.56MM STONER Rifle
50	21 %	14 %
100	16 %	12 %
200	12 %	8 %
300	27 %	21 %

The proportion of hits caused by ricochet seen in the ORO SALVO II Rifle Experiment (Ft Benning, GA, 10 -12 December 1957) tends to be somewhat less than the PDDT. The summary data available to the author do not break out the data by range, consequently the following are average values against prone and crouching man targets from 62 to 310 meters. Rounds were fired semi-automatic from the prone position.

The SALVO II experiment used the .30 caliber M1 rifle chambered for a single-bullet (sometimes called simplex by ORO) and for duplex (2 bullets) and triplex (3 bullets) cartridges. The M1 was also chambered for a caliber .22 single-bullet (62 grains, launched at 3540 fps), and a caliber .22 duplex cartridge. ORO T-397 reported the following percent of ricochet hits (averaged over range): [42: Table 9]

	.30 CALIBER M1 RIFLE	.22 CALIBER MOD M1 RIFLE
SINGLE	16 %	20 %
DUPLEX	6 %	15 %
TRIPLEX	7 %	NONE FIRED

The SALVO II Rifle Experiment report had this to say about ricochets:

> One factor not recognized in SALVO I and not previously recognized as significant in combat rifle effectiveness was isolated in the SALVO II experiment--the importance of the ricochet characteristics of ammunitions. . . . If it is found to be an effect that

> occurs under most conditions of combat rifle fire, it may be well worthwhile modifying .30-cal duplex or 7.62mm NATO duplex ammunition for improved ricochet characteristics. [42: p.35]

An estimate of ricochet hits made before WW I tends to confirm the values reported in the PDDT and ORO reports. The U.S. Army Small Arms Firing Manual, 1913 says, "While various results may be quoted, it is probably correct to say that the maximum number of ricochet hits to be expected is about 20 per cent of the hits scored." [13:p.132] Musketry training of that period specified a POA at the bottom of the target.

The ORO thought enough of the potential of ricochets to enhance the effectiveness of rifle fires that it recommended that, " . . . the value and feasibility of improving the ricochet characteristics of . . . duplex ammunition should be investigated." [42: p.3] Note that the Army type classified the 7.62 x 51 mm, M198 Duplex. As late as 1981, the M198 was carried in the AMC complete round charts as an obsolete round for the M14 Rifle and M60 MG.

Ricochets have a potential to wound, suppress, and when properly used, provide the rifleman (who usually does not use tracer) with strike feed-back. Of all of the rounds that miss, rounds fired short of the target are infinitely more useful than rounds fired over. We should systematically look for ways of increasing the proportion of ricochets.

Changing the aiming policy in the current M16A1/A2 Rifle FM from a COT POA to a BOT POA might be one means of increasing ricochet hits and enhancing strike feed-back. In this regard, see Paragraph 5.2, FM 23-9, 1974 and Paragraph 3.9 Change 3, FM 23-9, 1983.

4.1.3 Scenario-Induced Stress in Peacetime Experiments. The author has seen the hitting performance and aiming errors from the 1957 SALVO II experiment advertised by some analysts to represent the performance of troops under stress. It is true that the SALVO II test design attempted to induce stress by making the test subjects run before firing, wiring them for electric shock,exposing them to battle noise sounds and setting off demolitions adjacent to them. A comment from the SALVO II report indicates that these artifacts were not able to create the stress the test designers had hoped to achieve:

> The most important conclusion that can be drawn from the report of the men is how little they felt their accuracy was affected by the experimental stresses. Questions on fatigue, effect of electric shock, battle noise, and explosions in the area all tended to elicit the same reaction: the men were not even aware of these stresses most of the time. The low temperature, snow, and rain did, in their opinion, adversely affect their scores, and they also complained about the heavy recoil of the shotgun [loaded with 32 flechettes]. [42:p.42]

The subject of stress and our ability to design and conduct a test where the test subjects are placed under conditions of "high combat stress" is topical once again.

A major user requirement, hence a major goal of the ACR development program, is to field a new GP rifle with a 100 percent increase in hitting performance compared to the M16A2 Rifle. AMSAA has said that improvements in hitting are likely to be considerably less than the user requires.

AMSAA's assessment notwithstanding, publications that are likely to shape the opinion of user rank and file say that the Army is looking for a new GP rifle that will increase combat hitting performance. Two brief examples illustrate: The IDR says that the goal is to produce, " . . . a rifle that increases the soldier's combat efficiency by 100 percent as compared to the currently issued Colt M16A2 weapon." [IDR, 5/1989, p. 540]

The American Rifleman sums up the goal this way:

> The Army hopes to field a rifle that will help infantrymen hit the enemy 100 percent more often than they can with the M16A2. [American Rifleman, July 1989, p.42]

Articles with more or less similar statements concerning the goal to increase combat performance can be found in the Army Times, Infantry magazine and Soldier magazine.

The P_H curve labeled WORST FLDEX in Figures 9 and 10 estimates the worst hitting performance likely to be seen for typical GP riflemen in a peacetime experiment. P_H was calculated using the delivery errors in Table 2.14 (which clearly indicates that it does not contain combat aiming errors). The meaning and attributes of the WORST FLDEX P_H curve given by the author have changed since it was first seen outside of AMSAA. In about 1984, it was used in a JSSAP briefing to represent a rifleman using the M16A2 in a high-stress situation. More recently, the Small Arms Master Plan used it (unchanged) to represent the hitting performance of a rifleman under combat stress, in order to quantify the improvements required by the user.

No one knows what the rifleman's combat hitting performance would be with the M16A1 or M16A2, the ACR, or any other rifle for that matter. Thus, the user will have to decide if any of the ACR candidates meet his combat hitting performance requirement by comparing them to the performance of the M16A2 in a peacetime test.

In sum: It is unlikely that any of the ACR candidates will produce 100 percent more hits than the M16A2 in the USAIB test. Even if this did happen, there is no assurance that the ACR could match this performance in combat--just as there is no assurance that the USAIB test truly represents the performance of the M16A2 in combat.

4.1.4 Full-Solution (Best Case) Rear Sight. Table 4.2 and Figure 9 show the single-shot hitting performance of a typical GP infantry rifle--the U.S. M16A2. A crouching man (E Silhouette) target--approximated by a single rectangle 0.50 meters wide by 0.87 meters high--is used in these (and all other) P_H calculations. A COT POA is used.

The P_Hs represent a rifleman using a full-solution rear sight who is correctly estimating range and setting his rear sight. The sight is properly designed, manufactured and is not damaged. The estimates labeled proving ground errors represent the intrinsic (best possible) performance of the M16A2 rifle.

The P_Hs for proving ground delivery errors represent the intrinsic performance of the rifle and M855 ball ammunition under benign test conditions. Table 4.2 contains the basic three-condition single-shot hitting performance estimates for the M16A2 rifle. Figure 9 shows the estimates graphically. The estimates were made using the system errors explained in Section 2. Note how the P_Hs decrease dramatically when RIFLE QUAL and WORST FLDEX delivery errors are introduced.

Table 4.2. M16A2 with Full-Solution-Range-Rear Sight: Probability of Hit vs Crouching Man (E-Silhouette) Target [a]

SINGLE SHOT - NO RANGE ESTIMATION ERRORS

DELIVERY (AIMING) ERROR

RANGE METERS	PROVING GROUND	RIFLE QUAL	WORST FLDEX	PH FROM ORO T-160 [b]
50	1.00	1.00	0.34	0.93
100	1.00	0.89	0.21	0.61
200	1.00	0.64	0.12	0.23
300	1.00	0.46	0.09	0.11
400	0.98	0.35	0.07	0.07
500	0.90	0.27	0.06	0.05
600	0.79	0.21	0.05	NOT ESTIMATED
700	0.63	0.17	0.04	NOT ESTIMATED
800	0.43	0.14	0.04	NOT ESTIMATED

a. REFERENCE: AUTHOR'S UNPUBLISHED WORK.
b. SEE TABLE 4.1; ORO T-160 CONTAINS THE EARLIEST PH ESTIMATES SEEN BY THE AUTHOR.

Armament and fire control engineers and soldiers responsible for the planning and conduct of training should use the region between the proving ground and the other P_H curves as a solution space. Viewed in this manner, it could indicate the degree and, perhaps, the kind of corrective action (including engineering designs) needed. Trainers, in particular, might examine the rounds and hours obligated to marksmanship programs.

Table 4.3 and Figure 10 allow the hitting performance of the U.S. M16A1 and M16A2 and Soviet AK-47 and AK-74 to be compared directly. The four P_Hs were calculated on a single occasion by the same analyst from a single data base using identical assumptions and algorithms, so the relative performance of the four rifles should be directly comparable. Figure 10 shows separate P_H curves for each of the four rifles for proving ground conditions,

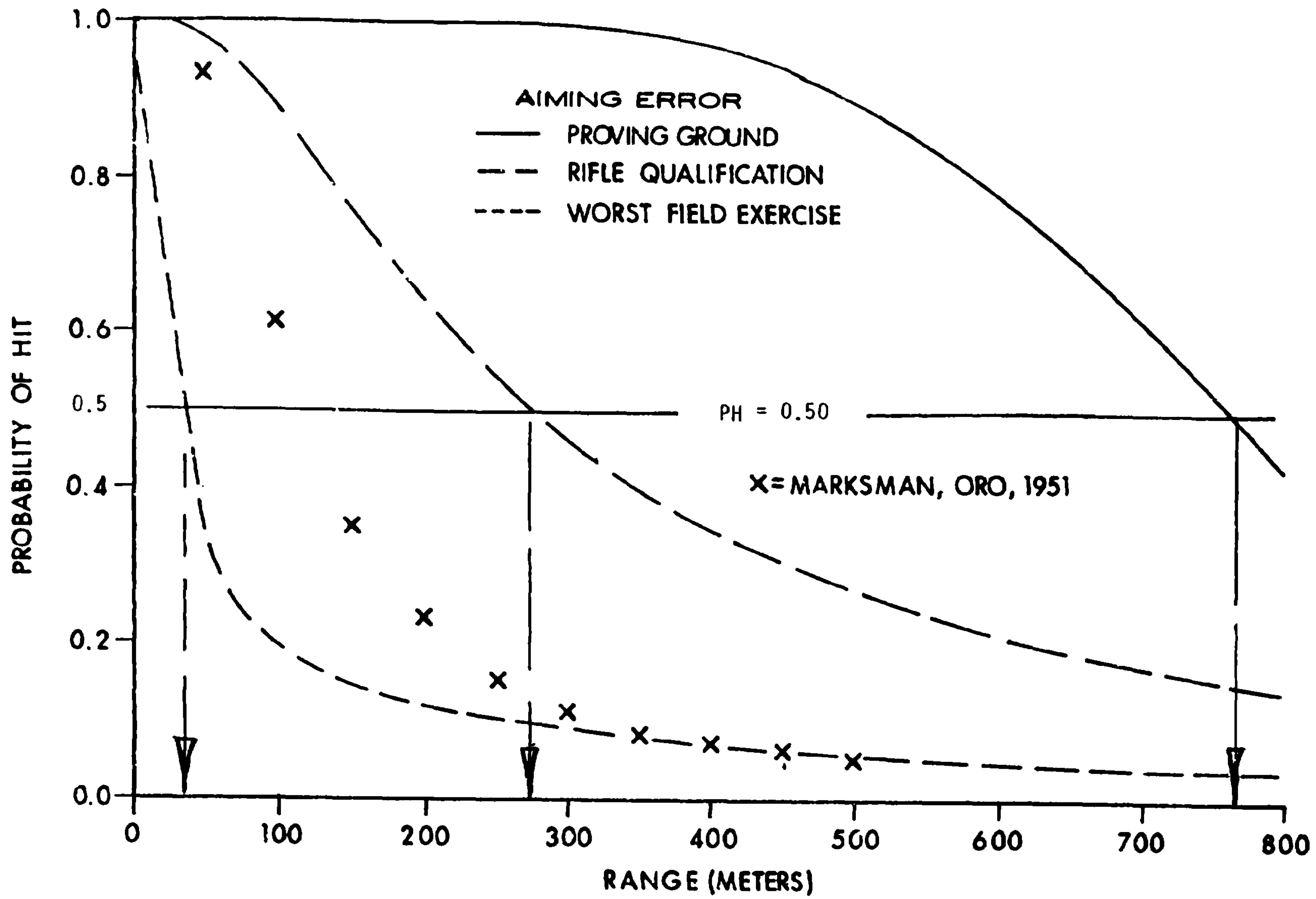

Figure 9. M16A2 With Full-Solution Rear Sight; Single Shot, No Range Estimation Errors: Probability of Hit (PH) vs. Crouching Man (E Silhouette) Target.

indicating that there are apparent differences in the intrinsic performance of the rifles. On the other hand, a single curve is sufficient to represent the performance of all four rifles when used by a rifleman shooting with WORST FLDEX aiming errors.

Table 4.3. Comparative Hitting Performance of M16A1, M16A2, AK-47 and AK-74 Rifles: [a]
Probability of Hit vs Crouching Man (E-Silhouette) Target

SINGLE SHOT - NO RANGE ESTIMATION ERRORS
WITH PROVING GROUND AND WORST FIELD EXERCISE AIMING ERRORS

	AK-74		AK-47		M16A1		M16A2	
	<-------- TYPE PS -------->				M193		M855	
RANGE METER	PROV GRND	[b] WORST FLDEX	PROV GRND	[b] WORST FLDEX	PROV GRND	[b] WORST FLDEX	PROV GRND	[b] WORST FLDEX
50	1.00	0.34	1.00	0.34	1.00	0.34	1.00	0.34
100	1.00	0.21	1.00	0.21	1.00	0.21	1.00	0.21
200	1.00	0.12	0.99	0.12	1.00	0.12	1.00	0.12
300	0.99	0.09	0.94	0.09	1.00	0.09	1.00	0.09
400	0.93	0.07	0.82	0.07	0.96	0.07	0.98	0.07
500	0.81	0.06	0.67	0.05	0.87	0.06	0.90	0.06
600	0.66	0.05	0.54	0.05	0.73	0.05	0.79	0.05
700	0.51	0.04	0.42	0.04	0.56	0.04	0.63	0.04
800	0.34	0.03	0.31	0.03	0.39	0.04	0.43	0.04

a. REFERENCE 9, TABLE 5.2.
b. WITH RIFLE QUAL AIMING ERROR, MAXIMUM DIFFERENCE IN PH AMONG ALL RIFLES IS 0.04.

It is not unusual for differences to be found in the intrinsic, technical performance of different weapons measured at a proving ground. It is almost certain that these differences will not have any operational significance. It is true, however, that the differences in the intrinsic RRD of the four rifles shown in Table 4.3 are large enough to be a concern to a championship-quality, competition shooter.

4.1.5 Maximum Effective Range of GP Rifles.

4.1.5.1 Nature of the Problem. Ask any rifleman what the maximum effective range (MERN) of the M16A1 is and practically all of them will give the "correct" answer--460 meters. Unfortunately, it appears that many in the small arms community (the users, trainers, doctrine writers, tacticians, analysts and materiel developers) disagree on fundamental aspects of the meaning of effective range as it applies to the GP rifle. This situation probably exists with all small arms, but is topical now with the GP rifle. Two examples are offered here to illustrate the existence of a problem and establish the need for a simple, unambiguous definition of MERN:

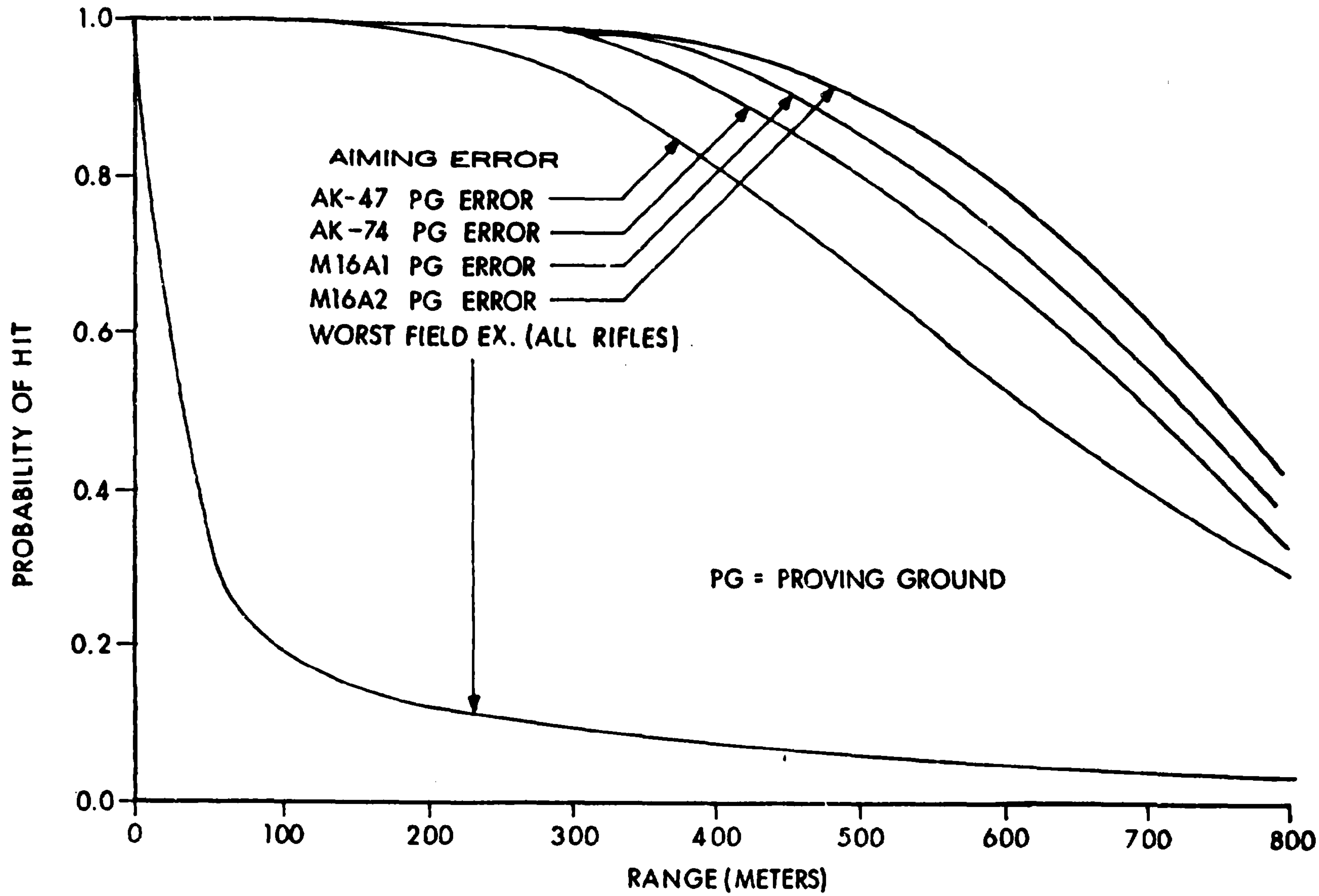

Figure 10. Comparative Hitting Performance of Soviet AK-47, AK-74 and U.S. M16A1 and M16A2 Rifles; Single Shot, No Range Estimation Errors: PH vs. Crouching Man Target.

a. Small unit leaders are taught to use MERN as the basis for certain fundamental tactical decisions. In this regard, the basic FM for the USMC Rifle Squad says, "Normally, it [the squad] should not open fire at ranges greater than 460 meters, the maximum effective range of the rifle." [FMFM 6-5, April 1966, p. 43] Similar examples could be provided from Army FM, but would be redundant.

b. The author recently heard the need for additional development effort for a standard night vision device justified on the basis of the day-time MERN of the M16A1. Here, additional development work on the device was thought to be necessary because the maximum distance to which the device allowed a standing-man target to be recognized at night was less than the day-time MERN of the M16A1 (given as 460 meters).

The scope of the problem begins to emerge when it becomes necessary to decide what the GP rifle must do or be capable of doing in order to be considered effective: A target or class of targets must be selected and acceptable levels of hit and terminal effects given a hit must be agreed on But, most important of all, a decision must be made on whether the rifleman will be included in the system error budget. Once agreement on the required tasks/capabilities has been reached, it is necessary to decide how far away the weapon of interest does the things the definition requires of it. A seemingly simple exercise, but as will be shown, one we have not come to grips with.

Any evaluation of the MERN of a weapon based on terminal effects (for example, the range to which helmets and body armor are penetrated) is only looking at the weapon indirectly. The bullet is the proper agent for assessing terminal effects. The only worthwhile difference in the operational performance (hit/kill) of the M16A1 Rifle (M193 Ball) and M16A2 Rifle (M855 Ball) has to do with the two cartridges.

4.1.5.2 Maximum Effective Range Defined. The U.S. Army has used 500 yards (460 meters) as the MERN of its GP rifles for about 40 years. While the value has remained constant, the definition of MERN has changed. The 1951 edition of FM 23-5, U.S. Rifle, Caliber .30, M1, said:

> At ranges over 500 yards, a battlefield target is hard for the average rifleman to hit. Therefore, 500 yards is considered the maximum effective range . . . . [p. 4] [underline in the original]

Editions of FM 23-5 for 1940 and 1943 do not mention MERN. The limiting range remained at 500 yards but the definition of MERN changed with the 1958 version of FM 23-5. Note the addition of the detection task to the definition of effective.

> The maximum effective range of the [M1] rifle is considered to be 500 yards. A battlefield target beyond 500 yards is hard for the average rifleman to detect and hit. [p.7] [underline in the original]

FM 23-9 gives the MERN of the M16A1 Rifle as 460 meters, defining MERN as, "The greatest distance at which a weapon may be expected to fire accurately to inflict casualties or damage." [46: p.6] JCS Publication 1, Dictionary Of Military And Associated Terms, January 1986, defines MERN as the maximum distance at which a weapon may be expected to be accurate and achieve the desired result." [p. 221] JCS Pub 1 does not define effective range. Note in the last two definitions that the reader must define minimum acceptable levels of accuracy and damage; thus, up to this point, the 460 meter value used for MERN can co-exist with the somewhat ambiguous way MERN has been defined.

The most recent definition of MERN is contained in the Army's FM 101-5-1, Operational Terms And Graphics. FM 101-5-1 was designed to ensure rapid transmission of instructions to subordinates, " . . . with a minimum risk of misunderstanding." This definition of ERN removes most of the ambiguity but creates a dilemma in its stead. ERN is defined as, "That range at which a weapon or weapons system has a 50 percent probability of hitting a target." [FM 101-5-1, October 1985, p. 1-28] MERN, was defined in the 1980 edition of FM 101-5-1 in a way that was identical to the definition of MERN in JCS Pub 1; however, MERN is not defined in the 1985 edition of FM 101-5-1.

4.1.5.3 Assessment. Throughout this report, the term weapons system has been taken to mean that the rifleman's aiming error is included in the system error budget. With this in mind, look at Figure 9 and the nature of the dilemma mentioned above becomes apparent. The greatest range to which any of the GP rifles achieve a 0.50 P_H with a rifleman in the loop (the WORST FLDEX curve) is less than 100 meters.

The author has read more than one assessment where the 5.45mm, AK-74 is said to be more "accurate" and have a greater "effective range" than the 7.62 mm, AK-47. The DA Foreign Materiel Catalog (FOMCAT) gives 500 and 300 meters as the ERN of the AK-74 and AK-47, respectively. [44: pp.18, 30]

The FOMCAT assessment may be based on the understanding that the AK-74 has a smaller round to round dispersion and a flatter trajectory than the AK-47, so should be more accurate. The higher proving ground P_Hs for the AK-74 in Table 4.3 support such an assessment, the WORST FLDEX P_Hs do not. It is expected that WORST FLDEX P_H curves will resemble actual operational hitting more often than will proving ground P_H curves. For this reason, it is extremely difficult to support statements that the AK-74 is more accurate or has a greater effective range than the AK-47--unless effectiveness is based on something other than hitting.

AMSAA concluded after an evaluation of the AK-74:

> If "effective range" is gauged by the singleshot hitting performance of typical riflemen in operational situations, the Soviet AK-47, AK-74, U.S. M16A1 and M16A2 have the same "effective" range. This statement can be extended to all general-issue military rifles (including 7.62 NATO-caliber). [9:p.63]

The FOMCAT estimate allows a final example to be offered on the need to agree on the required characteristics of an "effective" GP rifle. Note how the nominal 160 meter ERN stand-off advantage the M16A1 supposedly enjoyed relative to the AK-47 (460 compared to 300 meters) became a 40 meter disadvantage with adoption of the AK-74.

The USMC, in part, justified the need for a replacement for the M16A1 rifle on their perception of the increased ERN of the AK-74 over the AK-47. It seems reasonable to believe that the Marines were influenced by the FOMCAT estimates. The nominal 200 meter increase in ERN of the AK-74 rifle and consequent loss of stand-off-effective range was one reason the Marines called the M16A1 "deficient" in their Combat Rifle Study, ca. 1980. [45:p.1] The study said:

> The maximum effective range [of the M16A1 replacement] must be equal to or greater than the current threat individual weapon [GP rifle] (550 meters). [45:p.3]

Not surprisingly, the USMC Operator's Manual for the M16A2 (replacement for the M16A1) (TM 05538C-10/1, June 1983) gives its MERN to be 550 meters against "individual/point targets" and 800 meters against "area targets"). [p.3] COLT Firearms Division, in a brochure, ca. 1984, gives the MERN of the M16A2 with M193 Ball as 460 meters; COLT says MERN is 800 meters with M855 Ball. The values used by COLT and the Marines must be set alongside the performance estimate seen in Figure 10.

The 800 meter MERN quoted by COLT for the M855 may be related to the range at which there is a 50-50 chance of penetrating a protective helmet (given a hit). The author is not sure whether the USMC used the chance of a hit or the chance of damage (helmet penetration) given a hit as the basis for the 800 meter MERN. Claims of effectiveness against "area targets" based on hitting are, at best, ambiguous without defining the size of the target and the frequency with which it is hit.

4.1.6 Considering the Effect of Wind. In theory, wind has the potential of influencing hitting performance beyond some nominal distance. The Range at which wind would become a matter of concern depends on the weapon, the capability and mission of the shooter and the size of the target.

In actuality, wind has a minor affect on the operational hitting performance of a typical GP rifleman because of his large aiming error and because his targets tend to be at relatively close range; both circumstances tend to wipe out most or all of the wind's error potential. It has already been said several times that the affect of wind (and range) is a matter of major concern to a sniper engaging targets at long range; thus, biases caused by range and wind errors are a much more serious matter to the sniper than the GP rifleman.

The relative importance of solving the problem caused by wind depends in large measure on an estimate of how enemy targets are distributed in the area of operation. It is obvious that wind plays no part on hitting performance at the extremely close ranges encountered in a jungle. If the ORO 155 meters mean range target distribution used in Section 3 is appropriate, the great majority of the targets will be at ranges that are not overly influenced by wind.

Wind causes the shooter to make adjustments to his rear sight or select an offset POA (Kentucky Windage). If either course is not undertaken, the rifleman diminishes his chance of hitting. Estimates of wind speed and direction and actions taken to compensate for wind are subject to error and might distract the rifleman at a critical time. It is difficult for the author to believe that the rifleman will attempt to compensate for wind in a firefight.

The only way to estimate the practical effect of the wind sensitivity of a rifle bullet is to see what impact it has on the hitting performance of the rifle. Table 4.4 estimates P_Hs for the M16A2 rifle and M855 ball cartridge under the influence of a 2.24 mps (5 mph) cross wind. Three delivery errors are considered in the P_H calculations.

It is important to bear in mind that Table 4.4 presents optimistic estimates of P_H for the reason that range (Y) errors have been arbitrarily set to zero--a full-solution-range-rear sight is used. This is artificial, but necessary in order to illustrate the effect that wind, alone, has on P_H.

Table 4.4. Sensitivity of M16A2 Rifle to Wind: [a]
Probability of Hit vs Crouching Man (E-Silhouette) Target

SINGLE SHOT - NO RANGE ESTIMATION ERROR
FULL-SOLUTION-RANGE REAR SIGHT (NO Y BIAS)

2.24 MPS (5 MPH) CROSS-WIND [b]

DELIVERY ERROR

RANGE	PROVING GROUND		RIFLE QUAL		WORST FLDEX	
METERS	NO WIND	WIND	NO WIND	WIND	NO WIND	WIND
100	1.00	1.00	0.89	0.89	0.21	0.21
200	1.00	1.00	0.64	0.62	0.12	0.12
300	1.00	0.91	0.46	0.43	0.09	0.09
400	0.98	0.45	0.35	0.29	0.07	0.06
500	0.90	0.12	0.27	0.18	0.06	0.05
600	0.79	0.02	0.21	0.11	0.05	0.04
700	0.63	0.00	0.17	0.05	0.04	0.03
800	0.43	0.00	0.13	0.02	0.04	0.02

a. REFERENCE 9, TABLE 5.6.
b. SEE TABLE 2.11 FOR WIND DEFLECTION VALUES.
c. M855 V_0 = 940 MPS.

Recall that the single-shot proving ground delivery error is, effectively, zero. In effect, the P_Hs tabled under the heading PROVING GROUND were calculated using the rifle and ammunition RRD only. These P_Hs show the greatest sensitivity to the wind.

Look at the PROVING GROUND delivery error and see the differences between the P_Hs for the wind and no wind conditions beginning at about 400 meters. With small aiming errors, a 5 mph wind has some effect on hitting beyond 300 meters; it has a major effect on hitting beyond about 400 meters. Note how the RIFLE QUAL aiming error moves the range at which differences are seen out about another 100 meters.

Perhaps it would be better to put the proposition differently. Wind need not be considered as a major aspect in GP rifle fire control design or training at ranges less than, say, 400 - 500 meters--well inside the rifle's calculated danger space.

We expect the sniper to have a very small aiming error. A wind of modest speed would, if improperly compensated for, devastate the sniper's hitting performance at longer ranges. On the other hand, the effect of a 2.24 mps cross-wind is lost (the wind-no wind P_Hs are identical) when the shooter is burdened with RIFLE QUAL and WORST FLDEX aiming errors.

Figure 11 looks at the influence of wind on GP rifles from a different perspective. Here, the accuracy of the two rifles is being judged on the basis of their relative sensitivity to wind. Note at the outset that it is not correct to compare the M16A1 and M16A2 rifles on this basis--although the author has seen reduced wind sensitivity listed as one of the benefits resulting from adopting the M16A2.

Like other phenomena associated with the trajectory, wind sensitivity is explicitly a function of the exterior ballistics characteristics of the M193 and M855 cartridges--it is only indirectly related to the rifles. Put this way, Figure 11 is really comparing the wind sensitivity (more precisely, the time of flight) of the M193 and M855 ball cartridges. This is an important thought whose logic can be extended to comparisons of different weapons based on wounding/lethality, penetration and other phenomena properly attributed to the projectile.

The author is certain that the key to improving the sniper's long-range hitting performance is the elimination of Y (range) and X (deflection) biases from the error budget. Given present-day fire control, it is likely that a decrease in TOF would contribute more to long-range hitting than a reduction in RRD. The user might want to re-examine the two SLAP rounds shown in Table 2.6A with this idea in mind.

4.1.7 Using Battle Sights. This portion of the hitting effectiveness estimates deals with the performance of a GP rifle using battle sights. It has been lifted (with some modification) from AMSAA TR 440. [Reference 9] AMSAA TR 440 deals with the topic of battle sights (for the AK-74) in more detail than has been thought to be appropriate for this report.

Recall that U.S. and Soviet doctrine requires the rifleman to carry his rifle, habitually, with the rear sight set at battle sight. The rifleman

A. SITUATION: RANGE: 600 METERS; TARGET: CROUCHING MAN;
2.24 MPS (5 MPH) CROSS WIND [a]

B. WEAPON CHARACTERISTICS [b]	M16A1	M16A2
AMMUNITION DESIGNATION	M193	M855
MUZZLE VELOCITY [MPS]	991	940
TOF TO 600 METERS [SEC]	1.06	0.93
BIAS FOR 5 MPH X WIND [METER]	1.02	0.65
INTRINSIC WEAPON AND AMMUNITION ROUND TO ROUND DISPERSION [SD-MILS]	0.36	0.32

C. RELATIONSHIP OF DELIVERY ERROR SD AND WIND BIAS ON PH:

WHEN THE SYSTEM ERROR BUDGET INCLUDES:			PROBABILITY OF HIT IS	
SN	INTRINSIC WEAPON & AMMUNITION RRD PLUS	WIND BIAS	M16A1 /M193	M16A2 /M855
1	NOTHING ELSE	NONE	0.73	0.79
2	NOTHING ELSE	5 MPH	0.00	0.02
3	RIFLE QUAL AIMING ERROR	NONE	0.21	0.21
4	RIFLE QUAL AIMING ERROR	5 MPH	0.04	0.11
5	WORST FLDEX AIMING ERROR	NONE	0.05	0.05
6	WORST FLDEX AIMING ERROR	5 MPH	0.03	0.04

a. AUTHOR'S UNPUBLISHED WORK.
b. FROM TABLES 2.1 AND 2.11, TR 461.

Figure 11. Evaluation of The Assertion That The M16A2 is More "Accurate" Than The M16A1 Because The M16A2 is Less Sensitive To Wind.

is allowed to engage targets at ranges greater than BSR by estimating range and setting the rear sight to that range, but is told to reset his sights to BSR after such a fire mission. As a practical matter, it is to be expected that the rifleman will use battle sights in almost all engagements. Recall as well that BSR for the AK-74 rifle is estimated by AMSAA to be 450 meters (Section 2.4.3); at this range, the height of the ordinate with respect to the LOA is 0.0. At any range other than the BSR, the trajectory will be above or below the LOA creating a range (Y) bias.

The selection of a BSR depends in great part on some understanding of the type (size) and distribution of enemy targets. If the majority of targets are expected to be at long range, a longer-range BSR is indicated. The actual value of the BSR is determined with ease, given knowledge of the type and distribution of targets--something that will probably never be known with any degree of certainty. Table 4.5 and Figure 12 are meant to illustrate this thought by comparing the efficacy of 300 and 450 meter BSR with the AK-74 rifle.

The value of competing BSR can be judged in abstract simply by comparing the P_Hs associated with each BSR to the P_Hs for a perfect notional rear sight--one that does not introduce range (Y) biases as does a battle sight. It is necessary to assume that the rifleman does not make any range estimation errors or make any mistakes setting the baseline rear sight.

The P_Hs in Table 4.5 are calculated using the AK-74 RRD from Table 2.1, Y biases from Table 2.12A and the RIFLE QUAL aiming error from Table 2.13. Several aiming errors could have been used in the calculations; each would have produced a somewhat different P_H. The RIFLE QUAL errors were selected as a compromise. Very small errors would have been quite useful in illustrating differences, but are artificial; large errors tend to mask any differences.

Table 4.5. Comparison of Two Battle Sight Ranges [a] for the Soviet AK-74 Rifle: Probability of Hit vs Crouching Man (E-Silhouette) Target

RIFLE QUAL AIMING ERROR - COT POA
SINGLE SHOT - NO RANGE ESTIMATION ERRORS

RANGE METERS	OPTION 1 SET EACH 50 METERS	OPTION 2 BSR = 300 METERS	OPTION 3 BSR = 450 METERS
50	0.99	0.99	0.99
100	0.89 [0.21] [b]	0.86 [0.20]	0.72 [0.18]
200	0.63	0.58	0.27
300	0.45 [0.09]	0.45 [0.09]	0.24 [0.07]
400	0.33	0.22	0.30
450	0.29	0.07	0.29
500	0.26 [0.06]	0.02 [0.03]	0.19 [0.05]
600	0.20	0.00	0.01
700	0.16	0.00	0.00
800	0.13	0.00	0.00

NOTES ON THE FOLLOWING PAGE.

a. REFERENCE 9, TABLE 5.4.
b. PHs IN BRACKET AT 100, 300 AND 500 METERS USE WORST FLDEX AIMING ERROR TO SHOW EFFECT ON SELECTION OF BSR.

The best way to visualize the effect of battle sights on hitting and to compare different BSR is to look at Figure 12; however, before doing this, note the P_Hs in brackets at 100, 300 and 500 meters in Table 4.5. These PHs were calculated using WORST FLDEX aiming errors. Look at the P_Hs in brackets across the three columns for each range. There is no practical difference in any of the P_Hs. This says that large aiming errors wipe out differences in P_H that may be attributed to the two BSR.

The solid-line curve in Figure 12 represents the P_H for a perfect notional sight. The other two curves represent the P_Hs for the 300 and 450 meter battle sights. Note how the P_Hs for the 300 and 450 meter BSR touch the notional perfect sight curve at those BSR; this is because the battle sights only have zero bias at those exact ranges; at any other range the BSR P_H is less than the notional perfect sight P_H.

Look at the relative P_Hs for the two BSR in several range bands. Look at 0 - 300 meters. The 300 meter BSR has practically the same P_H as the notional perfect sight; the 300 meter BSR P_H exceeds the 450 meter BSR PH at any range less than about 375 meters. The P_H for the 300 meter BSR goes to zero between 500 and 550 meters; the 450 meter P_H is zero at about 600 meters. The only region where the 450 meter BSR produces a P_H higher than a 300 meter BSR is indicated on Figure 12 by cross hatching. If the BSR comparison were to be made on the basis of Figure 12 alone, it is clear that the 300 meter BSR produces a higher P_H over a larger range band than the 450 meter BSR, so would be judged the better choice of a BSR.

The ultimate value of competing rifle fire control (sight) designs must somehow be weighted, as it were, by the amount of time the rifle will be used set on battle sights (effectively a single-position-range rear sight), and how often the more sophisticated features of the new sight are used. Finally, the value of any fire control enhancement that requires the average GP rifleman to change his sights under stress must be calculated: (a) under a best case scenario where he does everything correctly all of the time and (b) under a worst case where he does some (all) things wrong some (all) of the time.

4.2 <u>Sniper Rifle</u>.

<u>4.2.1 Context for Analysis by User</u>. In the discussion that follows, it is important to keep in mind that the desirability of one cartridge or another is based solely on hitting. Any apparent superiority in the hitting performance of one weapon/cartridge over another must be tempered with other considerations that bear on the selection process. Two such considerations are terminal effects and human factors (weight and kick).

It will be seen that at long range P_H generally increases with increasing caliber. The M118 and the two conceptual sniper cartridges in Table 4.6 are conventional ball cartridges using gilding-metal jacketed,

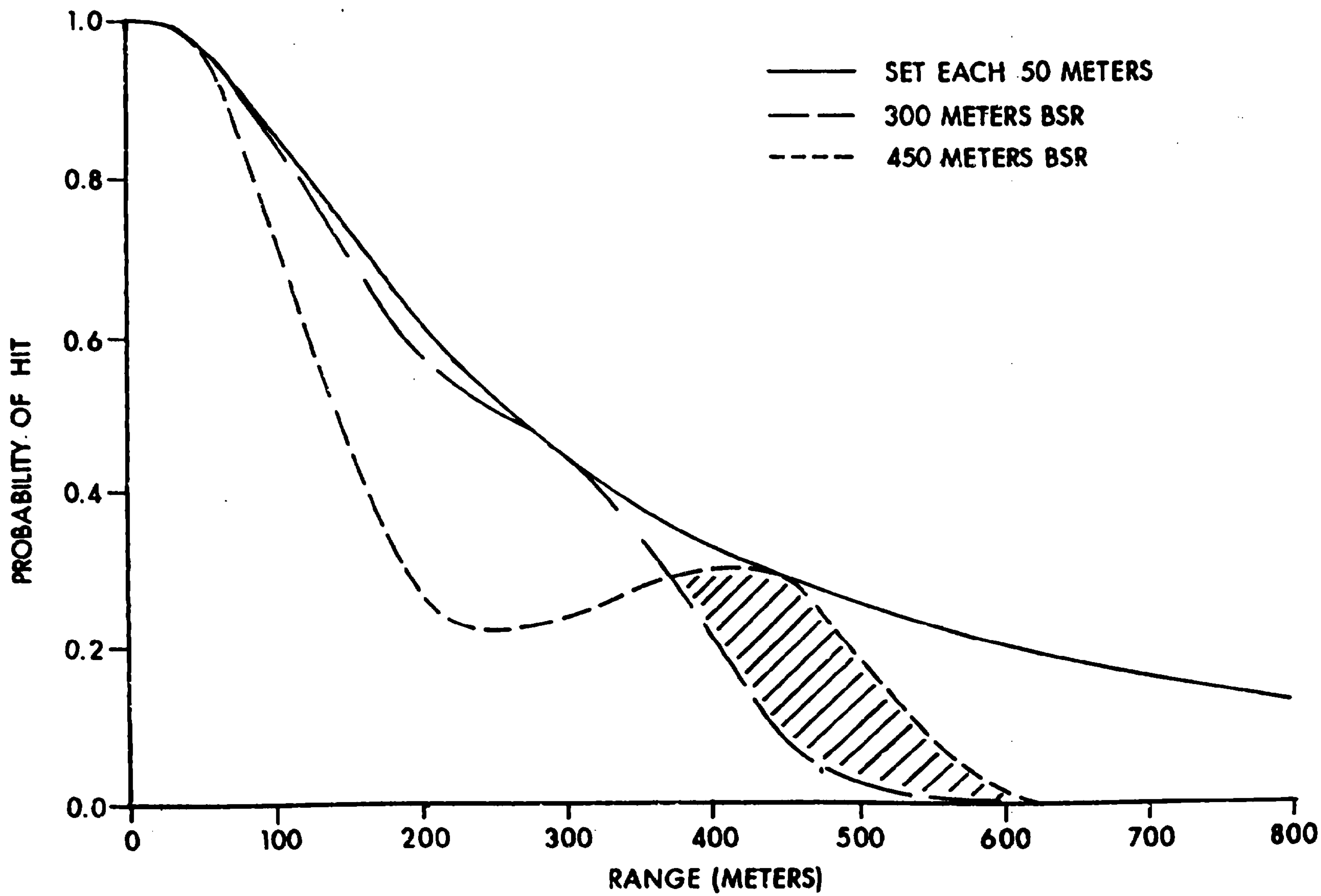

Figure 12. Comparison of Two Battle Sight Ranges For AK-74 Rifle; Single Shot, No Range Estimation Errors, Rifle Qualification Aiming Errors: PH vs. Crouching Man Target.

lead-core bullets. These bullets probably have adequate terminal effects against personnel targets (even those clad in woven fabric-type body armor) to the mid-range of the weapon. Generally, ball projectiles are not suited to attack hard (materiel) targets.

Kick (recoil energy) generally increases with increasing caliber. Within a given caliber, kick can be reduced by increasing the weight of the weapon or by fitting the weapon with a high-efficiency muzzle brake. Since there does not seem to be any intrinsic merit in adding weight, muzzle brakes are usually employed when kick becomes objectionable. (Some notion of their efficiency can be seen in Section 2.5.3.5.)

The user must be circumspect in adopting a muzzle brake, and, once adopted, must develop procedures to remove or minimize the blast and flash that are the usual byproduct of an efficient brake. If this is not done, the sniper's survivability in some missions will be diminished with each round he fires.

There is a compelling argument for a true single-shot high-P_H sniper system if we really are seriously considering a large-caliber SASR: High value targets are not likely to remain exposed while the sniper fires the "will adjust" rounds necessary to compensate for miss-estimated range, wind and non-standard atmospheric conditions. The correlation between the sniper's survivability and the number of rounds fired has already been mentioned, but bears repeating.

Hitting performance (especially the SASR) should be viewed with these burdens in mind. Reference 24 contains an excellent discussion of the trade-offs between P_H and kick for cartridges from 7.62 x 51mm, M118 to about 9.6 mm caliber (.378-inch) in rifles weighing 20 to 40 pounds.

4.2.2 Best-Case Hitting Performance. Table 4.6 shows estimates of P_H against a crouching man target for the standard U.S. Army and Marine Corps sniper rifles and two of Mr. McCoy's conceptual weapons. The author did not calculate P_Hs for the M24/M40A1 at 1,500 and 2,000 meters because he was unwilling to estimate their RRD at these ranges with the existing data base. Table 4.6 is very important since it contains the author's best estimate of the non-operational P_Hs for the sniper rifles included under the conditions described in the table.

The estimates in Table 4.6 are characterized as Best Case. The intrinsic RRD from Tables 2.2 and 2.5 were combined with the appropriate aiming error from Table 2.19 using formula [2] in Section 2.1.3. No other errors or biases were included when P_H was calculated, thus the COI and POA were both placed at the target center where the pattern of shot (the RRD) can make its greatest contribution to P_H. These best-case PHs will be used later in Table 4.8 as baseline values with which to abstract the effect that wind has on hitting.

The hitting performance of the conceptual .300 MAGNUM rifle is topical since the Army may still have plans to reconfigure some or all its M24's from 7.62 x 51mm to .300 MAGNUM caliber. Lacking any better information, the author is prepared to use the estimates in Table 4.6 to represent the performance of the M24 re-configured to .300 MAGNUM caliber.

Table 4.6. Hitting Performance of Three Sniper Weapons: Best Case (Only Intrinsic RRD and Aiming Error) [a]

PROBABILITY OF HIT FOR VARIOUS AIMING ERRORS
CROUCHING (E SILHOUETTE) TARGET - POA AT TARGET CENTER

PART A. CALIBER =< .30 MAGNUM (SMALL CALIBER):

	<1> 7.62 X 51MM, M118 M24/M40A1 [b] AIMING ERROR SIGMA (MILS) [c]			<2> CONCEPTUAL .300 MAGNUM [e] AIMING ERROR SIGMA (MILS) [c]		
RANGE METERS	0.10	0.30	0.80	0.10	0.30	0.80
500	0.99	0.85	0.33	1.00	0.90	0.34
1,000	0.70	0.40	0.10	0.95	0.49	0.10
1,500	NOT ESTIMATED			0.58	0.24	0.05
2,000	NOT ESTIMATED			0.18	0.10	0.02

PART B. CALIBER = CONCEPTUAL .35/50 (LARGE CALIBER): [e]

	<3> IF SMALL CALIBER AIMING ERROR FROM TABLE 2.19 USED SIGMA (MILS) [c]			<4> IF LARGE CALIBER AIMING ERROR FROM TABLE 2.19 USED SIGMA (MILS) [d]		
RANGE METERS	0.10	0.30	0.80	0.20	0.50	1.20
500	1.00	0.90	0.34	0.99	0.63	0.17
1,000	0.97	0.50	0.10	0.75	0.24	0.05
1,500	0.77	0.27	0.05	0.46	0.11	0.02
2,000	0.40	0.14	0.03	0.24	0.06	0.01

a. NO ERRORS DUE TO RANGE, WIND OR NON-STANDARD ATMOSPHERICS.
b. STANDARD SNIPER RIFLES: US ARMY = M24, USMC = M40A1.
AIMING ERROR LEGEND (TABLE 2.19):
c. SMALL CALIBER (=< .300 MAGNUM): 0.10 = LEVEL 2 BEST, 0.30 = LEVEL 1 BEST/LEVEL 2 WORST, 0.80 = LEVEL 1 WORST.
d. LARGE CALIBER (> .300 MAGNUM): 0.20 = LEVEL 2 BEST, 0.50 = LEVEL 1 BEST/LEVEL 2 WORST, 1.20 = LEVEL 1 WORST.
e. ROUND ROUND DISPERSION: TABLES 2.2, 2.5.

Table 4.6 is presented in two parts: Part A for calibers equal to or less than .300 MAGNUM, Part B for calibers greater than .300 MAGNUM. Note that Part A is further identified as SMALL CALIBER and Part B as LARGE CALIBER. Part A contains P_H estimates for the M24 and M40A1 Sniper Rifles with 7.62 x 51mm, M118 Special Ball cartridge, and a conceptual .300 MAGNUM caliber sniper rifle. Part B contains P_H estimates for a conceptual .35/50 caliber rifle.

The reason that Table 4.6 has been organized as described has to do with the estimate of the sniper's aiming error in Table 2.19. It would probably be useful to have a look at Table 2.19 before getting any deeper into the sniper's hitting performance estimates. The values contained in Table 2.19 were developed with the author's notion that the aiming error of both classes of military sniper will increase at some level of kick.

Table 2.19 represents a simplistic treatment of what is almost certainly a complex matter. Nonetheless, a decision was made to call weapons larger than .300 MAGNUM, LARGE CALIBER, and to increase the aiming error of all snipers using these weapons approximately 1.5 times the small caliber aiming errors. Table 2.19 was also designed to show the extremes in performance seen in test data by providing limiting (BEST and WORST) boundaries within which it was estimated that the true aiming errors would lie.

There is common ground in Table 2.19, within both calibers, across both levels of sniper quality. For example, with SMALL CALIBER weapons the aiming error of the Level 2 sniper is at WORST 0.30 mils SIGMA; the aiming error of the Level 1 sniper is at BEST 0.30 mils as well. There is similar common ground in the LARGE CALIBER portion of the table.

The P_H estimates at <1>, <2> and <3> in Table 4.6 allow direct comparison of three sniper rifles using aiming errors of 0.10, 0.30 and 0.80 mils SIGMA. In this case (same aiming errors across caliber), the P_H really reflects differences in the round to round dispersion of the three rifles. In order to have direct comparability, the conceptual .35/50 was given, artificially it is thought, a small caliber aiming error. Those who think that the sniper's aiming error will be unaffected by kick would be most interested in the comparisons just made.

Note how in practical terms, the P_H of all three calibers is the same with aiming errors of 0.30 and 0.80 mils SIGMA. One would have to conclude that the .35/50 does not make sense from the standpoint of hitting unless the sniper can be trained to an aiming error of something approaching 0.10 mils SIGMA, and the targets were at ranges beyond 1,000 meters. Note that even under best case conditions, P_H tails off rapidly for the M24/M40A1 beyond 500 meters and beyond 1,000 meters for the other two. The reader is cautioned again that the effectiveness of sniper rifles of different caliber cannot be evaluated intelligently without some notion of required terminal effects in mind.

The change in hitting performance of the M24 (or the M40A1) reconfigured to .300 MAGNUM caliber can be estimated by comparing <1> and <2>. The penalty on hitting thought to be imposed by kick can be assessed directly by comparing P_Hs in <3> and <4>. A plan to change the caliber of the M24 to something like the .35/50 should compare <1>, <2> and <4>.

It is appropriate to remind all that these values and those that follow represent the best performance of an unhurried, unstressed sniper in a peacetime setting. The author has no idea how much the sniper's hitting performance will be degraded in an operation.

Table 4.6 presented P_Hs for two basic sets of aiming errors that were estimated to place limits on the performance of snipers with small and large caliber rifles. The portion of Table 4.7 labeled NO WIND looks at the hitting performance of an operational (U.S. Navy SEAL) sniper firing a 12.7 x 99mm SASR. For the moment, disregard the wind-perturbed hitting performance.

The P_H values in Table 4.7 were calculated directly using the TOTAL SYSTEM SIGMAs for each range from Table 2.18 (which were, themselves, calculated using mean radius test data). The SEAL was not shooting at an E silhouette, but was firing 10-round groups at a bull's-eye. For this reason, the P_Hs in Table 4.7 might overstate his capability somewhat because it is expected that he would have a somewhat larger aiming error against a less distinct aiming point.

A separate large caliber aiming error was not taken from Table 2.19, because the TOTAL SYSTEM SIGMA in Table 2.18 includes all error sources at work during the test, including his aiming error. Remember that the test at APG was done at known range and at what is taken to be, practically, no wind. The snipers fired sighting rounds to get on the target, effectively removing all non-standard conditions from the error budget for this occasion.

Note c in Table 4.7 speaks to the variability seen in test data; it has been added to show that the same class of shooter fired the same weapon/ammunition on a different occasion and obtained a remarkably smaller TOTAL SYSTEM SIGMA. Note d has been added to illustrate again the effect that variability in the test data in Table 2.18 has on the perception of a central-value (mean) P_H. The SEALs fired nine ten-round shot groups at each range in the APG test. At 1,500 yards the smallest (BEST) shot group observed would produce a P_H of 0.41, the largest (WORST) group results in a 0.09 P_H.

It is useful to compare the performance of a real operational sniper using a 12.7mm SASR seen in Table 4.7 with the 1985 draft USMC requirement for the SASR. (See Section 2.3.2.2.) The draft required that the SASR give the sniper at least a 0.50 P_H against a 1.0 by 1.0 meter target at range of 2,000 meters in an eight to ten-mph cross wind. Disregard wind for the moment. If the TOTAL SYSTEM SIGMA for 1828 meters (0.62 mils) shown in Table 2.18 is used to calculate a P_H at 2,000 meters (something that would tend to overstate PH), the sniper has a P_H of 0.10 against the 1.0 x 1.0 meter target. This value assumes no other errors such as wind, range or non-standard atmospherics are operating--a perfect fire control system.

Those with more than passing interest who desire additional perspective on the topic of snipers and sniper materiel, should obtain reports from Ordnance Research and Development Project TS2-2015; for example, TR 461 Reference 21 is the 37th Report of TS2-2015.

Table 4.7 - Hitting Performance of Operational Snipers with 12.7 X 99mm, Special Application Sniper Rifle (SASR):

PROBABILITY OF HIT FOR UNSTRESSED, NON-OPERATIONAL CONDITIONS
CROUCHING (E SILHOUETTE) TARGET - POA AT TARGET CENTER

AIMING ERROR AND ROUND TO ROUND DISPERSION FROM ACTUAL PERFORMANCE AT APG, MD, 1984-85 [a]

		<----- PROBABILITY OF HIT ----->		
		<1>	<2> IF WIND SPEED =	
RANGE METERS	YARDS	NO WIND	1.12 MPS 2.50 MPH	2.24 MPS [b] 5.00 MPH
457	500	0.93	0.85	0.61
914	1,000	0.55	0.17	0.00
914	1,000	0.67 [c]	0.14	0.00
1,371	1,500	0.17 [d]	0.02	0.00
1,828	2,000	0.05	0.01	0.00

a. ROUND TO ROUND DISPERSION SIGMA FROM TABLE 2.18.
b. WIND DEFLECTION FOR EX 211 FROM TABLE 2.12.
c. OTHER DATA: SIGMA = 0.26 MILS AT 1,000 YARDS FOR SAME TYPE SASR AND CLASS OF SHOOTER; PH = 0.67. [NOTE G, TABLE 2.18]
d. PHs FROM EXTREME LIMITS OF DATA: BEST = 0.41, WORST = 0.09.

Note that the USMC 1985 SASR requirement has the effect of requiring an essentially perfect wind solution for a wind speed of not more than eight to ten-mph in order to meet the P_H requirement. It may be recalled that the author believes that judging wind (particularly in an operational situation) is almost certainly the most difficult task to be performed by the sniper.

4.2.3 Hitting Perturbed by Wind-Caused Bias. Table 4.8 shows the hitting performance in wind of the 7.62 x 51mm, M24/M40A1 sniper rifles (M118 Ball) and Mr. McCoy's conceptual.35/50 sniper rifle. Part A of Table 4.8 show P_Hs for the two cartridges in a constant-value cross wind (90 degrees to line of fire) for wind speeds of 1.12 and 2.24 mps (2.5 and 5.0 mph). P_H was calculated using the same grouping of large and small-caliber aiming errors used in Table 4.6; thus, the NO WIND and WIND P_Hs are directly comparable within aiming error.

Part B allows comparisons to be made for the Conceptual .35/50 of the NO WIND and WIND P_Hs for aiming errors of 0.10, 0.30 and 0.80 mils SIGMA.

Table 4.8. Effect of Wind Bias on Hitting Performance
Two Sniper Cartridges [a]
Cross Wind (90 Degrees to Line of Fire) [b]

CROUCHING MAN TARGET - POA AT TARGET CENTER

PART A. PROBABILITY OF HIT FOR TWO WIND SPEEDS:

		7.62 X 51MM, M118 M24/M40A1 AIMING ERROR [c] SIGMA (MILS)			CONCEPTUAL .35/50 AIMING ERROR [c] SIGMA (MILS)				
		<1>			<1>			[illegible]	
RANGE METERS	WIND SPEED	0.10	0.30	0.80	0.10	0.30	0.80	[illegible]	[illegible]
500	1.12 MPS	0.80	0.67	0.31	1.00	0.88	0.34	0.[illegible]	[illegible]
1,000	(2.5 MPH)	0.00	0.03	0.06	0.47	0.38	0.10	0.[illegible]	[illegible]
1,500		NOT ESTIMATED			0.02	0.11	0.04	0.06	[illegible]
2,000		NOT ESTIMATED			0.00	0.02	0.02	0.03	0.01
500	2.24 MPS	0.19	0.30	0.25	0.99	0.80	0.33	0.58	0.17
1,000	(5.0 MPH)	0.00	0.00	0.01	0.01	0.16	0.08	0.15	0.04
1,500		NOT ESTIMATED			0.00	0.01	0.03	0.03	0.02
2,000		NOT ESTIMATED			0.00	0.00	0.01	0.00	0.01

PART B. SELECTED COMPARISONS OF WIND AND NO-WIND PH:

CONCEPTUAL .35/50: [d]

AIMING ERROR SIGMA

	0.10 MILS			0.30 MILS			0.80 MILS		
METERS	NO WIND	2.5 WIND	5.0 WIND	NO WIND	2.5 WIND	5.0 WIND	NO WIND	2.5 WIND	5.0 WIND
500	1.00	1.00	0.99	0.90	0.88	0.80	0.34	0.34	0.33
1,000	0.97	0.47	0.01	0.50	0.38	0.16	0.10	0.10	0.08
1,500	0.77	0.02	0.00	0.27	0.11	0.01	0.05	0.04	0.03
2,000	0.40	0.00	0.00	0.14	0.02	0.00	0.03	0.02	0.01

a. ROUND TO ROUND DISPERSION FROM TABLES 2.2 AND 2.5.
b. WIND DEFLECTION FROM TABLE 2.12.
c. AIMING ERRORS FROM TABLE 2.19: <1> = SMALL CALIBER, <2> = LARGE CALIBER.
d. NO WIND PHs FROM TABLE 4.6.

In a NO WIND situation, given similar aiming errors, the .35/50 has a higher P_H than the M118 simply because of its smaller RRD. (Compare Table 2.2 and 2.5.) In any wind, the P_H of the .35/50 is higher than the M118 because of a smaller X bias--the results of a shorter time of flight. This fact might be used in a systems approach to upgrade hitting performance by placing as much importance on reducing time of flight as on reducing RRD of the weapon/bullet.

Note the .35/50 in Part B; with a 0.80 mil SIGMA aiming error, P_H is not affected by wind speed at any range. The NO WIND P_H is about the same as the 2.5 and 5.0 mph P_Hs. This means that the combination of RRD and aiming error (the only other errors included) dominate. It is senseless to spend lots of money removing biases from a fire control system unless the aiming errors are sufficiently small. Put another way, time and rounds must be allocated to training the sniper to a level where he can properly use the tools he is given.

Note the P_H of the M118 at 1,000 meters where, with a cross-wind of 2.5 mph, P_H increases with increasing aiming error. The same thing is happening, although not so apparently, at 1,000 meters with a 5 mph wind. Admittedly, the P_Hs being referred to are so low they have no practical military value; however, it is worthwhile to conduct the exercise since it allows several interesting points to be made. The answer involves the interplay of RRD, aiming error and wind-caused bias.

The end result of this sort of analysis suggests that under certain circumstances it might be desirable to trade-off RRD for a short time of flight. In some respects, the small RRD associated with sniper materiel are, potentially, a burden on the system. The SWS fire control must compensate for whatever biases are present on each fire mission; if the biases are not eliminated, snipers shooting weapons and ammunition of the quality seen at the 1984 Indiantown Gap One Mile Shoot, will miss the target every time. (See Table 2.6.)

If MELIOS performs about like what is seen in Table 2.8, the SWS does not now have a suitable device to measure range; further, AMSAA is not aware of any device that is being acquired or developed with which to calculate an effective (resultant) wind solution. The sniper should only be burdened with learning and carrying a single device that would provide the correct horizontal and vertical aim-off for each fire mission. The sniper should not be required to look up any tables or make any computations, no matter how simple they may be.

5. DISCUSSION

5.1 Need To Assess Accuracy Using A Common Definition.

5.1.1 The Problem. The author does not wish to be considered doctrinaire but is satisfied that the more or less universal definition of the term accuracy in place today is imprecise, widely misunderstood, thus frequently hides problems a system has hitting a target. The definition of accuracy must explicitly lead to a count of hits on a target. A shot group is an abstraction without some notion of the target it is to be fired at.

It is likely that our contemporary understanding of the concept of the maximum effective range of small arms--that is wrong in the author's judgment--may also stem from overly optimistic appraisals of system accuracy, where only a part of the error budget is examined. A single example should suffice to establish the existence of a problem.

5.1.2 Trade Journal Assessment of M24 SWS Accuracy. The International Defense Review (IDR) says this about the accuracy of the M24 SWS:

> The Remington M24 (SWS) sniper rifle is receiving mixed reviews. The Army acknowledges compliments on the gun's accuracy; it meets or exceeds every [accuracy] requirement.
>
> [Underline by the author; IDR Nr. 5/1989: p. 670]

The IDR is a widely read (monthly circulation about 32,000 copies world-wide) professional journal of some distinction that can be relied on to have its facts correct--in this case, that the M24 is an accurate sniper rifle.

The accuracy requirement that the IDR article refers to comes from a recent Initial Production Test (IPT) of the M24; it can be paraphrased as follows: The average mean radius for five targets of ten rounds each [fired from a machine rest] shall be less than or equal to 1.30-inches [3.30 cm] at 200 yards or 1.40-inches [3.56 cm] at 200 meters or 1.90-inches [4.83 cm] at 300 yards. [47: p. 21]

The CSTA test to which the IDR article apparently referred, reported that a sample of three M24 from the production lot being tested at 200 meters had average mean radiuses of 2.61, 3.43 and 2.68 cm respectively. The mean radius of each test sample M24 and the grand mean (2.91 cm) for all is less than the allowed 3.56 cm. [47: Table 5] Given the contemporary use of the definition, IDR was correct in reporting on M24 "accuracy" as it did.

The point being made here--certainly one of the major points made by this report--is that in this instance the way we talk about accuracy masked the fact that the M24 SWS has a potentially serious problem hitting operational targets which, in the author's judgment, should be the proper measure of accuracy.

5.1.3 TECOM Assessment of M24 Center of Impact Bias. The person writing the IDR article was probably unaware that the M3 telescope used in the M24 IPT was incorrectly designed for the exterior ballistics of the M118 cartridge. The TECOM evaluation of the M24 IPT says the following:

> The scope manufacturer . . . was mistakenly provided with trajectory data which does not represent M118 SB [Special Ball] ammunition and used these data to provide range indications on the elevation adjustment knob. The error may or may not be reversible in future production depending on contract terms; however, the user has told the developer that range indications

are not necessary and will be ignored. In addition, an adjustment procedure familiar to all marksmen may be used to compensate for additional bullet drop associated with M118 SB ammunition. [53: p. 4]

The M24 SWS has (perhaps permanently) a built-in range bias; Table 5.1 is instructive in this regard. [47: Table 5]

Table 5.1. Mean Horizontal & Vertical Center of Impact Bias (Accuracy) During Initial Production Test of: U.S. M24 Sniper Rifle with M3 (10 Power) Telescope Firing 7.62 X 51mm, M118 Special Ball [a][b]

M3 TELESCOPE ZEROED AT 200 METERS RANGE [c]

MACHINE REST AT KNOWN RANGE

TEST DATA: CENTIMETERS (EACH MEAN REPRESENTS 5 X 10-ROUND GROUPS

RANGE METER	IPT M24 NR	MEAN COI BIAS HORZ (X) CM	MIL	VERT (Y) CM	MIL	RANGE METER	IPT M24 NR	MEAN COI BIAS HORZ (X) CM	MIL	VERT (Y) CM	MIL
200	4	-0.97	-0.05	2.59	0.13	400	4	-4.93	-0.13	8.56	-0.22
	5	0.42	0.02	9.58	0.49		5	-2.72	-0.07	-3.43	-0.09
	6	-1.34	-0.07	2.73	0.14		6	-6.27	-0.16	3.10	0.08
600	4	-4.81	-0.08	-24.79	-0.42	800	4	-0.31	0.00	-33.93	-0.43
	5	-3.72	-0.06	-71.66	-1.22		5	42.79	0.54	-99.69	-1.27
	6	11.38	0.19	-30.97	-0.53		6	-0.58	-0.01	-45.74	-0.58
1000	4	21.11	0.22	-92.99	-0.95						
	5	64.65	0.66	-147.53	-1.50						
	6	5.99	0.06	-102.70	-1.05						

a. SOURCE 47: REPORT OF FIRST ARTICLE AND INITIAL PRODUCTION TEST OF M24 SWS, CSTA, APG, MD, MARCH 1989.
b. RRD OF M118 LOT NR. LC-86J136-002 AT 600 YARDS = 7.98 CM MR, = 0.12 MILS SIGMA.
c. AFTER ZERO, NO CHANGE MADE TO ELEVATION OR WINDAGE; KNOWN RANGE SET ON RANGE INDEX. VERT COI SHOULD BE ZERO AT OTHER RANGES IF M3 SCOPE BALLISTIC EQUATION FOR M118 IS CORRECT.
d. M24 WPN 4 USED SCOPE FROM M24 WPN 5 AFTER M24 WPN 5 HAD COMPLETED FIRING; SCOPE RE-ZEROED ON M24 WPN 4.

The data in Table 5.1 were taken during the IPT of the M24 SWS done by CSTA from November 1987 to January 1989. The data from which the horizontal and vertical components of the COI (HCI and VCI) can be assessed came from a sample of three M24 SWS; the same three weapons were used to obtain the mean radius data mentioned earlier. Each sample mean shown in Table 5.1 is based on 5 x 10-round shot groups. All firing was done by a CSTA civilian gunner; the gunner is not rated as an "NRA-Master Class Shooter." CSTA did not have any Master Class gunners at that time.

Figure 13 graphically shows the bias of the VCI shown in Table 5.1. Only the VCI has been selected for analysis. Figure 13 has been lifted unaltered, except for the addition of the 0.0 VCI dashed line, from the TECOM M24 SWS assessment. [47: Figure 11]

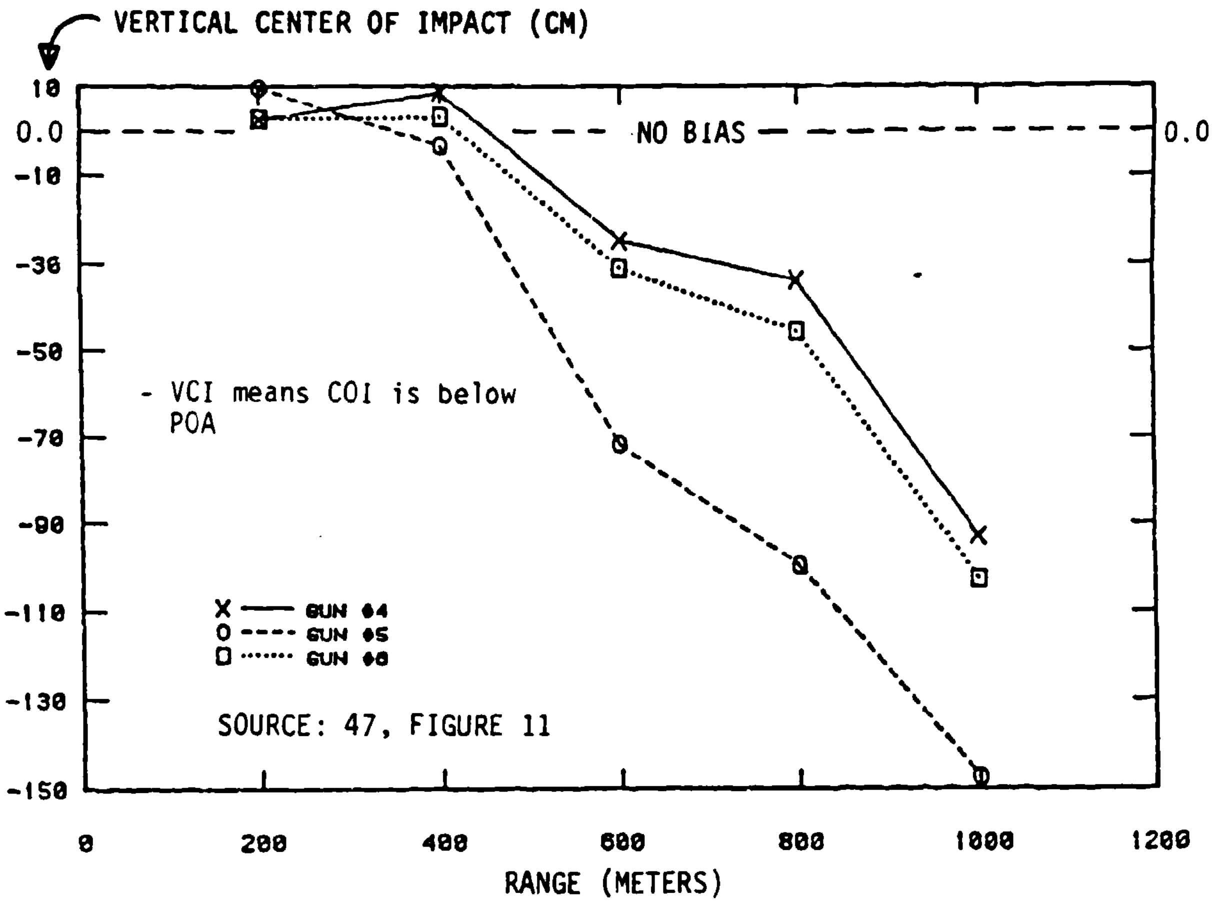

Figure 13. Accuracy Bias of M24 SWS: Test Data from M24 SWS Initial Production Test Showing Mean Vertical Component of Center of Impact vs Range.

The M24 SWS IPT firing was done from a machine rest; each sample was seated in the machine rest by firing ten rounds before data were taken. The three weapons were zeroed at 200 meters by adjusting the windage and elevation knobs on the M3 telescope to bring the COI of the shot groups to the POA. The weapon operator determined when each weapon was zeroed and made final zeroing adjustments. Inspection of 200 meter data in Table 5.1 shows rather small residual errors for each weapon when zeroing was completed.

Note that the elevation bias is positive, meaning that that each M24 was shooting above the POA.

After the weapons were zeroed, the M3 telescope windage and elevation scales were set to zero. No additional adjustments were made to the zero during the remainder of the test. Sights were set for range by turning the elevation knob until the proper range was indexed. CSTA gathered a "very limited" amount of meteorological data at the weapon firing point. [47: Encl 1, pp. 21,22]

5.1.4 Bias as a Surrogate Measure of Accuracy. In abstract, the simplest, most straightforward way of evaluating accuracy is to count bullet holes in a target at the completion of a test using the proper operational scenario. In most cases this is not possible for one of a number of reasons, so some other means must serve temporarily. The contemporary choice is to look at the RRD; a tight group is taken to portend an accurate system--the present situation with the M24 SWS. Another means has to be found. A bias offsets the pattern of shot from the target and removing the bias is likely to be necessary for a target hit. For this reason, assessing the magnitude and source of biases is a good way to evaluate accuracy.

The M24 SWS is being acquired to, " . . . deliver precision fires on selected man-size targets out to a range of 1,000 meters, ..." [53: p. 1, quoting the Special Operations Mission Development Plan, January 1985 (SECRET/NOFORN)] Look at the VCI bias at 800 and 1,000 meters with this need in mind.

Figure 13 is designed in such a way that the VCI will be plotted at 0.0 at any range for any of the M24 IPT sample whose M3 telescope has a correct ballistic solution (offset) for the M118 Ball cartridge. This statement does not account for the effect that non-standard atmospherics might have on the position of the VCI. It is thought that these latter effects will have a relatively minor impact on accuracy even at 1,000 meters. The negative sign indicates that the COI is below the POA.

5.1.5 User Test of the Sniper Weapon System in 1987.

5.1.5.1 Implications of Fielding a First-Round Hit SWS. The hit performance requirement (and other requirements) in the SWS LR has been stated so that it can be tested with as few uncontrolled variables as possible and assessed in a straightforward, even-handed manner. The following statement paraphrases that part of the LR of interest here:

Achieve an average PH of at least 0.85 against a stationary E silhouette target at known ranges to 800 meters from a prone-supported firing position. Tests to be conducted during clear daylight conditions with winds not to exceed a full-value effect [90 degree cross wind] of five knots [2.6 mps]. [54: para. 5.a.(1)]

Although the SWS requirement in the LR is suited to the task of selecting a sniper rifle, it leaves unanswered (as it should) a matter of fundamental importance to the acquisition of sniper system materiel and to the training and operational employment of snipers. The issue can be stated simply as a question: Does the user want a first-round hit capability in the SWS; if he does, how often and to what range? There also should be some statement of minimum acceptable terminal effects (penetrate/wound) given a hit.

The user really does want a first-round hit system; this can be seen in an earlier (21 March 1986) draft version of the SWS LR. A paraphrase of this document says: The SWS will be capable of delivering a single round with a probability of hit of 0.9 against an E-silhouette target, with a 0.85 confidence level out to 800 meters during clear daylight with a maximum wind speed of five knots. AMSAA non-concurred with the requirement on the basis that it could not be achieved with the fire control then available--the same fire control would be used today.

It is reasonable to have a single-shot hit capability at "long range" as a goal. For the M118 cartridge, long range should include 1,000 meters, but probably not much beyond 1,000 meters. The maximum included distance in a definition of long range should increase with the caliber of the SWS being considered. A goal of a first-round hit is particularly important to a sniper with a large-caliber rifle that requires a high-efficiency muzzle brake to keep recoil to a manageable level. The muzzle blast from each round he fires tends to give away his position. There must also be some concern about the response of a target to a near miss.

A true first-round hit capability with a reasonably high confidence level will probably require a major expenditure of R&D effort to obtain suitable fire control. (This statement is being made after concluding that the MELIOS is not a suitable range measuring device for this application.)

A lot of time and money can be saved if the sniper can be allowed more than one round per mission. It is tempting to say that the amount saved will be in direct relation to the number of rounds allowed, but this is probably only partially true. Each round the sniper is allowed can be used by him to remove the effects of incorrect solutions to his fire control problem.

5.1.5.2 Test Conditions. The USAIB tested two 7.62 X 51mm caliber SWS in 1987. This test formed a portion of the decision to type classify one of the candidates as the M24 SWS. This test did not provide the basis to assess the accuracy of the M24 under anything approximating the random firing conditions (unknown range and wind) that typify field operations. It is understood that all user tests need not simulate an operational environment; however, performance indicators such as PH tend to take on this flavor as time and distance pass.

The term user test normally conjures up a picture of a test with an operational flavor; in the case of the SWS, one might expect to have an individual sniper's performance assessed as he acquires targets at unknown range and uses some device to estimate range and wind. For example, one might expect to see the sniper use a device similar to the MELIOS to measure range.

The author recalls that a decision was made to conduct this test from known range; the reason given was that the hand-held LRF was expected to have an accuracy of 5 meters, thus it was unnecessary to conduct tests at unknown range. Review Section 2.4.1.2 in this regard.

Here is a summary of the 1987 USAIB SWS user test conditions and test results that affect the perception of the accuracy of the M24 SW: [Numbers in brackets are page numbers; all are keyed to Reference 52]

a. Sixteen experienced riflemen acted as test subjects. All firing done from prone supported position at E-silhouette targets at 500, 700 and 800 meters. [pp. 1-2,1-3]

b. All firing done on known distance ranges and target acquisition was not a variable. [p. 1-3]

c. Firing was conducted in two-man teams. One fired, while the other observed using a 100-mm observation scope to assist in sensing round impact. Firers were informed of the correct range to each target. An experienced spotter from the Ft. Benning AMU determined a wind direction and speed correction for all firers. A portable weather station was situated downrange to aid in determining wind and temperature conditions.[p. 2-2]

5.1.5.3 Test Results. The user SWS test discovered the same problem with vertical bias that would be discovered later in the M24 SWS IPT. The report says that two hit performance exercises were conducted: the first exercise used the zeroed elevation settings, the second exercise allowed the firer to adjust elevation to compensate for any vertical dispersion observed. Table 5.2 summarizes the hitting performance observed during the test. Two weapons were tested; the weapon shown in Table 5.2 was later type classified as the M24 SWS. Both weapons used the same 10x, bullet-drop compensating optical sight with mil dot reticle. [52: p. 1-1] Such a telescope was later type classified as the M3. (See Figure 3.) The SWS that is not shown in Table 5.2 also had a problem with the bullet-drop compensating mechanism.

Note how the difference in hit frequency between the two exercises increases with range; it is expected that the difference would be even greater at 1,000 meters. Wi ...u range measurement errors are the largest elements of the SWS error budget. Understanding this, it is difficult to predict what the hitting performance would have been if individual snipers had been tested at unknown ranges and measured or estimated wind and range with the equipment they are now issued.

The 1987 SWS user test did not gather data at 1,000 meters, although the basic hitting requirement for the SWS extends to 1,000 meters. This is unfortunate in view of the difficulties experienced at 1,000 meters with similar troops and materiel in the 1982 USAIB Concept Evaluation Test. See Section 2.5.3.4, this report and Reference 34.

Table 5.2. Hitting Performance of M24 SWS [a]
with 7.62 X 51mm, M118 Special Ball Cartridge

PRONE SUPPORTED AT AN E SILHOUETTE TARGET [b]

	FIRST EXERCISE [c] TELESCOPE WITH INCORRECT M118 BALLISTICS (VERTICAL BIAS)			SECOND EXERCISE [d] TELESCOPE WITH CORRECT M118 BALLISTICS (NO VERTICAL BIAS)			
RANGE METERS	ROUNDS FIRED	HITS	HIT FREQUENCY	ROUNDS FIRED	HITS	HIT FREQ	[e] DIFF
500	256	247	0.96	256	249	0.97	0.01
700	256	217	0.85	256	223	0.87	0.02
800	256	199	0.78	256	224	0.88	0.10
ALL	768	663	0.86	768	696	0.91	

a. REFERENCE: 1987 USAIB USER TEST OF THE SWS [52: pp.2-2, 2-3]
b. TEST CONDITIONS AFFECTING HITTING:
   1) TARGET ACQUISITION NOT TESTED, KNOWN RANGE, NO TIME STRESS, BENIGN PEACETIME CONDITIONS.
   2) 16 EXPERIENCED RIFLEMEN FROM AMU, USAJFKSWS, 3/75 TH INF (RANGER) WITH COMBAT EQUIPMENT.
   3) 2 MAN TEAM (OBSERVER SENSING WITH 100 MM SPOTTING SCOPE).
   3. EXPERIENCED AMU SPOTTER WITH DOWN RANGE WEATHER STATION USED TO DETERMINE WIND DIRECTION AND SPEED CORRECTIONS FOR ALL
c. 1ST EXERCISE ROUNDS FIRED USING APPROPRIATE ELEVATION SETTINGS FOR RANGE USED (USED M118 EXTERIOR BALLISTICS COMPENSATION).
d. 2ND EXERCISE USED SIGHT CORRECTIONS FOR EACH ROUND TO COMPENSATE FOR ANY VERTICAL DISPERSION OBSERVED. [52: p. 1-3]
e. DIFF = HIT FREQ 2ND EXERCISE - HIT FREQ 1ST EXERCISE.

5.1.5.4 User Tests Overstate Troop Operational Hitting Performance. Recall that it was said in Section 4.1.3 that it is impossible to create "combat" stress on test subjects in a peacetime test. For this reason, the typical user test will overstate the operational hitting performance of soldiers and systems. A case probably can be made that a sniper conducting a surprise engagement at long-range from a prepared, concealed position, is not under the same high level of stress as a rifleman in eyeball-close combat. It may be that the aiming error of a trained sniper measured in a peacetime experiment approximates his operational aiming error. There is no data with which to support or reject this supposition.

It is understood that the 1987 SWS user test was designed to pick the better of two candidate rifles using identical test procedures and conditions. This must be done in order to make an unbiased selection. It simply is not correct to use these test results to estimate operational hitting.

The author expects that a similar test done under simulated "operational" conditions (at a minimum, with unknown range and wind) would reduce the hit frequencies in Table 5.2 by as much as nine tenths. Failure to test at unknown range masks problems a sniper probably will have with the MELIOS. Having "an experienced AMU spotter" and downrange wind measurement equipment hides the need for this equipment as well.

The author has searched diligently back as far as MAJ Brophy's work in the Mid-1950's [Reference 21], but cannot find any evidence of tests of snipers and sniper materiel conducted under random operational conditions. More to the point, the author has not seen any sniper system test that was not done at known range with some external assistance provided to the sniper in compensating for the effects of wind and non-standard atmospherics.

Even though it is impossible to simulate "combat" stress, it is possible to place the sniper in a variety of operational scenarios and measure his performance and estimate the value of his tools. A test of this sort would measure the performance of all elements of the system under typical operational scenarios at unknown range under random atmospheric and meteorological conditions.

5.1.6 The Contemporary Definition of Accuracy.

5.1.6.1 Origin of the Term Accuracy. It is likely that the contemporary use of the term accuracy to describe the size of the group of shots on a target stems from the way our small arms technical specifications have been written over the years. All specifications that have been observed as far back as the U.S. Caliber .30 Rifle Cartridge, Model of 1898 (Krag), define accuracy as it is commonly defined today.

For whatever it is worth, the specification for the Model 1898 Cartridge required a, "Ballistic test of: (a) Six targets of 10 shots each at 500 yards fired from a fixed rest. For the model 1898 cartridge, no target shall have a mean radius greater than 7-inches." [Ordnance Department, USA, Specification No. 472, June 7, 1918] Ammunition just making the 7-inch limit would have had a 0.33 mil SIGMA using present-day methodology.

Normal practice today is for the RRD and the COI-POA relationship of 100 percent of small arms weapons to be tested as part of a government acceptance test; rifles are usually tested at 100 yards; the .45 Caliber, M1911 Pistol was tested at 15 yards, the M9 Pistol is tested at 50 meters. Tests are done from machine rests using ammunition of known quality--in the case of the M16A1, M193 ball with a RRD SIGMA of not more than 0.17 mils. (Note that this is less than half of the RRD SIGMA of the Model 1898 cartridge mentioned above.) The M16A1 accuracy specification allows an ES (distance between two bullet holes with the maximum separation) of no more than 4.8-inches (12.2 cm); a SIGMA of 0.36 mils for a ten-round group.

The COI-POA relationship of the typical small arms specification is tested in a targeting requirement done concurrently with the RRD test. The targeting requirement describes a rectangular area around a point of aim within which all rounds of the test-sample shot group must impact. As an example, at 100 yards (91.6 m) the M16A1 targeting outline is 11.6-inches (29.5 cm) wide by 17.6-inches (44.7 cm) high with corners rounded with a radius of 2.8-inches (7.1 cm); the center of the figure (the desired COI) is 0.5-inches above the POA. Ten rounds must be placed inside this figure to pass the targeting requirement.

The targeting acceptance specification for GP rifles is designed to insure that there is enough travel in the elevation and windage mechanism that the user has the range of adjustment needed to zero the rifle--make the POA and COI coincident at the zeroing range.

5.1.6.2 Redefinition of Accuracy. The term accuracy as it is presently used should be changed and used to describe the relationship of the COI and POA. The targeting definition needs no modification since it does not deal with matters of any particular importance beyond the acceptance-test location. The term dispersion should be used to describe the size and shape of the pattern of shot, without respect to a target.

It is understood that there is almost no chance that the contemporary definition of accuracy will be changed, but all users and appropriate decision makers should be aware of the situation and ask appropriate questions concerning the location of the COI with respect to the target. Target hits and COI biases should be the measures and indicators of interest, not the size of the group.

5.2 Ways of Increasing Hitting Performance.

Before outlining possible ways of increasing hitting, it must be re-emphasized that hitting is only one task of a number of tasks that must be performed in order to accomplish some useful operational function. A target must be acquired before it can be hit and must be struck with a suitable number of projectiles having useful terminal effects. Target acquisition and terminal effects are major elements of system effectiveness.

Note that one of the ways to increase hitting discussed below has the effect of enhancing the performance of all GP rifles; the other way discussed increases hitting at the unit level, by adding what is, effectively, a new weapon.

Given appropriate missions, the ground inside about 100 meters is the ground contested by opposing riflemen. At this range the GP rifleman's aiming error is relatively the dominant error in the error budget. Historically, engineers have approached the problem of the close range aiming error from one or both of two directions: They have sought to reduce the aiming error by using various types of special sights or have attempted to compensate it by shooting multiple rounds with a single trigger pull.

AMSAA estimates that the rifleman's close range aiming error is circular thus, any shot pattern designed to compensate for the aiming error should be circular as well. Recall that the rifleman's aiming error varies with range (Table 2.14 uses about 12, 8 and 5 mils SD for 25, 50 and 100 meters, respectively). The effect of this condition is that attempts to compensate for aiming error using a patterned burst-fire dispersion can only be made optimum within a narrow range band. The user should select the range to be optimized.

5.2.1 Hit-Kill Trade-off Required with Multiple Projectiles. At close range the simplest way of increasing the chance of a hit is to increase the number of projectiles fired. Anyone considering such a concept needs to ensure that it does not reduce terminal effects to an unacceptable level.

5.2.1.1 Recoil Energy. There are several ways of increasing the number of rounds fired per trigger pull: it can be done by launching them simultaneously (like a shotgun) or by launching them in rapid succession (serially: a burst). In the first case, there is a limit to the number and individual mass of projectiles that can be launched; generally this is controlled by the amount of recoil energy (kick) that a firer can sustain.

TECOM Test Operating Procedure 3-2-504, 1 March 1977, uses 60 foot-pounds (ft-lb) (about 81 joules) as the threshold of unsafe recoil energy levels. For perspective, BRL TN 1557, January 1965, says that the recoil energy of a 7 1/2 pound shotgun is about 32 ft-lb. Table 2.18A provides additional perspective in this regard. No basis can be found for the 60 ft-lb threshold; it may have been selected to protect proving ground gunners who fire a relatively large number of rounds on a given occasion. The TECOM 60 ft-lb limit may or may not be an appropriate limit for troops in training or combat.

The USMC may adopt a family of muzzle launched rifle grenades to be fired from an unaltered M16A2 Rifle using ball ammunition. The 60 ft-lb limit may be critical in this program, depending on the launch weight (critical to terminal effects) and velocity (critical to accuracy) of the grenades they adopt. The practical upper limit of recoil must balance the need to fire from the shoulder to obtain some reasonable level of accuracy against the risk of troop injury and flinching that will destroy accuracy. Launching grenades with the rifle butt on the ground may substitute one hazard for another. There is some combination of high recoil and unyielding ground which will cause the metal and plastic components of the rifle to break. If memory serves, launching the 0.71 kg (25 oz) M31 HEAT rifle grenade from the M16A1 Rifle resulted in an unacceptable number of broken stocks. The M16A2 may or may not have such a problem.

Any program to replace the M16A2 with a grenade launcher will have to trade-off range, accuracy and terminal effects with recoil.

5.2.1.2 Burst-fire Systems. As a practical matter in systems designed to compensate for aiming error, a design limit to the total mass that can be launched is reached far short of the point that would endanger the firer. The burst-fire design limit is determined by the geometry and physics associated with the rifle, by human physiology and by the weight and stature of a particular rifleman. Recoil rotates the upper body of a standing rifleman backward and pivots it laterally, moving the pattern of shot up and to one side (usually to the right for right-handed firers). The total amount of "climb" depends on the number and mass of the projectiles launched and on the cyclic rate of the weapon. The allowed weight of each sub-projectile must be reduced as the number of projectiles is increased in order to remain within some practical recoil limit.

The following should be considered in evaluating designs that use very small projectiles launched serially or simultaneously in order to compensate for aiming error:

a. The importance of the mean range (RBAR) used to define a target distribution and calculate the range to each enemy target in an evaluation such as the ACR evaluation was discussed in Section 3.3.3. Acquisition, hitting and terminal effects depend almost totally on the range to the target. Disregard acquisition for a moment; suppose that, given a shot, the hitting performance of the four ACR designs is like the four GP rifles with WORST FLDEX aiming errors shown in Figure 10--that is to say identical. The major difference in the effectiveness of the four now depends on the terminal effects of interest and on the chance of multiple hits.

The terminal effect of a projectile on a hard or soft target is directly related to its kinetic energy (mass times the square of its velocity) and on how the energy is deposited. Other things like the size, length, shape and composition of the projectile and the target (to name a few) impact on wounding and penetration; in the end, kinetic energy is the main driver of terminal effects.

b. Lightweight projectiles (in particular, fragments that tend to be irregularly shaped) tend to loose velocity at a greater rate than do heavier, streamlined projectiles like bullets. This statement should raise a caution when it is proposed to use small, lightweight projectiles at long range. Loss of kinetic energy with its consequent reduction of lethality or lethal area is a critical consideration in any program to arm the rifleman with a new weapon that fires a grenade rather than a bullet.

c. The wounding power of tumbling flechettes in the body is dramatically higher than those that do not tumble. Small flechettes intended for use in small arms only tumble reliably in soft tissue at velocities greater than the speed of sound; this effectively limits the range at which they can be employed. Both flechettes entered in the ACR competition are steel and weigh 10.2 grains (0.66 grams); one is launched at about 4,600 fps [about 1,400 mps], the other is launched at about 4,900 fps [1,490 mps].

d. Woven fabric (nylon, kevlar) body armor was designed to stop mortar, artillery and grenade fragments of some nominal size and velocity. Given sufficient velocity and relatively small obliquity and yaw, rifle bullets and flechettes penetrate this type of armor readily. During the NATO Small Arms Trials, ca. 1978, four different types of 5.56mm, M193 and M855-type GP rifle bullets were fired at 15 plys of fabric body armor at 800 meters range. Each of the test shots of all types went through the armor; for this reason, testing was terminated at that range and the actual limiting range for penetration was not determined. Body armor made of metal or ceramic is expected to be at least as effective as fabric armor against fragments, and somewhat more effective than fabric against rifle-caliber bullets and flechettes. Flechette penetration of hard armor (such as the Soviet titanium vest) at other than zero obliquity and yaw should be rigorously tested and then compared to the baseline 5.56mm, M855 Ball cartridge. It does not make sense to give up the excellent hard-target penetration characteristics of the M855.

<u>5.2.1.3 Grenades to Compensate for Aiming Error</u>. Several years ago the Deputy Commandant of the Infantry School thought that the hitting performance of the GP rifleman could be improved by arming him with a weapon that shoots a grenade. It is likely that his idea contemplated that the lethal area of a grenade would compensate for some or all of the rifleman's

aiming error. One of the reasons offered to support the proposal was that more soldiers were wounded during WW II and Korea by fragments than by bullets.

The notion that fragments caused more casualties than bullets in WW II and Korea (perhaps based on the 1962 Wound Ballistics Study [Reference 7]) is only true for certain campaigns and is only true for mortar and artillery fragments. What data the author has seen show that grenades (generally, with much smaller fragments and lethal areas than artillery and mortars) were not a major source of casualties in either of those wars. There is compelling evidence (to the author at least) that grenade fragments are not as lethal as rifle bullets.

A report dealing with error budgets and hitting performance is not the place to address the subject of wounding (a subject for which the author claims no particular expertise). But it is necessary to do so in order to raise a caution flag before embarking on a program to replace the M16A1/A2 Rifle with a grenade launcher. The brief excerpts that follow are not the result of a thorough study nor were they selected for balance; they are provided to indicate the need for systematic study of the matter by the user.

Both aspects of the problem are highlighted in turn. The author has rounded off some of the values thus one series adds up to 101 percent.

a. The number of casualties caused by grenades:

- All casualties, South Pacific, WW II: shell fragments, 50 percent; small arms, 33 percent; grenades, 12 percent; mines and other, 5 percent. [7: p. 77]

- 4,600 WIA, Korea, November 1950 - May 1951: fragment, 84 percent; rifle and MG, 7 percent; mortar, 5 percent; grenade, 2 percent; other causes, less than 1 percent each. [7: p. 699]

- 677 POW wounded in ground action, Korea: gunshot, 64 percent; shell fragment, 35 percent; grenade, 2 percent [7: p. 723]

b. The relative lethality of bullets and fragments:

- Bougainville, Pacific, WW II: "Bullet wounds tended to produce more immediate fatalities than did wounds produced by mortar and artillery shells." [7: p.330]

- New Georgia Island and Burma, Pacific, WW II: "The grenade continued to have the lowest relative lethal effect and the highest return to duty rate in the casualties it caused. The majority of small arms casualties were either KIA or were evacuated to the rear echelon or to the United States (84.0 percent MG and 67 percent rifle)." [7: p. 265]

- Estimated cause of death of 1,500 United Nations Forces KIA, Korea, January 1951: small arms, 63 percent; shell fragments including artillery, 28 percent; mortars, 3 percent; mines, 2 percent; grenades, 1 percent; miscellaneous causes, 4 percent. [7: p. 720] o Look again at Table 3.2. Field data taken by the WDMET team in Viet Nam showed that 52 percent of the 193 bullet casualties surveyed died.

A final caution. The medical teams doing the field work for the WW II Wound Ballistics study were not sure in all cases what caused the wound. (This was more likely to be the case for KIA than it was for WIA.) The Bougainville casualty survey can serve as a typical example of this; its author said, "It was frequently impossible to judge with any accuracy whether the wound had been produced by a bullet or a grenade shell or bomb fragment." [7:p. 323] See also 7: pp. 442, 446, 451.

All of this says that concepts employing multiple projectiles--admittedly not explicitly a main concern with fire control engineers--should be looked at with caution. Before increases in hitting are allowed to dominate the analysis, terminal effects given a hit must be evaluated. It may turn out that even though P_H goes up, the P_K given a trigger pull goes down. (Where PK is defined as P_H times the probability of penetrating (damaging) a hard target, or P_H times the probability of incapacitating (wounding) a soft target.)

5.2.2 Muzzle brake/compensator (MBC). In general, there are two ways to launch multiple projectiles: fire several sub-projectiles from a large case with one trigger pull (the shotgun is a good example) or fire several individual projectiles in rapid succession. The first method tends to develop the circular pattern required to compensate for aiming error but the second method, unless assisted by a MBC, does not.

Figures 14 and 15 clearly show the value of a MBC by comparing samples of 20 x three-round bursts fired by the same soldiers with and without a MBC. [8: Figs 7 & 9] Figure 14 shows the M16A1, as issued (without MBC); Figure 15 shows that a MBC dramatically reduces the size of the M16A1 burst-fire pattern, makes its shape more nearly circular and brings the pattern center closer to the POA. The bursts illustrated in Figure 15 were fired using an M16A1 that was modified to accept an MBC that was taken from a Soviet AK-74 rifle. A test done several years ago with the M16A2 by the NAVWPNSUPPCEN shows that a MBC designed by them for the M16A2 was at least as efficient as the AK-74 MBC. [Reference 10]

5.2.3 Optical Sights for GP Rifles and Squad Automatic Weapons (SAWs).

Author's Note. This section and Section 5.2.3, Appendix A, FCPR, have inconsequential differences. The section appearing in Appendix A, FCPR, was written after the U.S. Army terminated in 1985 its program to equip the M16A2 with an optical sight. Section 5.2.3, TR 461, contains modifications needed to accommodate the re-activation (spring of 1990) of the optical sight program, now expanded to include the SAW.

5.2.3.1 Optical sights in Other Armies. The United Kingdom (UK) has fitted a 4 x 25 mm optical sight (the L9A1 SUSAT) to their new 5.56 x 45mm, L85A1 Individual Weapon (a GP rifle) and to their L86A1 Light Support Weapon (LSW), a squad base of fire weapon (SAW-type). The UK forces on operations in Northern Ireland have been equipped with the L85A1 GP rifle since about 1988. (This statement is based on observation by the author of the weapon in TV news broadcasts.)

RANGE: 25 METERS FIRING POSITION: STANDING (002)

TROOPS WITH PROVING GROUND DELIVERY ERRORS

TARGET: RECTANGLE APPROXIMATING CROUCHING MAN (50 CM WIDE X 87 CM HIGH)

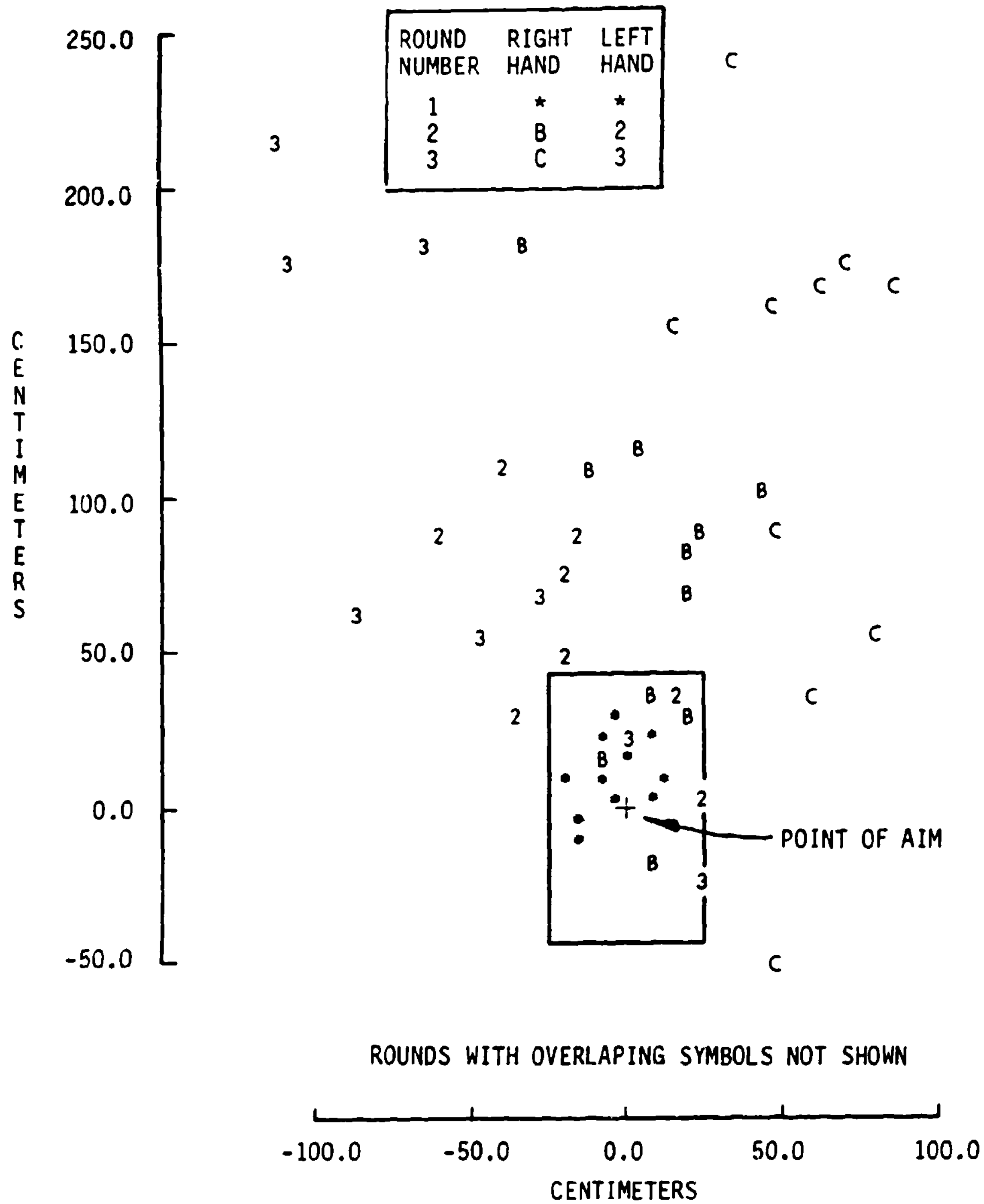

Figure 14. Plot of Rounds on Target: M16A1, As Issued (No MBC).

RANGE: 25 METERS FIRING POSITION: STANDING (006)

TROOPS WITH PROVING GROUND DELIVERY ERRORS

TARGET: RECTANGLE APPROXIMATING CROUCHING MAN (50 CM WIDE X 87 CM HIGH)

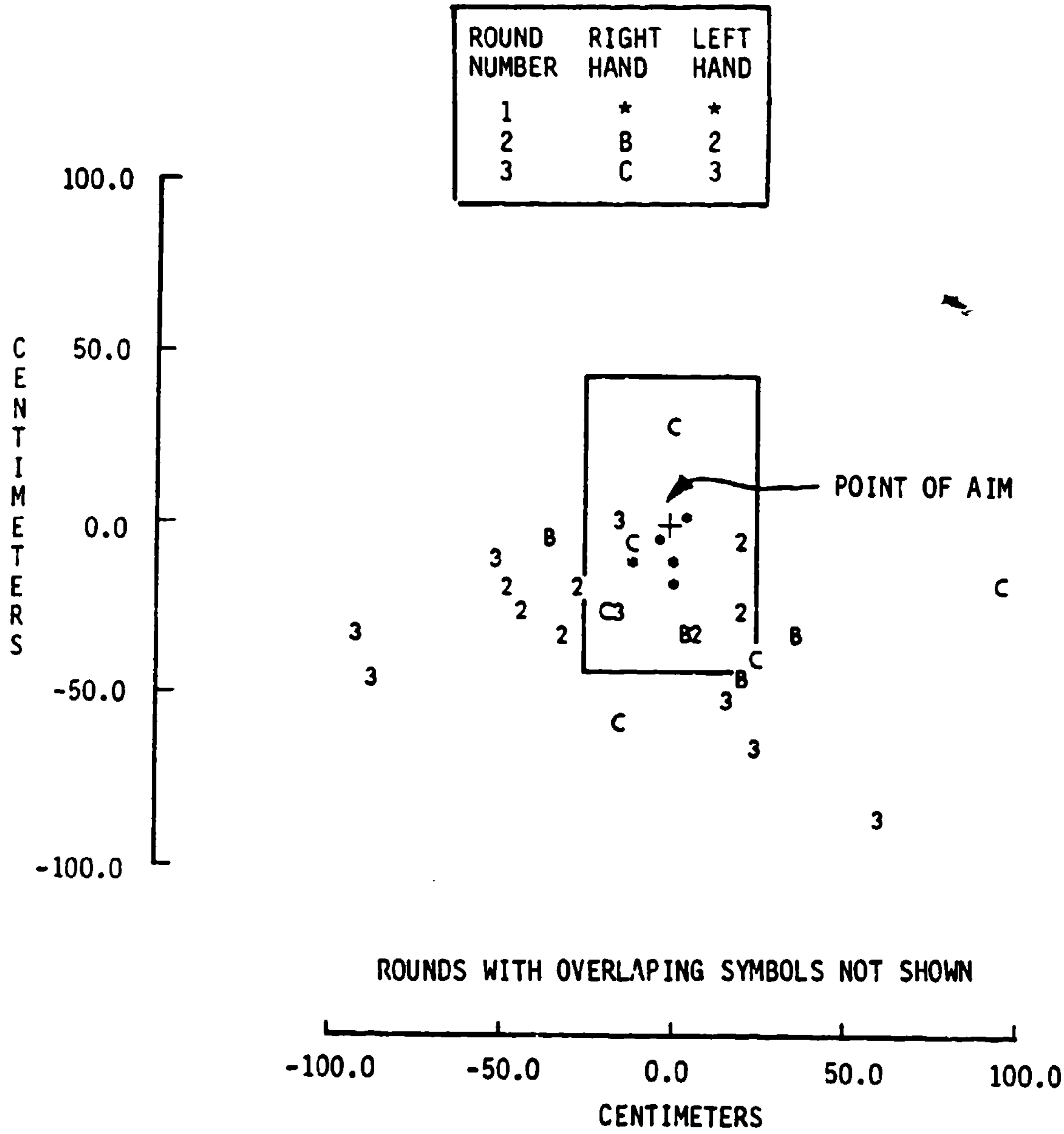

Figure 15. Plot of Rounds on Target: M16A1 With AK-74 MBC.

The Australians have adopted the Swiss 5.56mm, AUG (GP rifle). Although several optics are available it is thought that the AUG is being acquired with a 1.5x telescope.

The Canadians will shortly field a new 5.56mm, M16-type GP rifle designated the C7. Apparently, temporarily at least, due to cost, only some of the C7s will have an optical sight. This 3.5 X 28mm sight, made by Ernst Leitz of Canada (ELCAN) will have a 7 degree real field and a 52 or 72mm eye relief (fixed at the factory). The ELCAN is also known as the WILD CAT. The M16 carrying handle will be removed and the scope will attach to a rail on the C7 receiver. The Canadians are also fielding a new 5.56mm, C9 LSW (the Fabrique Nationale (FN) MINIMI); it will use the same 3.5 x 28mm ELCAN sight.

The U.S. Colt ACR, like two of the other three ACR designs, can be used (selectively) with iron or optical sights. The Colt optical sight option uses a sight much like (probably, identical to) the Canadian 4 x 28 ELCAN (WILD CAT).

Note that the new Canadian C9 and UK L86A1 squad base of fire weapons use an optical sight identical to the one used on their GP rifles. Up until recently, the U.S. Army has not shown any interest in equipping its SAW with an optical sight. All of this changed recently. The draft ROC [U.S.Army Infantry School Letter, ATSH-CDM-S (70), 22 May 1990] that calls for an optical sight as the primary sight for the M16A2 Rifles in the infantry platoon, also says that the same sight is to be used on its SAWs.

The Canadians and the UK have both fielded a 7.62 x 51mm, GPMG based on the FN MAG. Both GPMG have similar optical sights that can be mounted when the weapon is being used in the indirect-fire role. The UK L7A2 GPMG uses the C2 Trilux sight--the same sight used by them on their 81-mm mortar. The author recalls being taught to employ the caliber .30 Browning Heavy MG in the indirect-fire role, but an optical sight similar to the C2 was not used. The only fire control was a device called a clinometer (a small gunner's quadrant) that was used to lay the gun for elevation. Whatever interest the U.S. Army may have had with MG in the indirect-fire role seems to have died with the introduction of the 7.62mm, M60 GPMG.

5.2.3.2 Recent Efforts in the U.S.Army. The U.S. Army considered placing an optical sight on all the M16A2 rifles and tested several types of optical sights in 1985. Neither the Canadian nor UK sights then being fielded by them were rigorously tested in that program; neither were, for example, tested at night or other dim light to assess their usefulness in acquiring as well as hitting targets. This optical sight program was terminated (or so it was thought at the time) in 1985 by the user for non-technical reasons before a decision could be reached based on the intrinsic merits of GP rifle optical sights. The Infantry School May 1990 draft ROC reactivates the program and expands it to include SAWs with the May 1990 draft ROC. The 1990 optical sight procurement strategy seeks to test optics already adopted by other armies, so it is expected that both the ELCAN and SUSAT will be tested.

The U.S. Army never conducted a trade-off analysis of the various optical sight parameters during the 1985 program. Such an analysis, whose first iteration can be done quite adequately on paper, would begin by taking parameters such as magnification, eye relief, exit pupil and field of view, in various combinations and in various quantities, to see their impact on such physical dimensions as eye and objective lens diameters and focal lengths. Design complexity, weight and cost could also be estimated in such a paper exercise by appropriate experts. Table 5.3, discussed farther on, displays the outcome of a simple, narrowly focused analysis done by the author using the formulas contained at Enclosure 1 of Appendix A, TR 461.

This author believes that a trade-off analysis of the sort just described should shed light on questions of why certain parameters such as the eye relief, exit pupil and objective lens diameter of the ELCAN and SUSAT are not as large as simple theory, unencumbered by reality, might lead one to select as optimum. Reconciling the many-times conflicting optical sight parameters while producing a sight of reasonable dimensions is the quintessential example of the saying that there is no free lunch.

AMSAA's formal position with respect to placing an optical sight on each GP rifle was at the time the Army terminated the optical sight program:

a. A potential exists to enhance the ability of riflemen, SAW and MG gunners to acquire and hit operational targets using optical sights.

b. The Army should not type classify and procure until certain critical, additional tests and evaluations are conducted. The optical sight should be type classified as a separate item.

c. Inclement weather will probably seriously degrade optics.

d. The user will probably not benefit from having an optical sight on each infantryman's rifle in the arctic and in close terrain such as jungles.

e. The Army should seriously consider Canadian and UK sights and mounts as candidate enhancements for rifles, SAW and MMG.

5.2.3.3 Need to Test Optical Sights for Target Acquisition Under Dim Light. The Army did not test the dim-light target acquisition of optical sights during the 1985 M16A2 optical sight tests. The test done in 1985 at the USAIB was supposed to do this, but did not. Reference 7 of the FCPR is an outline test plan for the USAIB test. [The FCPR is TR-461 Reference 56] No other tests done since that time, including the HEL test described in Appendix B of the FCPR, have measured the ability of a soldier to detect the presence of a target using an optical sight under dim light conditions (dawn, dusk, night, daylight in deep shadows and shade).

The British Army adopted an optical sight for its GP rifle and SAW at least in part because of improvements they saw in dim-light target acquisition compared to the naked eye. Several years ago the author examined a test report where a low contrast, standing target was acquired (detected) at a distance of about 350 meters (the maximum range tested) during twilight (1.00 millilambert) and a similar distance under a full-moon (0.01 ml). In both cases the detection distance for the naked eye was less than 100 meters. Detection under five other light conditions that were not defined in the report, was always better with the optical sight than a naked eye--but with smaller, less remarkable differences.

The meaning of that test outcome is simple and unambiguous: On average, on the occasions and under the light conditions tested, a rifleman had about a 250 meter acquisition standoff (advantage) over a rifleman armed with an iron sight. The potential importance to riflemen and tacticians is obvious. Recall in Section 4.1.5.3, that a nominal 40 meter loss of standoff caused by the introduction of the Soviet AK-74 was at least part of the reason given by the USMC for replacing the M16A1 Rifle and requiring the M16A2 to have a MERN of 550 meters.

Standoff is a relative condition where differences, not absolute values are important. One need not always have megavalues in order for the differences to be useful; in some cases, perhaps, decisive. Under some circumstances, even something as modest as a 50 meter acquisition standoff could be converted into a local tactical advantage for a rifleman, making him, like the one-eyed man in the kingdom of the blind, king of his part of the fire fight for a moment at least.

Early-on in the process of evaluating their optical sights, an official of the British or Canadian government or a manufacturer's representative said that one thing that made an optical sight better than an iron sight was that it, "extended the length of the combat day." He probably meant that an optical sight would allow more targets to be seen and engaged than by iron sights in the dim light of morning and evening before full dawn and full dusk (something generally corresponding to morning and evening nautical twilight).

Actually, emphasis on "twilight" performance tends to obscure the fact that there is enough starlight and moonlight throughout the balance of many nights to provide sufficient light to acquire targets. There are at least two other conditions where an optical sight is likely to "see" more things than does a naked eye: (a) at night under flares and other man-made light; (b) looking into deep shadow during daylight (for example, looking back into the interior of buildings through windows and other openings, and looking into a woods back beyond the sun-lit edge of its tree-line). Given a side by side test, the author is confident that an optical sight suitable for a GP rifle would be found to be better than a naked eye under these conditions.

Appendix B of the FCPR gives the following as the desirable characteristics of a GP rifle optical sight: magnification, 4 power; exit pupil diameter, 8 - 10mm; objective lens diameter, 32 - 40mm; eye relief 50 - 75mm; field of view, undetermined. To say that the field of view is undetermined is to say that whatever is left over in the design process is an acceptable field of view. This is the antithesis of this author's perception of the critical importance of field of view.

Table 5.3 was mentioned earlier as an example of a type of simple trade-off analysis that can be done now, quickly. The whole idea of showing this table now is to say that there is no free lunch--show the price one must pay in order to hold one or more optical design parameters in some theoretically optimum quantity. Table 5.3 is only a strawman. A thorough trade-off assessment of the cost of owning any particular optical design must be made in terms of design complexity, ruggedness, weight, size, money, and development and test time. Such an exercise goes way beyond the scope of this report and the expertise of its author.

Table 5.3, whose formulas come from Appendix 1 to Annex A, is very narrowly focused in order to keep the table on a single page and to hold the "what-if" distraction to a minimum. It would probably be useful to review the optical design formulas now or mark their location before going farther with Table 5.3 since the influence of one parameter on the others may not be immediately obvious.

The construction of Table 5.3 reflects the author's perception of the fundamental importance of field of view and magnification (controls target apparent size) on the performance of a telescope used in small arms fire control. In this instance, magnification and real field of view and apparent field of view are collected under the heading REQUIRED; eye relief and objective lens diameter are shown as VARIABLE. The results of taking these arguments in various combinations are tabled under a heading called OUTCOME. The result, which is thought of by the author as a cost, is measured as a change in the physical size of the telescope (eye lens diameter and total focal length) and as a reduction in the size of the exit puil--both bad things in abstract. Other arrangements are possible and desirable in a more thorough analysis. The present scheme may understate the importance of exit pupil compared to field of view in dim-light acquisition; nonetheless, a point needs to be made and, in any event, suitable tests can be designed to set the matter right.

Five degrees was selected as the lower limit of real field of view. By way of perspective, the SUSAT has a 10 degree real field. Field of view is sometimes expressed as a linear field at some specified distance, typically 1,000 meters for military telescopes. Quantified in this manner, a telescope with a 5 degree real field of view has linear field of 87 meters. Magnification times real field equals apparent field of view.) The eye lens (not the objective lens) controls field of view. Note b indicates a practical limit on the size of the apparent field of view that can be designed into an eye lens; given this, 15 degrees seems like a reasonable upper limit to real field. Notes c and d bear on the matter of acquisition, providing estimates of the field of view of the human eye and its ability to resolve a target under field conditions.

A 4 power magnification is used as a central value since there seems to be some concensus in this parameter; 3 and 5 power excursions were selected to show what happens to the size of a GP-rifle telescope with modest changes in magnification. The 75mm eye relief represents HEL's recommended optimum value and 25mm represents at least one iteration of the SUSAT design. Table 5.3 is divided in half by a dashed line; the upper half is for a telescope with an objective lens of 25mm diameter (about equal to ELCAN and SUSAT) and the lower half is for an objective lens of twice that diameter. The 40 mm diameter objective lens recommended by HEL (4 power, 10 mm exit pupil) is roughly enclosed by the two values used in Table 5.3.

At the outset, note that the eye lens diameter and total focal length are, for each required and variable value tabled, identical for 25mm and 50 mm diameter objective lens. The only differences are in exit pupil diameter and the minimum angle that can be resolved. (See Notes d and g dealing with resolution.)

Table 5.3. Simple Analysis of Affect of Certain Optical Design Parameters on the Physical Size of a GP Rifle-Type Telescope [a]

(DIMENSIONS IN MILLIMETERS, FIELD OF VIEW IN DEGREES)

	REQUIRED			VARIABLE		OUTCOME			
NR	MAG	FIELD OF VIEW REAL [b]	FIELD OF VIEW APPARENT [c][d]	EYE RELIEF	DIAM OBJ LENS	DIAM EYE LENS [e]	EXIT PUPIL [e]	TOTAL FOCAL LENGTH [f]	RES OF OBJ @ (MOA) [g]
1	3X	5.0	15.0	25.0	25.0	6.6	8.3	75.0	0.09
2				75.0	"	19.7	"	225.0	"
3	3X	15.0	45.0	25.0	"	20.7	"	75.0	"
4				75.0	"	62.1	"	225.0	"
5	4X	5.0	20.0	25.0	"	8.8	6.3	100.0	0.09
6				75.0	"	26.4	"	300.0	"
7	4X	15.0	60.0	25.0	"	28.9	"	100.0	"
8				75.0	"	86.6	"	300.0	"
9	5X	5.0	25.0	25.0	"	11.1	5.0	125.0	0.09
10				75.0	"	33.3	"	375.0	"
11	5X	15.0	75.0	25.0	"	38.4	"	125.0	"
12				75.0	"	25.0	"	375.0	"
13	3X	5.0	15.0	25.0	50.0	6.6	16.7	75.0	0.05
14				75.0	"	19.7	"	225.0	"
15	3X	15.0	45.0	25.0	"	20.7	"	75.0	"
16				75.0	"	62.1	"	225.0	"
17	4X	5.0	20.0	25.0	"	8.8	12.5	100.0	0.05
18				75.0	"	26.4	"	300.0	"
29	4X	15.0	60.0	25.0	"	28.9	"	100.0	"
20				75.0	"	86.6	"	300.0	"
21	5X	5.0	25.0	25.0	"	11.1	10.0	125.0	0.05
22				75.0	"	33.3	"	375.0	"
23	5X	15.0	75.0	25.0	"	38.4	"	125.0	"
24				75.0	"	115.1	"	375.0	"

@ - RES OF OBJ = RESOLUTION OF OBJECTIVE LENS

NOTES ON THE FOLLOWING PAGE

NOTES TO ACCOMPANY TABLE 5.3

a. SEE APPENDIX 1, ANNEX A, AMSAA TR 461 FOR OPTICAL FORMULAS.
b. MIL-HDBK 759A [p. 7-47] GIVES 60 DEGREES AS THE MAXIMUM PRACTICAL APPARENT FIELD OF VIEW (FOV) FOR A HIGHLY CORRECTED EYE LENS, TM 9-258 [p. 2-40] USES 45 DEGREES. FULL FOV OF SCOPE ONLY SEEN WHEN EYE IS AT PLANE OF EXIT PUPIL (LOCATED BEHIND EYE LENS A DISTANCE CALLED EYE RELIEF).
c. HUMAN EYE FIELD OF VIEW (NO HEAD MOVEMENT, ROTATING EYES IN SOCKETS) IS ABOUT 160 DEGREES HORIZONTAL & 70 DEGREES VETICAL. FIELD OF DISTINCT VISION IS SOMETHING LESS THAN 1 DEGREE OF ARC. [TM 9-258, pp. 3-8, 3-16]
d. RESOLUTION OF 20/20 HUMAN EYE: FAVORABLE (HIGH CONTRAST) CONDITIONS, ABOUT 1 MINUTE OF ARC; CONSERVATIVE ESTIMATE FOR FIELD CONDITIONS, 1.5 TO 2.0 MOA. [56: NO PAGE NUMBER]
e. AREA OF OBJECTIVE AND EYE LENS GLASS INCREASES BY SQUARE OF INCREASE IN DIAMETER; AT A MINIMUM, WEIGHT OF SCOPE INCREASES PROPORTIONATELY; MAY ALSO REQUIRE ADDITIONAL OPTICAL ELEMENTS.
f. TOTAL FOCAL LENGTH (NOT INCLUDING HOOD OR EYE CUP) IS APPROX LENGTH OF SCOPE IF LENS ERECTORS USED; OVERSTATES LENGTH IF PRISM ERECTORS USED.
g. RES = RESOLUTION OF THE OBJECTIVE LENS: THE MINIMUM ANGLE (USUALLY IN MINUTES OF ARC) THAT CAN JUST BE RESOLVED (SEEN SEPARATELY); SMALL VALUES BETTER THAN LARGE VALUES; IMPROVES WITH LARGER OBJECTIVE LENS.

With a 50 mm diameter objective lens, the size of the exit pupil increases and the minimum target dimension that can be resolved (separated) decreases. Both of these parameters change in a manner that, in abstract, should cause an improvement in the performance of the telescope. This turn of events seems to say that it is possible to improve the performance of a telescope at no cost by specifying a large objective.

There is a cost, but the author is not able to show it explicitly since he does not have a formula with which to estimate the size, weight or complexity of a telescope given an increase in the diameter of its eye or objective lens. Note e says that the area of a lens increases by the square of the increase in its diameter; a 50mm diameter lens has four times the area of a 25mm diameter lens. At a minimum the weight will increase in proportion with the increase in area; if additional optical elements or additional metal in the body of the telescope are required, there will be a disproportionate increase in weight. So there is likely to be a cost to owning a telescope with a large objective lens (exit pupil) after all.

Only a few examples are needed now for the author's perception of cost to be seen in Table 5.3. For a given objective lens diameter, exit pupil decreases with increasing magnification. There is a relatively modest increase in the diameter of the eye lens when magnification is increased from 3 to 5 power. The total focal length becomes longer with increases in magnification and eye relief. Of the two, eye relief causes the greater increase (increasing in direct proportion to the increase in eye relief). The effect on total focal length attributed to magnification alone is seen by comparing lines 1, 5 and 9.

Increasing real or apparent field of view only increases eye lens diameter, it does not increase focal length. It is important to note in this regard that the full field of view of a telescope can only be seen when the pupil of the eye is at the same position as the plane of the exit pupil; the exit pupil is located to the rear of the eye lens a distance that is defined as the eye relief. [p. 2-41, TM 9-258]

The total focal length can be taken to be an estimator of the overall length of the telescope, thus it should give some abstract notion of size and weight. Note f says that the physical length of a telescope (not including a hood or eye cup, if needed) would be about equal to the total focal length for a design that used lens to erect the target image. (Practically all commercial telescopes used for hunting use lens erectors.) The total length of a telescope that uses prism erectors (like the roof prisms used by the ELCAN and SUSAT) is probably more nearly half the total focal length value shown.

<u>5.2.3.4 Optical Sights on Selected GP Rifles</u>. The assessment that follows, <u>unmodified from Appendix A, FCPR, must be taken</u> in the context of the Army's reactivated optical sight program:

AMSAA's reservation concerning the general issue of optical sights does not extend to the use of optics by selected members of an organization when a particular combination of mission, situation and terrain indicate that this is an appropriate action. One option is for the Army to consider designating selected riflemen--perhaps one per rifle squad--as expert marksmen and providing this specially selected and trained marksman with a suitable optical sight. Other arms and organizations might find this an attractive proposition as well.

It is difficult to say whether or not there will be sufficient targets at ranges beyond, say, 500 meters to warrant the proliferation of an expensive or otherwise burdensome engineering design on what it is hoped will remain a GP rifle. An alternative approach might be to adopt a limited number of a special-purpose variation of the basic rifle and assign the task of servicing targets beyond the GP rifleman's zone of interest or marksmanship ability to an expert marksman. This man should not be called a sniper.

It is possible to visualize specially selected, trained and equipped individuals employed by troop leaders with much the same care as an important crew-served weapon. Properly trained, motivated and employed, such an expert marksman might make a disproportionately large contribution to the effectiveness of his unit. The expert marksman's performance beyond, say, 500 to 600 meters, would be degraded unless he were given appropriate fire control.

<u>5.2.3.5 The GP Rifle Must be Used by Other Arms and Services</u>. Thus far, <u>the rifle has been portrayed as a tool to be used by riflemen</u> exclusively. Certainly there must be no compromise made in its design for this purpose. It must also be recognized that the rifle is an individual weapon for many other soldiers including those assigned to combat support and

combat service support organizations. These soldiers will perform exactly like a rifleman on occasion. It is likely that the conduct of rear area defense operations will look very much like a small unit rifle fire fight.

Each soldier requires a personal defense weapon. Some soldiers that are not riflemen might, in extraordinary circumstances, be used in the close-in defense of their place of duty. In these cases, it is likely that engagement ranges will be relatively close. A true GP rifle must be able to service this class of targets. Traditionally, pistols, carbines or submachine-guns are issued when the basic rifle does not meet all the needs of the force.

6. CONCLUSIONS

6.1 General.

a. The contemporary use of the term accuracy to describe the size of the RRD of a weapon tends to mask any problem that weapon may have hitting a target. No assessment of accuracy is complete without knowledge of the magnitude of all elements of the error budget, including biases.

b. There is great variability in the performance of weapons and shooters; by and large, the shooter's variability is not only the larger but also the lesser understood of the two.

c. Effectiveness depends critically, on the ability of a GP rifle or ACR system to acquire, hit and kill a target. All of these measures vary with range--perhaps, unevenly among systems; thus, the ACR evaluation will be sensitive to the mean range selected to represent the enemy range-target distribution.

d. It is not true that fragments, universally, caused more casualties than did bullets in WW II and Korea. When fragments were the major wounding agent, the majority of fragment wounds were caused by mortar and artillery fragments, not grenade fragments. Generally, grenade fragments cause less severe wounds than do the larger fragments and rifle-caliber bullets.

e. The terminal effects over range of multiple projectile concepts designed to increase hitting performance should be carefully examined. There is a minimum kinetic energy required to produce a soft target wound or penetrate a hard target and the velocity of small projectiles (particularly fragments) of necessarily low mass falls off rapidly with range.

6.2 GP Rifles.

a. The differences in the intrinsic single-shot RRD of various GP infantry rifles are great enough to cause concern to a competition-quality, bull's-eye shooter; they are also large enough to cause notable differences in P_H against a crouching-man target engaged by PG gunners from a bench rest.

b. The differences in P_H against field targets caused by differences in the intrinsic single-shot RRD decrease as the shooter's contribution to the system error budget increases. When the shooter's error approximates the worst hitting performance seen in peacetime field experiments, all differences in hitting a crouching man target caused by the intrinsic RRD are wiped out.

c. If "effective range" is measured by the single-shot hitting performance of typical riflemen in operational situations, the Soviet AK-47, AK-74, U.S. M16A1 and M16A2 all have the same "effective range." This statement can be extended to all GP rifles of any caliber. It is instructive to review Figure 9 in this regard and see the maximum range to which a P_H of 0.5 is to be expected under various conditions.

d. The Army and Marine Corps should review the tactical instructions that are given to small rifle units that key actions to a maximum effective range of 460 meters for the M16A1 or 550 meters for the M16A2 Rifle.

e. Wind and range errors have no practical effect on the operational hitting performance of the typical rifleman, since engagement ranges tend to be relatively close and his large aiming error effectively wipes out the effects of wind and range biases.

f. A MBC controls the very close-range burst-fire dispersion pattern of GP rifles such as the M16A2. The MBC used on the Soviet 5.45mm, AK-74 and the one designed for the M16A2 by the USNAVWPNSUPPCEN have demonstrated this facility.

g. It appears that a substantial number of targets hit in field experiments are hit by ricochets. The potential of ricochets to surpress and to provide strike feedback to riflemen and SAW gunners should be investigated. The relative efficiency of center of target and bottom of target points of aim should be examined concurrently.

h. AMSAA has reservations concerning the proliferation of optical sights as primary sights to all M16A2 Rifles.

i. An M16A2 Rifle with an optical sight should be treated as a special-purpose weapon organic to the rifle platoon; it should be issued to a specially, rigorously trained rifleman. If such a weapon were found to be desirable, the Infantry School should develop the necessary doctrine and programs to train troop leaders in order that maximum combat power is obtained from the employment of this special weapon.

6.3 <u>Sniper Weapon System</u>.

a. Wind, range and other bias errors are matters of great concern to snipers who, as a class, have small aiming errors and who shoot weapons of very small RRD at long range; such errors will, if uncompensated for, devastate the sniper system's performance.

b. Existing sniper materiel of all calibers are not true first-round hit systems except under the most narrowly constrained conditions--very close range or where the range is known exactly and there is little or no wind blowing.

c. The sniper must fire "will adjust" rounds to compensate for the lack of full-solution, real-time fire control equipment. "Will adjust" rounds are unsatisfactory in an engagement where the sniper must remain undetected or the target must remain unwarned.

d. When shooting the same ammunition under identical conditions, the intinsic RRD of the U.S. Army M24 and USMC M40A1 sniper rifles may be considered to be the same. The accuracy of the two weapons is identical given the use of similar fire control equipment. Army and Marine snipers should have about the same range of aiming errors.

e. AMSAA does not have any data for tests of snipers and sniper materiel under operational conditions. Data from existing user tests tends to overstate troop performance.

f. It is expected that the sniper's aiming error will increase at some level of increasing recoil. The blast and flash of a high-efficiency muzzle brake will, if not masked from the enemy's view, increase the chance the sniper will be detected.

g. It might be possible to develop a modular general purpose fire control system that, suitably modified with wind and firing table equations, could be used for a variety of small caliber direct-fire weapons.

h. The knobs used to set range on some or all of the M3 telescopes being acquired as part of the M24 SWS have the wrong elevation angle offsets for the exterior ballistics of the 7.62mm M118 cartridge for which it is engineered.

6.4 Range Measurement.

6.4.1 Summary. Appendix A of the FCPR does not have a separate section of conclusions dealing with range measurement. A separate section has been added to TR 461 to draw attention to the outcome of a more thorough evaluation of the AN/PVS-6 (MELIOS) OT I data than had been possible within the confines of the FCPR deadline.

Our current perception of how well soldiers estimate range by eye and measure it with a LRF must be reconciled with the realities of the MELIOS OT I, whose two most important results are:

a. The troop eye-estimation error is at least double what it had been thought to be for the last 20 years.

b. The MELIOS (and probably the entire class of portable LRF) does not have the 5-meter accuracy that had been, and probably still is being, claimed for it. Even if aiming error were not considered, its intrinsic range error is too large to measure range to a crouching-man target with usable precision beyond about 1,000 meters for a sniper armed with the M24 SWS.

These two results lead one down the following logic path: If eye-estimation is really as bad as the MELIOS OT I data portray it to be, and the MELIOS is not a satisfactory range finder, some other means to measure range must be found for those applications where it must be known nearly exactly. Although generally thought to be unsatisfactory for one or more reasons, stadia and other optical range finders might be re-examined in this context.

6.4.2 Eye Estimation and Optical Devices.

a. Estimates of the performance of troop estimating range by eye using the MELIOS OT I data (for a sample of about 1,300 observations) show that the error varies from 36 to 49 percent SIGMA. These values are generally double those given by HEL in HELBAT I in 1970.

b. Stadia, at its present state of development and application, is unsatisfactory for targets that are incompletely exposed and whose size is not exactly known.

c. Stadia and other direct-view, optical range-measuring devices are not burdened with an aiming error caused by an operator as is a LRF; none emits a detectable range-measuring signal.

6.4.3 AN/PVS-6 (MELIOS) Laser Range Finder.

a. If MELIOS (or its successor) performs about like what is seen in Table 2.8, the SWS (and other systems) does [not] have a suitable device to measure range. The 5 meter advertised accuracy of the MELIOS is not met when used by troops. The word not in [ ] above, inexplicably, does not appear in 6.4 (8), Appendix A, FCPR.

b. There is an exact analogy in the error budgets of the LRF and GP rifle. The values are different, but there is an almost perfect correspondence between the GP rifle and LRF. Both systems have relatively small precision errors, but in both cases the soldier imposes an aiming error on the system gross enough to seriously degrade its performance.

c. Unlike optical range measuring devices and eyeball range estimation, a LRF must hit its target before it can measure range; thus the MELIOS adds a unique element to the system error budget of the weapons it supports.

d. The LRF is an active device, thus its location can be detected by suitable equipment.

e. The LRF range measurement error is uniquely influenced by terrain and the way the ground may be cluttered with potentially false targets. The magnitude of the LRF error is sensitive to the relative location of the LRF and its target.

f. The actual intrinsic dispersion of the MELIOS is not known; however, a type-LRF whose intrinsic dispersion is contained inside a 1 mil diameter circle probably only has the precision needed to measure range to a man-sized target at ranges less than about 1,000 meters. A type-LRF with a 1/4 mil diameter beam has the precision needed to measure range to a man-sized target to about 4,000 meters. Both estimates assume zero aiming error.

g. The fraction of targets to which MELIOS measured range in OT I with accuracy acceptable to the user (no more than a 5 meter error) was never more than 68 percent (in the 0 - 1,000 meter range band), it decreased with range at a rate that has the general outline of the falloff seen in the hitting performance of small arms.

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APPENDIX A

EXPERIMENTAL DATA ON THE RESPONSE OF THE EYE PUPIL TO VARIOUS LEVELS OF AMBIENT BRIGHTNESS (ORIGINALLY PUBLISHED IN 1920) [REFERENCE 37]

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APPENDIX A

EXPERIMENTAL DATA ON THE RESPONSE OF THE EYE PUPIL TO VARIOUS LEVELS OF AMBIENT BRIGHTNESS (ORIGINALLY PUBLISHED IN 1920)

This appendix supplements the brief narrative contained in Section 2.5.2 of the body of the report. It has been added because it is thought that some might wish to explore this important topic in some depth using (what the author believes to be) the original experimental data. The values seen in Table A-1 and Figure A-1 were taken by the author from an article by Prentice Reeves in the March 1920 Journal of the Optical Society of America (JOSA). [Reference 37]

The author cannot say with certainty, but it appears that these are the only generally published experimental data on the topic. Others may have confirmed the data independently, but the author has not seen any evidence of this. Two characteristics of Reeves' experiment should be highlighted: first, the data are based on a sample of six test subjects; second, there is considerable variability in the data.

The UK has adopted a new 5.56mm GP rifle--called by them the L85A1 Individual Weapon--and a new 5.56mm rifle squad base of fire weapon--called the L86A1 Light Support Weapon (LSW). Both weapons use as their primary sight the L9A1 Sight Unit Small Arms-Trilux (SUSAT)--an optical sight of about four power magnification. It appears that Canada will also equip some or all of its new 5.56mm, C7 Rifles and all of its C9 LSW with optical sights made by Ernst Leitz of Canada (ELCAN); the ELCAN has approximately the same characteristics as the SUSAT. When the author asked why optical sights were being adopted, two reasons were offered: one, targets can be engaged at longer ranges than is customarily the case with iron sights; two, an optical sight can see more in dim light (dawn and dusk are most often mentioned) than an unaided eye. The diameter of the human eye pupil is a matter of critical concern in the latter situation.

The author had seen several different values used to represent the diameter of the human eye pupil under varying ambient light (brightness) conditions. For example, TM 9-258, Elementary Optics and Application To Fire Control Instruments, says this in a section dealing with the functioning of the human eye:

> The pupil varies in size from 2 to 8 millimeters, depending upon the illumination. In intense illumination, the iris steps the pupil down to about 2 millimeters. In moderate (daytime) illumination, the opening is about 4 to 5 millimeters. This is considered to be the opening for maximal acuity or best resolution. In very faint (night) illumination, the diameter of the pupil is approximately 8 millimeters. [38:p.3-3]

It is important to understand how the eye responds to light since this phenomenon directly influences the basic design of any optic from the start. TM 9-258 says in a section dealing with optics to be used at night:

> When the eye is subjected to very faint illumination, as at night, the pupil opens to a diameter of 8 millimeters. Thus, for use at night an optical instrument must have an exit pupil of at least 8 millimeters to provide the pupil of the eye with all the light it will admit. [38:p.5-17]

Several years ago, a major manufacturer of sporting telescopes spoke in an advertisement of an optical triangle and said that, " . . . a rifle scope is a finely balanced blending of three physical properties: magnification, eye relief and field of view." The author agrees with the importance of magnification and field of view, but believes the size of the exit pupil of the scope, not its eye relief should form the third side of the triangle. TM 9-258 defines eye relief as the distance from the rear surface of the eye lens to the plane of the exit pupil and exit pupil as the diameter of the bundle of light leaving an optical system; it says that the full field of view can only be seen when the eye is at the exit pupil. [38:pp.2-41, B-13] Given these definitions, it is likely that the author and the manufacturer are in agreement on the importance of the exit pupil.

The important notion to have from a discussion of the optical triangle is that the three elements are inextricably linked by certain physical laws. Any one element can only be increased at the expense of the other two.

The exit pupil of a telescope is equal to the diameter of the objective lens divided by the magnification . With a four power (magnification) telescope, the designer must provide objective lens diameters of 24, 28, 32, 36 and 40mm diameter in order to have, respecticvely, 6, 7, 8, 9, and 10mm diameter exit pupils. A penalty in weight/size, cost, ruggedness is to be expected as the size of the objective lens increases. All elements of the optical design are linked and there is no free lunch; thus other less obvious changes can be expected to occur if the exit pupil is increased.

Those interested in working up the trade-offs required to rationalize several optical parameters should consult Enclosure 1 for the necessary formulas. Enclosure 1 also contains the basic optical characteristics of the L9A1 SUSAT as they were published in a brochure several years ago, by way of providing the baseline for those who may desire to check their calculations.

Now look at Table A-1. Reeves measured brightness in millilamberts (ml) and tabled his experimental data in ml and the LOG ml, where the LOG of 0.1 ml is -1.0, the LOG of 1.0 ml is 0, the LOG of 10 ml is 1.0, etc. Reeves did not use the descriptive ambient conditions contained in < > in Table A-1, they were added by the author using for source, AMC P(amphlet) 706-188, one of the AMC 706-Series of Engineering Design Handbooks. Table 3-2, AMCP 706-188, gives a descriptive label for brightness levels from 0.00001 ml (LOG -5.0), OVERCAST STARLIGHT, to 10,000.0 ml (LOG 4.0), HAZY daylight. Notes accompaning Table 3-2 say: 1 ml is approximately equal to 1 footcandle; "The maximum brightness condition which is likely to be encountered is that of the sky on a slightly hazy day at noon." [38: Table 3-2]

Table A-1. Response of Eye Pupil to Light Intensity:Experimental Data Reported by Reeves in JOSA, March 1920: [a]

BRIGHTNESS (B) [b] MILLILAMBERTS (ML)	(LOG B)	DIAMETER OF EYE PUPIL (MM) TEST SUBJECTS [c] J.B.	C.B.	K.H.	F.J.	R.M.	R.W.	MEAN
0 [d][e]	-6.0	7.4	8.7	7.0	7.8	8.3	8.7	8.0
0.00001 <OVERCAST STARLIGHT>	-5.0 [f]			NO DATA				
0.0001 <CLEAR STARLIGHT>	-4.0			NO DATA				
0.00015	-3.8	7.1	8.4	6.8	7.6	8.1	7.9	7.6
0.001 <QUARTER MOON>	-3.0			NO DATA				
0.01 <FULL MOON>	-2.0	6.7	8.0	6.7	7.0	7.1	6.3	7.0
0.1 <DEEP TWILIGHT>	-1.0			NO DATA				
1. <TWILIGHT>	0.0	5.0	5.9	4.8	5.2	4.6	4.5	5.0
10. <HEAVY OVERCAST>	1.0	3.9	4.8	3.6	4.6	3.5	3.5	4.0
55.	1.7	3.0	3.5	3.1	3.1	3.0	2.9	3.1
100. <LIGHT OVERCAST>	2.0	2.7	2.9	2.7	2.9	2.8	2.9	2.8
1000. <CLEAR>	3.0			NO DATA				
2000.	3.3	2.0	NO DATA OTHER SUBJECTS					2.0
10,000. HAZY [c]	4.0			NO DATA				

a. TABLE II, JOURNAL OF THE OPTICAL SOCIETY OF AMERICA, MARCH 1920, [REFERENCE 37].
b. DESCRIPTIVE AMBIENT CONDITIONS IN < > AND ASSOCIATED BRIGHTNESS LEVELS IN ML FROM TABLE 3-2, AMCP 706-188 [REFERENCE 38].
c. REEVES REPORTED THAT ALL 6 TESTS SUBJECTS HAD "NORMAL" EYES.
d. REEVES ARBITRARILY USED LOG ML = -6.0 TO REPRESENT TOTAL DARKNESS.
e. TEST SUBJECT EYES CONDITIONED FOR 15 MINUTES IN TOTALLY DARK ROOM TO REPRESENT 0 LIGHT CONDITION.
f. 0.00001 ML (OVERCAST STRLIGHT) IS MINIMUM BRIGHTNESS USED IN AMCP 706-188; 10,000 ML (HAZY) IS MAXIMUM.
g. 1 MILLILAMBERT ≈ 1 FOOTCANDLE.

Reeves said that all of his six test subjects had "normal eyes;" he conditioned them for 15 minutes in "total darkness," calling this light level 0 ml in his Table II. Since the LOG of 0 is undefined in mathematics, Reeves took a brightness of 0 ml to be a LOG of -6.0. (The LOG of 0.000001 ml is -6.0, actually.) The notation, NO DATA used in Table A-1 indicates that Reeves did not take measurements at each light level used in AMCP 706-188. His last data for all six subjects was taken at 100 ml; however, Reeves observed that, " . . . the ammount of contraction of the pupil for brightnesses in excess of 100 millilamberts is slight, ..." [37: p.36]

Figure A-1 is a facsimile of some of the actual curves drawn by Reeves from the data in his Table II; it does not represent a contemporary regression or plot of Reeves' data. [37: Fig 2] Reeves' Figure 2 showed a curve for each of the six subjects used in his 1920 experiment and a mean of the six; Figure A-1 only shows the mean pupil diameter and two extreme values. The maximum and minimum response to change of any individual pupil is shown as a solid line above and below the mean pupil diameter. Except at 0 ml, when the same size as R.W., the eye pupil of C.B. became larger than any other subject at any level of brightness. The solid line representing the least response is a composite of subjects K.H. and R.W.

A few moments spent inspecting Table A-1 and Figure A-1 should impress an observer with the variability in the response of the eye pupil of individual test subjects to changing light. (Reeves spoke of "marked variations".) At the light level taken by AMCP 706-188 to represent TWILIGHT, the pupil diameter of Reeves' subjects varied from 4.5 to 5.9mm (mean 5.0); the diameter of the pupil in Reeves' "total darkness" ranged from 7.0 to 8.7mm (mean 8.0). Reeves said, "In ordinary practice we seldom use either the maximum or minimum diameters which may be taken as 8mm and 2mm, but ordinarily take the range from 2.5 to 7 mm." [37: p. 39]

Table I and Figure 1 of the JOSA article show the pupil diameter of Reeves and one test subject when one eye is closed and when both eyes are kept open. The data show that at each of the eight different light levels examined, the pupil of the single eye kept open was larger than was the pupil when both eyes were kept open. Reeves concluded, " . . . in the range of ordinary intensities there is a marked effect of closing one eye." [37:p. 36] Reeves' Figure 1 shows that the maximum difference in pupil size (about 1 to 1-1/2 mm) occurs approximately in the region AMCP 706-188 calls Deep Twilight, Twilight and Heavy Overcast.

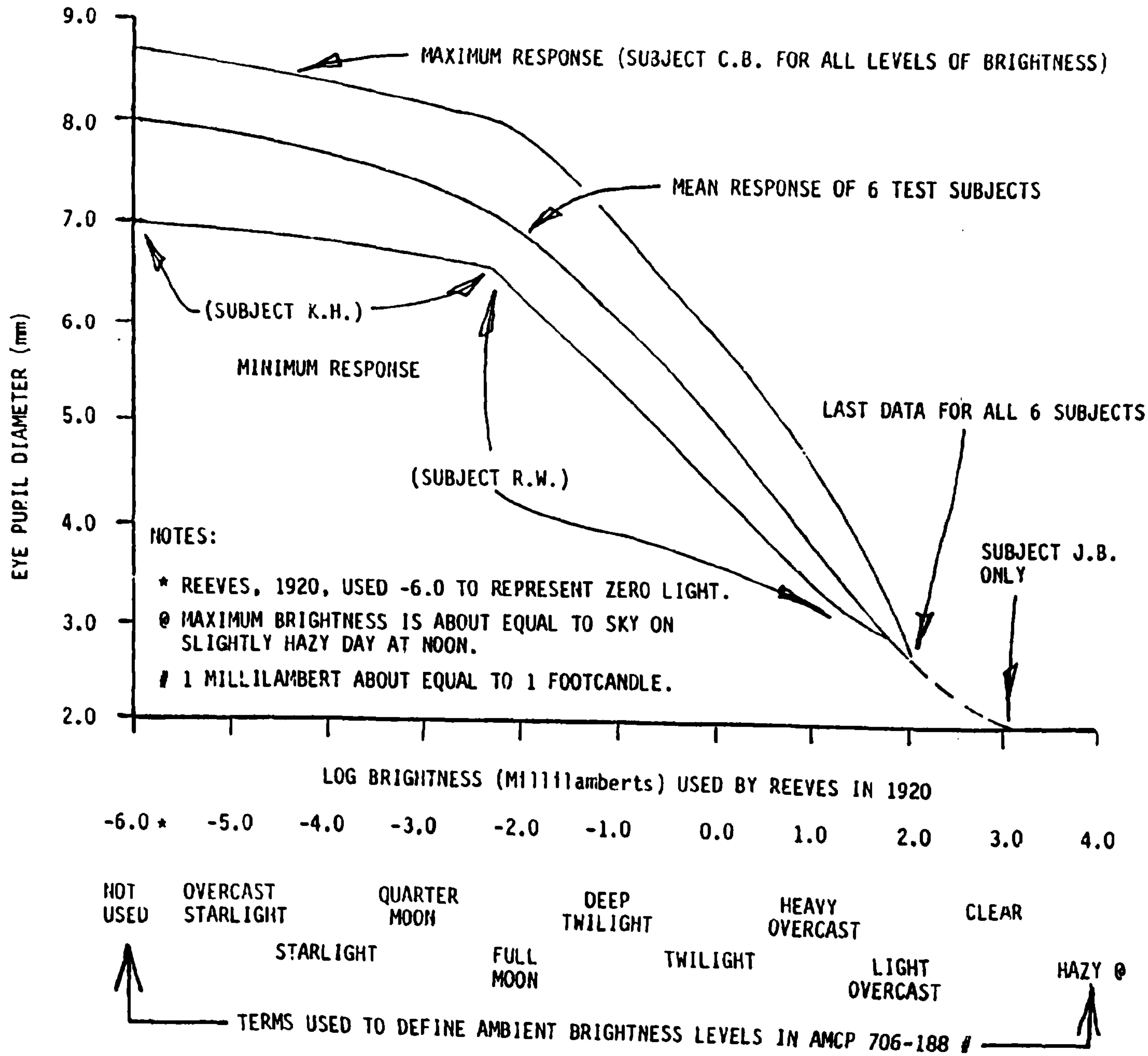

Figure A-1. <u>Response of The Eye Pupil to Varying Light Intensity: Experimental Data Reported By Reeves in The Journal of The Optical Society of America, March, 1920.</u>

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ENCLOSURE 1 SELECTED OPTICAL FORMULAS FOR DESIGN OF TELESCOPE

A. ABBREVIATIONS: (NOTES ON FOLLOWING PAGE)

RF = REAL FIELD OF VIEW [e]
MAG = MAGNIFICATION [b]
ER = EYE RELIEF [d]
DE = DIAMETER EYE LENS [h]
FO = FOCAL LN OBJ LENS
FE = FOCAL LN OF EYE LENS
AF = APPARENT FIELD OF VIEW [d]
XP = DIAMETER EXIT PUPIL [c,d]
DO = DIAM OBJECTIVE LENS [a,i,h]
TWI = TWILIGHT FACTOR [f]
RB = RELATIVE BRIGHTNESS [f]
TFL = TOTAL FOCAL LENGTH [g]
SRD = SMALLEST RESOLVED DETAIL (MINUTE OF ARC (MOA))
RES = RESOLUTION (MOA) [i,k]

B. BASIC OPTICAL DESIGN ENVELOPE OF L9A1 SUSAT:

MAG = 4.0, RF = 10.0, DO = 25.5, ER = 25.0

C. OPTICAL DESIGN FORMULAS AND EXAMPLE SOLUTION VALUES USING L9A1 SUSAT CHARACTERISTICS IN B:

1. XP = DO / MAG = 6.4 MM
2. MAG = DO / XP = 4.0
3. RF = AF / MAG = 10.0 DEG
4. DO = MAG * XP = 25.5 MM
5. MAG = AF / RF = 4.0
6. AF = RF * MAG = 40.0 DEG

7. DE (FOR 50% VIGNETTING) = 2 * ER * TAN (AF / 2) = 18.2 MM

8. $AF = 2 * \arctan \dfrac{DE / 2}{ER} = 40.0$ DEG

9. $ER = \dfrac{DE / 2}{\tan AF / 2} = 25.0$ MM

10. TWI = SQRT (DO * MAG) = 10.1 (A DIMENSIONLESS NUMBER)
11. RB = (DO / MAG) SQUARED = 40.6 (A DIMENSIONLESS NUMBER)
12. FE = [(ER * MAG) / (1 + MAG)] = 20.0 MM
13. FO = FE * MAG = 80.0 MM
14. TOTAL FOCAL LENGTH = FE + FO = 100.0 MM
15. RES OF OBJ LENS = 5.5 / DIA OBJ LENS (INCH) / 60 = 0.09 MOA
16. SRD = MAG * 5.5 / DIA OBJ LENS (INCH) / 60 = 0.37 MOA

D. TWILIGHT, RELATIVE BRIGHTNESS, RESOLUTION, SMALLEST RESOLVED DETAIL OF SEVERAL HYPOTHETICAL OPTICAL DESIGN ENVELOPES:

MAGNIFICATION X DIAMETER OBJECTIVE LENS (MM)

	6X30	7X35	7X42	7X50	8X30	8X56	10X40	10X70
TWI	13.4	15.7	17.1	18.7	15.5	21.2	20.0	26.5
RB	25.0	25.0	36.0	51.0	14.1	49.0	16.0	49.0
RES OF OBJ	0.08	0.07	0.06	0.05	0.08	0.04	0.06	0.03
SRD	0.47	0.47	0.39	0.33	0.62	0.33	0.58	0.33

NOTES ON FOLLOWING PAGE.

NOTES TO ACCOMPANY ENCLOSURE 1, APPENDIX A, TR 461:

a. OBJECTIVE LENS AND ENTRANCE PUPIL DIAMETERS TAKEN TO BE EQUAL.
b. PRACTICAL UPPER LIMIT FOR MAGNIFICATION OF UNSUPPORTED SIGHTS: RIFLE/PISTOL TELESCOPIC SIGHT = 4X, BINOCULAR = 8X [MIL-HDBK-759A, 30 JUNE 1981]; 7 X 50 IS CLASSIC "NIGHT GLASS."
c. APPROX DIAMETER, HUMAN EYE PUPIL: 2MM, BRIGHT DAY; 5 MM, AVERAGE DAY; 7MM, TWILIGHT; 8MM, DARK ADAPTED.
d. MIL-HDBK 759A [p. 7-47] GIVES 60 DEGREES AS THE MAXIMUM PRACTICAL APPARENT FIELD OF VIEW (FOV) FOR A HIGHLY CORRECTED EYE LENS, TM 9-258 [p. 2-40] USES 45 DEGREES. FULL FOV OF SCOPE ONLY SEEN WHEN EYE IS AT PLANE OF EXIT PUPIL (LOCATED BEHIND EYE LENS A DISTANCE CALLED EYE RELIEF).
e. HUMAN EYE FIELD OF VIEW (NO HEAD MOVEMENT, ROTATING EYES IN SOCKETS) IS ABOUT 160 DEGREES HORIZONTAL & 70 DEGREES VETICAL. FIELD OF DISTINCT VISION IS SOMETHING LESS THAN 1 DEGREE OF ARC. [TM 9-258, pp. 3-8, 3-16]
f. TWILIGHT AND RELATIVE BRIGHTNESS (MAY ALSO BE CALLED LUMINOSITY) ARE DIMENSIONLESS NUMBERS THAT PROVIDE A BASIS TO COMPARE THE DIM LIGHT PERFORMANCE OF OPTICS. LARGE NUMBERS ARE BETTER THAN SMALL NUMBERS.
g. SUM OF FE AND FO = LENGTH OF SCOPE (NOT INCLUDING EYE CUPS AND HOODS); THIS UNDERSTATES LENGTH OF SCOPE WITH LENS ERECTORS AND OVERSTATES LENGTH OF SCOPE WITH ROOF PRISM ERECTORS.
h. AREA OF OBJECTIVE AND EYE LENS GLASS INCREASES BY SQUARE OF INCREASE IN DIAMETER; AT A MINIMUM, WEIGHT OF SCOPE INCREASES PROPORTIONATELY; MAY ALSO REQUIRE ADDITIONAL OPTICAL ELEMENTS.
i. RES = RESOLUTION OF OBJECTIVE LENS: MEASURES ABILITY OF LENS TO DISTINGUISH TWO ADJACENT POINTS; IT IS THE MINIMUM ANGLE (IN MINUTES OF ARC) THAT CAN JUST BE RESOLVED (SEEN SEPARATELY); SMALL VALUES BETTER THAN LARGE VALUES; IMPROVES WITH LARGER OBJECTIVE LENS; FORMULA (APPROX): RES (IN SECONDS OF ARC) = 5.5 DIVIDED BY DIAMETER OF OBJECTIVE LENS (INCHES); DIVIDE BY 60 FOR MOA. [56: NO PAGE NUMBER] (NOTE THAT FORMULA ON p. 5-18, TM 9-258 IS INCORRECT.)
k. RESOLUTION OF 20/20 HUMAN EYE: FAVORABLE CONDITIONS, ABOUT 1 MINUTE OF ARC; CONSERVATIVE ESTIMATE FOR FIELD CONDITIONS, 1.5 TO 2.0 MINUTES OF ARC. [55: NO PAGE NUMBER]
l. WIDTH (SMALLEST) DIMENSION OF AN E SILHOUETTE = 0.5 METERS; SUBTENDS: 3.4 MOA AT 500 & 1.7 MOA AT 1,000 METERS.
m. TARGET AQUISITION: NUMBER OF RESOLVED CYCLES (LINE PAIRS) REQUIRED FOR PROBABILITY OF SUCCESS OF 0.50 AND 0.95 [IN BRACKETS] ACROSS TGT SMALLEST DIMENSION: DETECT (SOMETHING IS OUT THERE), 1.00 [2.00]; CLASSIFY (IT HAS TRACKS, NOT WHEELS), 2.00 [4.00]; RECOGNIZE (IT'S A TANK, NOT AN APC), 3.00 [6.00]; IDENTIFY (IT'S A T-72) 6.00 [12.00]. [REFERENCE 57: USACECOM DRAFT SENSOR ANALYSIS DATA REPORT (SECRET), 11 AUGUST 1988]

APPENDIX B

TEST DATA AND SIGMAs FOR INTRINSIC ROUND TO ROUND DISPERSION OF 7.62 X 51MM, M118 SPECIAL BALL CARTRIDGE

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APPENDIX B

TEST DATA AND SIGMAs FOR INTRINSIC ROUND TO ROUND DISPERSION OF 7.62 X 51MM, M118 SPECIAL BALL CARTRIDGE

PART A.

TABLE B-1 - INTRINSIC ROUND TO ROUND DISPERSION OF 7.62 X 51MM, M118 SPECIAL BALL CARTRIDGE: SUMMARY OF DATA FROM APPENDIX B.

10-ROUND GROUPS FROM ACCURACY (MANN-TYPE) BARREL & MACHINE REST

100 YARDS [49: TABLE 3.1]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 20-12	15	0.4	0.1
LARGEST GP		0.6	0.1
SMALLEST GP		0.2	< 0.1
MEAN, ALL GPS	15	0.4	0.1

200 YARDS [30: ENCL 2, p. 2]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (ML)
LC 81L132-004	3	1.18	0.09
LC 86H136-001	3	1.85	0.15
LARGEST GP		2.10	0.17
SMALLEST GP		0.92	0.07
MEAN, ALL GPS	6	1.51	0.12

300 YARDS [28: p.128 & 30: ENCL 2, p.7]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 20-23	9	1.02	0.08
LC 60-1	9	0.97	0.08
LC 81L132-004	3	2.02	0.16
LC 86H136-001	3	1.76	0.14
LARGEST GP		2.61	0.21
SMALLEST GP		0.46	0.04
MEAN, ALL GPS	24	1.44	0.10

600 YARDS [48:]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 60-18	6	3.77	0.15
LC 79K130-007	6	3.86	0.15
LC 86H136-001	6	3.57	0.14
LC 84F134-001	6	3.87	0.15
LC 85A135-005	6	4.11	0.16
LC 85D135-013	6	3.36	0.13
LC 86J136-002	9	3.14	0.12
LC 60-6	UNK	2.6	0.1
LARGEST GP		5.04	0.20
SMALLEST GP		2.25	0.09
MEAN, ALL GPS	45	3.67	0.15

TABLE B-1 (CONT'D)

700 YARDS [48:]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 60-18	4	4.07	0.14
LC 79K130-007	4	5.96	0.20
LC 86H136-001	4	5.52	0.19
LC 84F134-001		NOT FIRED	
LC 85A135-005	4	5.48	0.19
LC 85D135-013	4	4.59	0.16
LARGEST GP		7.31	0.25
SMALLEST GP		3.16	0.11
MEAN, ALL GPS	20	5.12	0.18

800 YARDS [48:]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 60-18	6	5.38	0.16
LC 79K130-007	6	5.66	0.17
LC 86H136-001	6	5.96	0.18
LC 84F134-001	6	5.82	0.17
LC 85A135-005	6	5.69	0.17
LC 85D135-013	6	5.37	0.16
LARGEST GP		7.35	0.22
SMALLEST GP		3.40	0.10
MEAN, ALL GPS	36	5.65	0.17

1000 YARDS [48:]

M118 LOT NR	NR GPS	MEAN RADIUS (INCH)	SIGMA (MIL)
LC 60-18	6	7.28	0.17
LC 79K130-007	6	8.90	0.21
LC 86H136-001	6	9.03	0.21
LC 84F134-001	6	10.17	0.24
LC 85A135-005	6	11.79	0.28
LC 85D135-013	6	8.76	0.21
LARGEST GP		13.34	0.32
SMALLEST GP		5.21	0.12
MEAN, ALL GPS	36	9.32	0.23

---

a. SIGMA (MIL) IS A ROOT MEAN SQUARE OF INDIVIDUAL SIGMAs.
b. SOME AMMUNITION LOT NUMBERS MAY BE INCOMPLETE.
c. SIGMA USING DR. GRUBBS' "RED BOOK", [25: TABLE 5] FOR n = 10.
d. M118 SPECIFICATION REQUIRES MEAN RADIUS FOR 9 X 10-ROUND TARGETS AT 600 YARDS TO BE NO MORE THAN 3.5 INCHES (EQUAL TO SIGMA OF 0.14 MILS); TEST CAN BE CONDUCTED AT 200 YARDS, THEN MR MUST NOT EXCEED 1.08 INCHES (0.13 MILS SIGMA).

PART B. TEST DATA AND SIGMAs FOR INTRINSIC RRD OF 7.62 X 51MM, M118,SPECIAL BALL CARTRIDGE

FROM A MACHINE REST WITH ACCURACY TEST BARREL

EACH MEAN RADIUS REPRESENTS ONE 10-ROUND TARGET

TEST LOCATIONS AND SOURCE OF DATA INDICATED

NOTES AND EXPLANATION OF LEGEND FOLLOW 100 YARD TABLE

RANGE = 100 YARDS:

SOURCE 49: (APG MT-4033, FEB 1972, Table 3.1)

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 20-12	60-2	1	0.4	0.1
2			2	0.4	0.1
3			3	0.3	0.1
4			4	0.2 S	< 0.1 S
5			5	0.2 S	< 0.1 S
6		60-7	1	0.5	0.1
7			2	0.5	0.1
8			3	0.4	0.1
9			4	0.6 L	0.1 L
10			5	0.4	0.1
11		60-10	1	0.5	0.1
12			2	0.5	0.1
13			3	0.5	0.1
14			4	0.5	0.1
15			5	0.3	0.1

100 YARD SUMMARY FOR 15 GROUPS:

AMMO LOT NR	NR OF GROUPS	MEAN RADIUS (INCH)	SIGMA (MILS)
LC 20-12	15	0.4	0.1
LARGEST 10-RD GROUP		0.6	0.1
SMALLEST 10-RD GROUP		0.2	< 0.1
MEAN FOR 15 GROUPS		0.4	0.1

NOTES AND LEGEND (ALL RANGES):

a. L = LARGEST, S = SMALLEST 10-ROUND GROUP AMONG ALL LOTS AT EACH RANGE.
b. SIGMA (MILS) USING DR. GRUBB'S "RED BOOK". [25: TABLE 5]
c. M118 SPECIFICATION REQUIRES MEAN RADIUS FOR 9 X 10-ROUND GROUPS AT 600 YARDS TO BE NO MORE THAN 3.5 INCHES (EQUAL TO 0.14 MILS SIGMA); TEST CAN BE CONDUCTED AT 200 YARDS: MR MUST NOT EXCEED 1.08 INCHES (0.13 MILS SIGMA).
d. SIGMA IN ALL SUMMARIES IS A ROOT MEAN SQUARE (RMS) OF INDIVIDUAL SIGMAs.
e. SOME LOT NUMBERS MAY BE INCOMPLETE.
f. SOURCE NUMBER, e.g. [48:], REFERS TO TR 461 BIBLIOGRAPHY.

RANGE = 200 YARDS:

SOURCE 30: (APG CSTA FIRING RECORD S-51037, MAY 1987, ENCL 2, p. 2)

(CSTA TEST DATA CONVERTED TO INCHES BY AMSAA)

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 81L132-004	C113	1	1.26	0.10
2			2	0.92 S	0.07 S
3			3	1.35	0.11
4	LC 86H136-001	C113	1	2.10 L	0.17 L
5			2	1.77	0.14
6			3	1.67	0.13

200 YARD SUMMARY FOR 6 GROUPS:

AMMO LOT NR	NR OF GROUPS	MEAN RADIUS (INCH)	SIGMA (MILS)
LC 81L132-004	3	1.18	0.09
LC 86H136-001	3	1.85	0.15
LARGEST 10-RD GROUP		2.10	0.17
SMALLEST 10-RD GROUP		0.92	0.07
MEAN FOR 6 GROUPS		1.51	0.12

RANGE = 300 YARDS:

SOURCE 28: (APG-MT-5089, FEB 1978, p. 128)

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 20-23	6	1	1.08	0.09
2			3	1.00	0.08
3			5	0.89	0.07
4			7	1.00	0.08
5			9	0.89	0.07
6			11	0.98	0.08
7			13	0.78	0.06
8			15	1.32	0.10
9			17	1.24	0.10
10	LC 60-1	6	2	1.33	0.11
11			4	0.76	0.06
12			6	0.46 S	0.04 S
13			8	1.10	0.09
14			10	0.97	0.08
15			12	1.07	0.08
16			14	1.03	0.08
17			16	0.93	0.07
18			18	1.27	0.10

RANGE = 300 YARDS:

SOURCE 30: (APG FIRING RECORD S-51037, MAY 1987, ENCL 2, p. 7)

NOTE: CSTA TEST DATA CONVERTED TO INCHES BY AMSAA

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
19	LC 81L132-004	C113	1	1.96	0.16
20			2	2.61 L	0.21 L
21			3	1.49	0.12
22	LC 86H136-001	C113	1	2.13	0.17
23			2	1.65	0.13
24			3	1.50	0.12

300 YARD SUMMARY FOR 24 GROUPS:

AMMO LOT NR	NR OF GROUPS	MEAN RADIUS (INCH)	SIGMA (MILS)
LC 20-23	9	1.02	0.08
LC 60-1	9	0.97	0.08
LC 81L132-0C4	3	2.02	0.16
LC 86H136-001	3	1.76	0.14
LARGEST 10-RD GROUP		2.61	0.21
SMALLEST 10-RD GROUP		0.46	0.04
MEAN FOR 24 GROUPS		1.44	0.10

RANGE = 600 YARDS:

SOURCE 48: (ARRADCOM ENGI‹ :ERING PROOF TESTING RECORDS FOR TESTS DONE AT ARDEC FT DIX TEST SITE, JUNE 1987; PROVIDED TO WEAVER BY SMCAR-CCL-L, JUNE 1989); SAME SOURCE FOR 600, 700, 800 AND 1,000 YARDS.

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 60-18	HART 5	1	3.58	0.14
2			2	3.34	0.13
3			3	4.11	0.16
4		HART 6	1	3.01	0.12
5			2	4.22	0.17
6			3	4.37	0.17
7	LC 79K130-007	HART 5	1	3.59	0.14
8			2	4.61	0.18
9			3	2.69	0.11
10		HART 6	1	4.12	0.16
11			2	4.30	0.17
12			3	3.87	0.15
13	LC 86H136-001	HART 5	1	3.31	0.13
14			2	4.45	0.18
15			3	3.72	0.15
16		HART 6	1	4.00	0.16
17			2	3.52	0.14
18			3	2.44	0.10
19	LC 84F134-001	HART 5	1	3.98	0.16
20			2	3.69	0.15
21			3	3.47	0.14
22		HART 6	1	3.29	0.13
23			2	3.73	0.15
24			3	5.04 L	0.20 L

25	LC 85A135-005	HART 5	1	4.20	0.17
26			2	4.00	0.16
27			3	3.54	0.14
28		HART 6	1	3.38	0.13
29			2	4.76	0.19
30			3	4.78	0.19
31	LC 85D135-013	HART 5	1	3.25	0.13
32			2	3.92	0.16
33			3	3.21	0.13
34		HART 6	1	2.25 S	0.09 S
35			2	3.85	0.15
36			3	3.68	0.15
37	LC 86J136-002 @	BBL 16	1	3.5	0.14
38			2	3.5	0.14
39			3	3.1	0.12
40		BBL 6	1	2.6	0.10
41			2	3.7	0.15
42			3	2.9	0.12
43		BBL 9	1	3.1	0.12
44			2	3.2	0.13
45			3	2.7	0.11

@ - LC 86J136-002 USED BY CSTA IN FAT/IPT OF M24 SWS.

600 YARD SUMMARY FOR 45 GROUPS:

M118 LOT NR	NO OF GROUPS	MR INCH	SIGMA MIL	
LC 60-18	6	3.77	0.15	
LC 79K130-007	6	3.86	0.15	
LC 86H136-001	6	3.57	0.14	
LC 84F134-001	6	3.87	0.15	
LC 85A135-005	6	4.11	0.16	
LC 85D135-013	6	3.36	0.13	
LC 86J136-002	9	3.14	0.12	
LARGEST 10-RD GROUP		5.04	0.20	
SMALLEST 10-RD GROUP		2.25	0.09	
ALL 45 GROUPS		3.67	0.15	
LOT LC 60-6	UNK	2.6	0.1	(USAIB PROJ NO 3563, FEB, 1978 p.2-1)

APPENDIX B TO AMSAA TR 461 (CONT'D)

RANGE = 700 YARDS [SOURCE 48]:

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 60-18	HART 5	1	5.55	0.19
2			2	3.16 S	0.11 S
3			3	4.30	0.15
4		HART 6	1	3.26	0.11
5	LC 79K130-007	HART 5	1	5.37	0.18
6			2	6.65	0.23
7			3	6.37	0.22
8		HART 6	1	5.44	0.18
9	LC 86H136-001	HART 5	1	5.11	0.17
10			2	7.31 L	0.25 L
11			3	4.47	0.15
12		HART 6	1	5.20	0.18
13	LC 84F134-001	HART 5	NOT FIRED		
14		HART 6	NOT FIRED		
15	LC 85A135-005	HART 5	1	6.68	0.23
16			2	6.54	0.22
17			3	5.70	0.19
18		HART 6	1	3.29	0.11
19	LC 85D135-013	HART 5	1	4.19	0.14
20			2	6.50	0.22
21			3	3.82	0.13
22		HART 6	1	3.83	0.13

700 YARD SUMMARY FOR 20 GROUPS:

M118 LOT NR	NR TGT	MR INCH	SIGMA MIL
LC 60-18	4	4.07	0.14
LC 79K130-007	4	5.96	0.20
LC 86H136-001	4	5.52	0.19
LC 84F134-001		NOT FIRED	
LC 85A135-005	4	5.48	0.19
LC 85D135-013	4	4.59	0.16
LARGEST 10-RD GROUP		7.31	0.25
SMALLEST 10-RD GROUP		3.16	0.11
ALL 20 GROUPS		5.12	0.18

APPENDIX B TO AMSAA TR 461 (CONT'D)

RANGE = 800 YARDS [SOURCE 48]:

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 60-18	HART 5	1	4.73	0.14
2			2	5.84	0.17
3			3	5.30	0.16
4		HART 6	1	5.19	0.15
5			2	6.51	0.19
6			3	4.68	0.14
7	LC 79K130-007	HART 5	1	5.82	0.17
8			2	4.48	0.13
9			3	3.40 S	0.10 S
10		HART 6	1	7.35 L	0.22 L
11			2	7.06	0.21
12			3	5.82	0.17
13	LC 86H136-001	HART 5	1	4.68	0.14
14			2	6.16	0.18
15			3	7.25	0.22
16		HART 6	1	6.10	0.18
17			2	5.88	0.17
18			3	5.67	0.17
19	LC 84F134-001	HART 5	1	5.20	0.15
20			2	5.89	0.18
21			3	5.21	0.15
22		HART 6	1	7.21	0.21
23			2	5.07	0.15
24			3	6.35	0.19
25	LC 85A135-005	HART 5	1	6.89	0.20
26			2	3.72	0.11
27			3	5.40	0.16
28		HART 6	1	6.38	0.19
29			2	5.63	0.17
30			3	6.12	0.18
31	LC 85D135-013	HART 5	1	5.92	0.18
32			2	4.79	0.14
33			3	4.77	0.14
34		HART 6	1	6.17	0.18
35			2	4.76	0.14
36			3	5.81	0.17

APPENDIX B TO AMSAA TR 461 (CONT'D)

800 YARD SUMMARY FOR 36 GROUPS:

M118 LOT NUMBER	NR TGT	MR INCH	SIGMA MIL
LC 60-18	6	5.38	0.16
LC 79K130-007	6	5.66	0.17
LC 86H136-001	6	5.96	0.18
LC 84F134-001	6	5.82	0.17
LC 85A135-005	6	5.69	0.17
LC 85D135-013	6	5.37	0.16
LARGEST 10-RD GROUP		7.35	0.22
SMALLEST 10-RD GROUP		3.40	0.10
ALL 36 GROUPS		5.65	0.17

RANGE = 1000 YARDS: [SOURCE 48]

LN NR	AMMO LOT NR	TEST BBL ID	TGT	MEAN RADIUS (INCH)	SIGMA (MILS)
1	LC 60-18	HART 5	1	7.33	0.17
2			2	7.94	0.19
3			3	6.35	0.15
4		HART 6	1	7.84	0.19
5			2	7.27	0.17
6			3	6.96	0.17
7	LC 79K130-007	HART 5	1	9.84	0.23
8			2	8.94	0.21
9			3	8.75	0.21
10		HART 6	1	7.64	0.18
11			2	7.27	0.17
12			3	10.95	0.26
13	LC 86H136-001	HART5	1	6.72	0.16
14			2	5.21 S	0.12 S
15			3	8.68	0.21
16		HART 6	1	12.20	0.29
17			2	9.99	0.24
18			3	11.38	0.27
19	LC 84F134-001	HART 5	1	11.28	0.27
20			2	9.44	0.22
21			3	9.24	0.22
22		HART 6	1	10.97	0.26
23			2	10.60	0.25
24			3	9.46	0.23
25	LC 85A135-005	HART 5	1	12.80	0.30
26			2	10.20	0.24
27			3	10.57	0.25
28		HART 6	1	13.34 L	0.32 L
29			2	11.77	0.28
30			3	12.08	0.29

31	LC 85D135-013	HART 5	1	6.07	0.14
32			2	7.17	0.17
33			3	7.92	0.19
34		HART 6	1	13.12	0.31
35			2	10.91	0.26
36			3	7.35	0.17

1000 YARD SUMMARY - MEAN MR AND RMS (POOLED) SIGMA:

M118 LOT NR	NR TGT	INCH	SIGMA MILS
LC 60-18	6	7.28	0.17
LC 79K130-007	6	8.90	0.21
LC 86H136-001	6	9.03	0.21
LC 84F134-001	6	10.17	0.24
LC 85A135-005	6	11.79	0.28
LC 85D135-013	6	8.76	0.21
LARGEST 10-RD GROUP		13.34	0.32
SMALLEST 10-RD GROUP		5.21	0.12
ALL 36 GROUPS		9.32	0.23

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AMSAA	TYPE OF REPORT: Technical REPORT NUMBER: 461 DATE: 31 May 1990	

SUBJECT: Error budgets and performance estimates for general-purpose (GP) and sniper rifles, and handheld laser range finders like the AN/PVS-6 (MELIOS); target distributions for GP and sniper rifles.

REASON FOR PERFORMING THIS EFFORT: Void in error budgets and performance estimates for GP and sniper rifles and MELIOS.

MAIN OBJECTIVES OF THE EFFORT: Collect an extensive set of test data in a single source; document and publish author's original work with GP and sniper rifle error budgets, target distributions and hitting performance estimates.

SCOPE OF THE EFFORT: Test data, error budgets and performance estimates for GP and sniper rifles; first error budget and "hitting" performance estimates for MELIOS; assessment that performance of MELIOS in hands of troops is likely to be unsatisfactory.

IMPACT OF THE EFFORT: Unknown

CONTRACTED ADVISORY AND ASSISTANCE SERVICES: Extensive intellectual and moral support to the author from AMSAA consultant, Dr. Frank E. Grubbs.

SPONSOR: U.S. Army Materiel Systems Analysis Activity

PERFORMING ORGANIZATION/POINT OF CONTACT: U.S. Army Materiel Systems Analysis Activity, Jonathan M. Weaver, Jr.

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